Report of Pilot study on Brinell hardness comparison CCM.H-P3

International Committee for Weights and Measures
Consultative Committee for Mass and Related Quantities
Working Group on Hardness

Report of Pilot study on Brinell hardness comparison CCM.H-P3

Final Report

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Authors:

Koichiro HATTORI,	NMIJ-AIST
Gun-Woong Bahng,	KRISS

Co-authors:

Alessandro Germak	INRIM
Edward G. Aslanyan	VNIIFTRI
Febo Menelao	PTB
He Li	NIM
Konrad Herrmann	PTB
Laurence Brice	NPL

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Abstract:

This is the pilot study report of Brinell hardness comparison organized by Consultative Committee for Mass and Related Quantities, Working Group on Harness (CCM-WGH). The measurand is the Brinell hardness of the blocks. The artifacts circulated are 250 HBW, 350 HBW and 450 HBW. The measurement hardness scales are 1/30, 2.5/187.5, 5/750, and 10/3000. For the 10/3000 scale, 350 HBW and 450 HBW are compared.

The additional items are circulated to investigate the bias of the Brinell hardness measurements. One is the 2D indentation, namely “artificial indentation”, which is thin metal layer with a hole deposited on the glass plate. The second one is the 3D indentation, “Reference indentation”, which is the designated Brinell indent on each circulated artifact. The 2D indentation can be used to know the edge-determination condition including calibration of diameter measuring apparatus, and 3D indentation can be used to know the difference among institutes regarding the Brinell indentation diameter.

This report of Brinell hardness comparison was firstly planned as a Key comparison for Brinell hardness (CCM.H-K2). A large bias were found in the first draft report which is due to the Numerical aperture of the observation optical system used to the indentation diameter measurement.

1. Introduction

Worldwide harmonization of hardness measurement standard among National Metrology Institutes (NMIs) is important to realize the CIPM Mutual Recognition Arrangement (MRA). According to the CIPM MRA, international comparisons of measurements (known as KCs) and supplementary international comparisons of measurements (SCs) are regarded as important processes to establish the degree of equivalence of national measurement standards maintained by NMIs [1]. In case of the hardness standards, the Working Group on Hardness (WGH) under Consultative Committee for Mass and Related Quantities (CCM) is responsible for the KC organized by the CIPM.

During the 2nd meeting of the WGH at the INRIM, Turin on September 19, 2001, it was agreed to carry out a KC of Brinell hardness scales between the hardness laboratories of NMIs. The National Metrology Institute of Japan (NMIJ/AIST) and the Korea Research Institute of Standards and Science (KRISS) are accepted the proposal to act as pilot laboratories of the comparison. After the comparison, the first draft report was circulated among participants at October 2005, and discussed in the WGH. In WGH

meeting September 2015 in NPL, the WGH members agrees to change the KC to the pilot study.

We was able to get the big knowledge on effect of observation optical system through the pilot study. The numerical aperture, including illumination, of indentation diameter measurement system gives very large change in measured Brinell indentation diameter.

In this report, we introduce the results of comparison among NMIs and the difficulties in diameter measurement by means of the same indentation measurement.

2. Organizations

The comparison was carried out following the CIPM guideline[2]. At first, a questionnaire was distributed by KRISS to the members of the WGH. Test conditions and hardness levels were determined according to the reply on questionnaire. A draft of technical protocol was also prepared by the pilot laboratories (G. W. Bahng, KRISS and K. Hattori, NMIJ/AIST) and distributed to the participants before performing the comparison. All participants accepted and approved the protocol.

The measurement started from November 2003 and ended in March 2005. First Draft was circulated at September, 2005.

2.1 Participants

Seven national metrology institutes from the three Regional Metrology Organizations of EUROMET, COOMET and APMP have participated in the comparison. The list of the participating institutes is given in table 2-1.

Table 2-1: participants

abbreviation	Institution
INRIM	Istituto Nazionale di Ricerca Metrologica Italy, EUROMET
NIM	National Institute of Metrology China, APMP
NPL	National Physical Laboratory United Kingdom, EUROMET
PTB	Physikalisch-Technische Bundesanstalt Germary, EUROMET
VNIIFTRI	All Russian Research Institute for physical-technical and Radio-technical measurements Russian Federation, COOMET
KRISS **(Pilot lab.)**	Korea Research Institute of Standards and Science Korea, Republic of, APMP
NMIJ **(Pilot lab.)**	National Metrology Institute of Japan Japan, APMP

2.2 Time schedule

The comparison started from November 2003 with initial measurements at NMIJ and the final data report was received in March 2005. There was no significant delay in the transportation of transfer standards although the data reporting was slightly delayed.

Table 2-2: Time schedule

Participants	planned	Sending notify	Results received
NMIJ	Nov. 2003	Nov. 2003	29 Nov. 2003
NIM	Dec. 2003	Jan. 2004	31 Mar. 2005
VNIIFTRI	Feb. 2004	Feb. 2004	3 Mar. 2004
INRIM	Mar. 2004	Mar. 2004	5 May. 2004
PTB	May 2004	May 2004	17 May 2004
NPL	Jun. 2004	Jul. 2004	26 Aug. 2004
KRISS	Jul. 2004	Oct. 2004	9 Dec. 2004
NMIJ	Aug. 2004	-	-

3. Artifacts used in the comparison

3.1 Brinell hardness blocks

The combination of three hardness levels (250 HBW, 350 HBW and 450 HBW) and four hardness scales (HBW1/30, HBW2.5/187.5, HBW5/750 and HBW10/3000) were selected as the item of the comparison. The nominal hardness levels and serial number of the blocks are shown in the table 3-1.

Table 3-1: Blocks used in the comparison.

Hardness Levels	Hardness Scale				
	1/30	2.5/187.5	5/750	$10/3000_A$	$10/3000_B$
250 HBW	93241	93243	93242	-	-
350 HBW	94041	94043	94042	94037	64038
450 HBW	95008	95011	95010	95004	95005

The dimensions of blocks are about 115 mm in diameter and 15 mm in thickness. The test surfaces of blocks were polished and were engraved with of 6 x 6 grids for hardness scale HBW10/3000, but only 33 measurement fields were available because of the roundness of the blocks (Fig. 3-1a). Then two blocks, Block A and B, were assigned for HBW10/3000, due to the limited number of measurement fields. For the all other hardness scales, the test surface has 11 x 11 grids and 46 measurement fields were available (Fig. 3-1b). A single block was enough to assign each of the hardness levels and scales.

The numbering was also engraved on the test surface in the alphabetic order to indicate the measurement field for the x-directions and in numerical order for y-direction as shown in the figs. 3-1a, 3-1b.

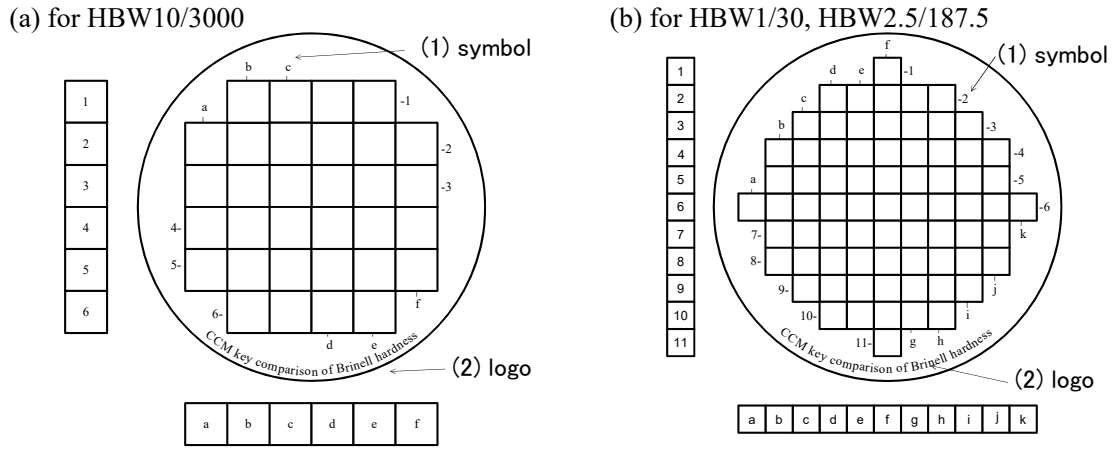

Fig 3-1: The layout of the measurement areas engraved on the test surface.

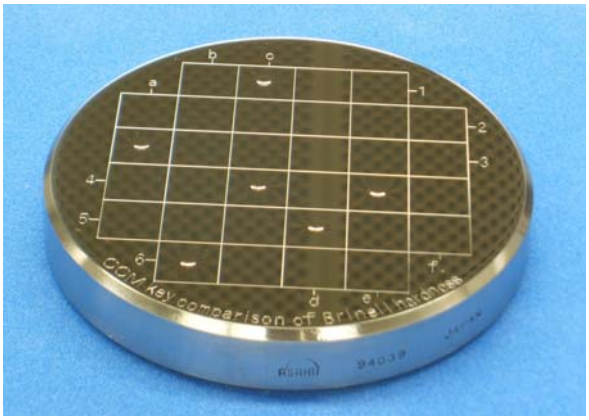

Fig 3-2: The Brinell block used for the comparison (HBW3000).

3.2 Artificial indentation

In a recent comparison of Vickers hardness, a significant difference was found on the reference indent measurement between participants. Generally, the diameter or diagonal measuring device is calibrated by using two-dimensional (2D) apparatus (eg. stage micrometer). On the other hand, the diameter of indentation having the three-dimensional (3D) shape is measured in the actual measurement. The image to be observed may vary from device to device.

In this comparison, an artificial indentation was adopted as a two-dimensional indent to figure out the difference among institutes of diameter measurement conditions.

Artificial indentation is a hole formed in a thin-metal coating on a glass plate. This

was kindly suggested and prepared by INRIM. There are four holes, 0.24, 0.4, 0.8 and 1.5 mm in diameter. Film thickness was thin enough to be used under microscope. These holes can be regarded as a two-dimensional indentation without regarding the change of depth of focus due to the change of numerical aperture of the objectives.
Figure 3-3 shows the photograph of artificial indentation.

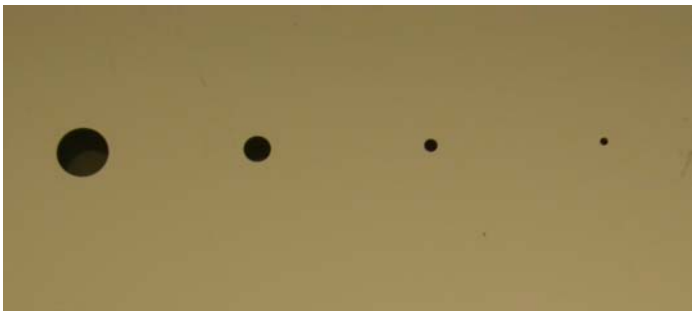

Fig. 3-3: Artificial indentation with four circular holes.
Nominal diameters are 1.5, 0.8, 0.4 and 0.24 mm from left-hand side, respectively.

4. Measurand

In this study, the item of the comparison is the Brinell hardness of blocks. To achieve harmonization of the measurement of Brinell hardness among institutes, two supplementary items were also compared. One was the diameter of reference indentation. Actual indentations were made on each combination of hardness levels and scales of blocks as a reference. The other one was the diameter of artificial indentations that can be regarded as a two-dimensional reference indentation in contrast with actual reference indentation.

4.1 Brinell hardness of Blocks

Each participant made five indentations on the designated fields of the blocks in accordance with the ISO 6508-3[4] requirements. And the average of five measurement, Brinell hardness of blocks, is the item of the comparison.

For HBW10/3000 hardness scale, the participants were divided into two groups, because of the limited number of measurement fields of blocks. For the other hardness scales, all the participants measure the same block.

Those assigned measurement fields are shown in the table 4-1. The symbols used for field assignment corresponds to that of those shown in fig. 4-1.

Table 4-1: assignment of the measurement fields.

(a)For HBW10/3000 (Reference indentation is located at d5 of Block A).

Participant	1	2	3	4	5	Pre-	Group
NMIJ	a3	b6	c1	c4	e4	f2	
NIM	a2	c5	d1	d3	e5	b1	
VNIIFTRI	b3	b5	d4	e1	f3	a5	BlockA
INRIM	b2	b4	d2	d6	f4	e6	
PTB	a4	c3	c6	e2	f5	e3	
NPL	a2	c5	d1	d3	e5	b1	
KRISS	b2	b4	d2	d6	f4	e6	BlockB
NMIJ	a3	b6	c1	c4	e4	f2	

(b)For other hardness levels/scales (location of reference indentation is f6).

Participant	1	2	3	4	5	Pre-	Group
NMIJ	c6	f2	f5	g8	i5	a6	
NIM	d7	f3	g2	g9	j5	b5	
VNIIFTRI	c7	e4	g6	g10	j4	e10	
INRIM	b7	e3	e6	h10	i4	f1	-
PTB	b8	e2	f7	h5	h9	b6	
NPL	d3	d6	d8	g3	h7	j7	
KRISS	d5	e9	f4	i3	i8	f11	

According to the protocol, measurement of indentation diameter was required to repeat three times for each X- and Y-direction was reported for further analysis.

4.2 Diameter of the reference indentation (supplemental item)

All the participants measured the diameter of the same Brinell indentation. The measurement of diameter and reporting of its result were performed following similar manner of Brinell hardness measurement. Three times of measurements were carried out for each of x- and y-direction of reference indentation. The reference indentation measurement is used to investigate the measurement bias among institutes combined with the artificial indentation diameter measurement explained next section.

4.3 Diameter of the artificial indentation (supplemental item)

In the recent comparison of Vickers hardness, a significant difference was found on the diameter measurement of reference indents among participants. Generally, the diameter/diagonal measuring device is calibrated by using two-dimensional apparatus (eg. stage micrometer). However, the actual hardness measurement was carried out for three-dimensional impression. This measurement of artificial indentation was introduced to investigate the cause of the difference between NMIs in hardness measurement. This process was proposed by Dr. A. Germak, INRIM.

Following the above suggestion, a supplemental item of measurement “artificial indentation” was added as a two-dimensional indent in this comparison. By this process, it is expected that whether the difference was caused by indent making procedure or indent measurement procedure.

5. Stability of artifacts

In order to evaluate the stability of the artifacts, the pilot laboratory (NMIJ) has performed measurement at the beginning and at the end of the comparison. The results are shown in the Table 5-1, 5-2 and 5-3. Here, *H* is the hardness of blocks, (the mean hardness of the five indentations) and *U* is the expanded uncertainty (*k*=2) of the measurements. The subscript *B* and *E* denote the result at the beginning and at the end, respectively.

The absolute value of *En* value, $|En| = \sqrt{(H_E - H_B)^2 / (U^2{}_E + U^2{}_B)}$ is used to evaluate the difference of artifact before and after the comparison which may occur during the circulation of the blocks. It is indicated in the last column of the tables 5-1, 5-2 and 5-3.

In the calculation of expanded uncertainties, the uncertainty of the mean value, which is calculated from the standard deviation of five measurements, was combined. If $|En| < 1$ is satisfied, we can conclude that the artifact was not changed with in the measurement uncertainty. Since the calculated *En* value for all of the blocks were smaller than 1, it is possible to conclude that the artifacts used in the comparison were stable during the comparison.

Table 5-1: Stability of artifact: hardness blocks, unit in HBW

Level	Scale	Block ID	at the Begginging		at the End		Difference	Exp. Uncertainty		ABS(En)
			Mean	std. dev	mean	std. dev		U_B	U_E	
250HBW	1/30	93241	253.3	1.02	251.6	0.96	-1.69	2.39	2.37	0.50
	2.5/187.5	93243	258.1	1.89	256.2	1.30	-1.89	2.08	1.67	0.71
	5/750	93242	250.4	2.16	249.2	0.63	-1.18	2.08	0.94	0.52
350HBW	1/30	94041	361.0	2.39	359.3	1.74	-1.71	3.79	3.49	0.33
	2.5/187.5	94043	357.7	1.66	356.2	1.29	-1.47	2.34	2.15	0.46
	5/750	94042	361.6	1.71	360.3	1.16	-1.34	1.85	1.47	0.57
	10/3000	94037	360.8	1.76	363.0	1.73	2.22	2.05	2.03	0.77
	10/3000	94038	-	-	357.3	1.66	-	-	1.98	-
450HBW	1/30	95008	450.4	1.97	447.5	0.98	-2.90	4.45	4.18	0.47
	2.5/187.5	95011	453.3	0.57	452.9	0.60	-0.44	2.95	2.96	0.10
	5/750	95010	454.8	0.95	455.2	0.96	0.33	1.59	1.6	0.15
	10/3000	95004	455.8	0.62	457.7	0.95	1.89	1.76	1.87	0.74
	10/3000	95005	-	-	454.4	0.80	-	-	1.82	-

Table 5-2: Stability of artifact: reference indentation, unit in μm

Level	Scale	Block ID	at the Beginning		at the End		Difference	Exp.uncertainty		ABS(En)
			diameter	std.dev.	diameter	std.dev.		U_B	U_E	
250HBW	1/30	93241	381.27	0.14	381.85	0.35	0.58	1.63	1.65	0.25
	2.5/187.5	93243	942.53	0.18	942.00	1.41	-0.53	2.18	2.52	0.16
	5/750	93242	1912.7	0.64	1912.00	4.24	-0.69	2.8	4.68	0.13
350HBW	1/30	94041	320.32	0.51	320.95	0.64	0.63	1.48	1.52	0.30
	2.5/187.5	94043	806.27	0.22	806.50	0.71	0.23	2.04	2.12	0.08
	5/750	94042	1601.91	0.52	1603.00	1.41	1.09	2.39	2.66	0.30
	10/3000	94037	3201.59	1.24	3203.50	2.12	1.92	5.99	6.19	0.22
450HBW	1/30	95008	287.97	0.38	288.50	0.42	0.53	1.32	1.33	0.28
	2.5/187.5	95011	717.35	0.55	718.50	0.71	1.15	2.32	2.35	0.35
	5/750	95010	1434.32	0.75	1436.00	2.83	1.68	2.19	3.28	0.43
	10/3000	95004	2859.94	0.92	2862.00	0	2.06	5.28	5.22	0.28

Table 5-3: Stability of artifact: artificial indentation, unit in μm.

Nominal diameter	at the Beginning		at the End		Difference	Exp.uncertainty		ABS(En)
	diameter	std.dev.	diameter	std.dev.		U_B	U_E	
1500	1498.74	0.70	1498.95	0.63	0.20	0.54	0.54	0.27
800	799.42	0.28	799.94	0.14	0.52	0.54	0.54	0.68
400	399.46	0.17	399.99	0.16	0.52	0.54	0.54	0.69
240	240.15	0.27	240.61	0.11	0.46	0.54	0.54	0.61

6. Results of measurements

6.1 Brinell hardness of blocks

In the following tables from 6-1 to 6-3, results of measurements are summarized for each hardness levels of 250HBW, 350HBW and 450HBW, respectively. The hardness of blocks which was calculated from the arithmetic mean of the five repetition of measurements, and standard deviations of it are shown in the tables.

The summary of reported uncertainties is also shown in table 6-4. Details of uncertainty budgets and results reported of each participant are shown in the appendix A.

In the last line of the tables, the standard deviations of hardness of blocks between institutes (SD_{inst}) and the average of standard deviations within institutes (SD_{mean}) are indicated to summarize the results. The average of standard deviations were calculated using Eq. 6.1.

$$SD\mathrm{mean} = \sqrt{\sum_{i=1}^{n} SD_i^{\,2} / n} \qquad (6.1)$$

Where n is the number of participants and the SD_i is the standard deviation of 5 measurements of i-th participants. The SD_{mean} may be corresponds to the non-uniformity of hardness block, if the measurement instability of each institute can be assumed as negligibly small compared with the observed variation.

Table 6-1: Results of the measurement for the hardness levels 250 HBW(unit, HBW).

Participant	250HBW1/30		250HBW2.5/187.5		250HBW5/750	
	hardness	SD	hardness	SD	hardness	SD
NMIJ	253.3	1.02	258.1	1.89	250.4	2.16
NIM	250.9	1.56	256.8	3.65	250.4	2.32
VNIIFTRI	247.8	0.95	253.3	0.84	250	0.27
INRIM	243.9	1.48	244.5	1.47	240.3	1.11
PTB	248.4	1.49	254.2	1.08	247.9	1.15
NPL	254	1.25	255.7	1.14	249.9	0.75
KRISS	252.5	1.28	259.2	0.93	249.9	0.86
Summary	SDinst	SDmean	SDinst	SDmean	SDinst	SDmean
	3.62	1.31	4.89	1.82	3.67	1.41

Table 6-2: Results of the measurement for the hardness levels of 350 HBW(unit, HBW)

Participant	350HBW1/30		350HBW2.5/187.5		350HBW5/750		350HBW10/3000	
	hardness	SD	hardness	SD	hardness	SD	hardness	SD
NMIJ	361.01	2.39	357.68	1.66	361.62	1.71	360.8	1.76
NIM	352.18	2.84	354.45	1.95	357.32	1.95	357.71	1.38
VNIIFTRI	358.69	1.62	348.16	1.44	360.44	0.38	358.78	1.03
INRIM	354.82	2.36	348.41	0.64	352.63	0.9	354.44	2.08
PTB	358.06	2.66	354.37	0.86	359.17	0.84	355.03	2.85
NPL	360.31	1.1	356.81	1.16	362.22	0.68	357.26	1.39
KRISS	357.47	1.71	357.77	2.18	361.04	0.57	354.73	1.88
NMIJ	-	-	-	-	-	-	357.33	1.66
Summary	SDinst	SDmean	SDinst	SDmean	SDinst	SDmean	SDinst	SDmean
	3.09	2.18	4.11	1.51	3.33	1.14	2.2	1.83

* Results from the block B.

Table 6-3: Results of the measurement for the hardness levels of 450 HBW(unit, HBW)

Participant	350HBW1/30		350HBW2.5/187.5		350HBW5/750		350HBW10/3000	
	hardness	SD	hardness	SD	hardness	SD	hardness	SD
NMIJ	450.42	1.97	453.34	0.57	454.82	0.95	455.83	0.62
NIM	442.19	2.06	452.56	1.3	452.33	1.68	454.42	0.79
VNIIFTRI	-	-	446.88	1.06	451.01	0.7	454.94	0.59
INRIM	447.41	1.83	448.88	0.98	449.62	1.39	453.77	0.73
PTB	449.65	3.26	453.55	1.51	453.8	0.15	455.33	0.65
NPL	449.29	0.87	454.97	1.07	455.38	0.88	454.97	0.48
KRISS	446.81	1.64	455.57	1.05	455.54	0.87	453.92	1
NMIJ	-	-	-	-	-	-	454.37	0.8
Summary	SDinst	SDmean	SDinst	SDmean	SDinst	SDmean	SDinst	SDmean
	3.00	2.06	3.20	1.11	2.29	1.05	0.70	0.72

* Results from the block B.

Table 6-4: Reported calibration uncertainties of institutes

Hardness	250HBW			350HBW				450HBW			
Scale	1/30	2.5/187.5	5/750	1/30	2.5/187.5	5/750	10/3000	1/30	2.5/187.5	5/750	10/3000
NMIJ	2.39	2.08	2.08	3.79	2.34	1.85	2.05	4.45	2.95	1.59	1.76
NIM	0.80	1.20	1.00	2.30	2.6	1.80	0.90	1.60	3.20	2.60	1.30
VNIIFTRI	3.02	1.47	1.40	5.70	2.90	2.32	2.20	-	3.84	2.90	2.72
INRIM	2.90	2.70	2.50	3.50	4.00	3.20	3.60	4.60	4.40	4.20	4.00
PTB	2.45	1.52	1.96	3.54	2.12	2.74	2.12	4.47	2.81	3.58	2.68
NPL	0.58	1.33	1.4	1.61	1.86	1.88	1.86	2.65	2.34	2.33	2.34
KRISS	2.99	1.43	0.96	4.76	2.69	1.08	1.75	6.49	2.78	1.53	1.13

The observed standard deviations between institutes (Stdev_hard) are in the rage of 3.62-4.89 HBW at 250 HBW, 2.20-4.11 HBW at 350HBW and 0.70-3.20 HBW at 450HBW, which decreases as the hardness increases. The average of standard deviation within institute (Ave_Stdev) also show the similar tendency, except HBW1/30 are 1.31-1.82 HBW at 250HBW, 1.14-1.83 HBW at 350 HBW and 0.72-1.11 HBW at 450HBW. That is also shown in the fig. 6-1.

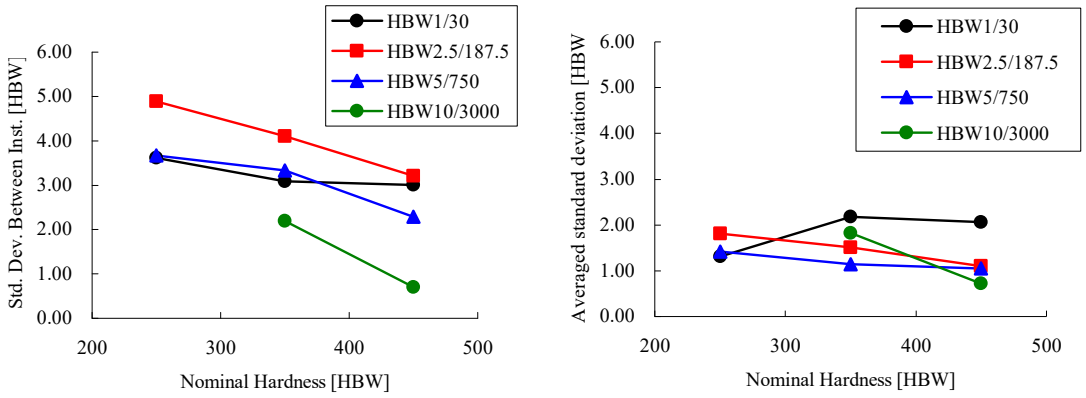

Fig. 6-1: Standard deviations of the hardness values between institutes (left).
The average of standard deviations within institutes (right).

6.2 Diameter measurement of reference indentation

The tables from 6-5 to 6-7, results of diameter measurement of the reference indentations, are summarized for each combination of hardness levels and scales. All of the participants measured the diameter in arbitrary direction, because measurement direction was not described clearly on the protocol. Based on the report of diameter measurement in length, Brinell hardness was calculated and included in the table also. It makes the comparison easier with those hardness values obtained from the participants' own indentation.

There was a comment from PTB for a non-ideal shape of the reference indentation for 250HBW2.5/187.5, 250HBW5/750 and 350HBW2.5/187.5 (see appendix B). It was confirmed after those blocks were recovered. The comment was appropriate, however, the analytical results did not show significant deviation from the other result. So in this report, we use all data including those reference indentations were adopted.

The details of analysis and discussions for reference and artificial indentation measurement are described in the appendix C.

Table 6-5: Diameter measurement of reference indentation for 250HBW

(a): Result Reference indentation diameter on 250 HBW blocks (unit, μm)

Participant	250HBW1/30		250HBW2.5/187.5		250HBW5/750	
	diameter	SD	diameter	SD	diameter	SD
NMIJ	381.6	0.05	943.4	0.09	1913.7	0.02
NIM	384.6	0.21	942.7	0.29	1905.7	1.76
VNIIFTRI	384.8	0.29	947.0	0.50	1918.5	1.50
INRIM	386.7	0.01	961.3	0.06	1949.0	0.14
PTB	382.3	0.10	937.9	0.03	1909.9	0.09
NPL	382.8	0.04	946.9	0.11	1910.3	0.46
KRISS	382.3	0.14	943.2	0.14	1914.0	0.25
Summary	SDinst	SDmean	SDinst	SDmean	SDinst	SDmean
	1.85	0.15	7.38	0.23	14.54	0.90

Table 6-6: Diameter measurement of reference indentation for 350HBW

(a): Result of Reference indentation diameter on 350 HBW blocks (unit, μm)

Participant	350HBW1/30		350HBW2.5/187.5		350HBW5/750		350HBW10/3000	
	diameter	SD	diameter	SD	diameter	SD	diameter	SD
NMIJ	320.67	0.07	806.90	0.17	1602.66	0.18	3204.31	0.36
NIM	323.75	0.17	806.33	1.26	1607.17	1.04	3210.67	0.58
VNIIFTRI	322.33	0.29	812.00	1.32	1607.50	1.00	3208.33	1.89
INRIM	323.27	0.01	813.22	0.03	1615.76	0.02	3221.91	0.12
PTB	320.80	0.05	807.98	0.10	1604.69	0.03	3204.80	0.18
NPL	321.09	0.05	806.75	0.10	1603.15	0.23	3202.56	0.19
KRISS	320.08	0.14	805.75	0.43	1602.08	0.52	3201.25	0.25
Summary	SDinst	SDmean	SDinst	SDmean	SDinst	SDmean	SDinst	SDmean
	1.41	0.14	2.96	0.71	4.74	0.59	7.06	0.77

Table 6-7: Diameter measurement of reference indentation for 450HBW

(a): Result of Reference indentation diameter on 450HBW (unit, μm)

Participant	450HBW1/30		450HBW2.5/187.5		450HBW5/750		450HBW10/3000	
	diameter	SD	diameter	SD	diameter	SD	diameter	SD
NMIJ	288.33	0.06	718.17	0.20	1434.88	0.72	2862.40	0.80
NIM	289.83	0.15	718.33	0.29	1439.50	0.50	2862.50	0.00
VNIIFTRI	-	-	722.00	0.50	1439.50	0.50	2866.67	1.04
INRIM	288.75	0.01	720.61	0.01	1438.46	0.05	2869.38	0.03
PTB	288.03	0.05	718.59	0.07	1437.25	0.10	2862.73	0.13
NPL	288.53	0.04	717.89	0.16	1434.32	0.20	2861.90	0.26
KRISS	287.83	0.29	716.67	0.14	1433.92	0.14	2857.00	0.90
Summary	SDinst	SDmean	SDinst	SDmean	SDinst	SDmean	SDinst	SDmean
	0.71	0.14	1.80	0.25	2.44	0.40	3.91	0.61

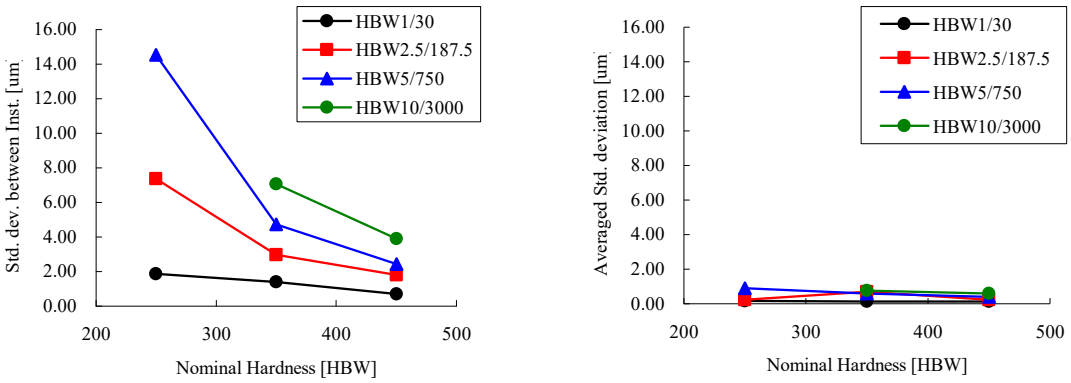

Fig. 6-2: Standard deviations of the mean diameter between institutes (left) and Average of standard deviation within institutes (right).

Figure 6-2 shows the standard deviation of diameter measurement of between institutes and also average of standard deviation within institute. The standard deviation between institutes is much larger with decreasing nominal hardness and it also become larger as measurement force increases. On the other hand, the average of standard deviation within institute, which is corresponding to the repeatability of the diameter measurement, is very small compared with the standard deviation between institutes. Similar tendency was observed in the hardness measurement. Therefore, we calculated the correlation between reference indentation measurement and hardness measurement.

Figure 6-3 shows the coefficient of correlation between reference indentations and corresponding own hardness results. The coefficients show high correlation about 0.8 and higher excepting HBW10/3000. The details are discussed in the appendix C.

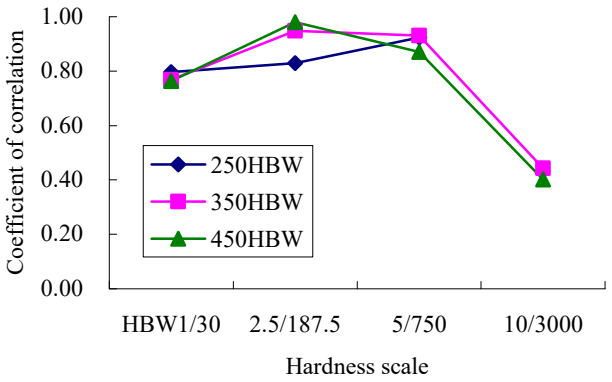

Fig. 6-3: Coefficient of correlation between the results of reference indentation and the hardness measurement for each hardness scales.

6.3 Diameter measurement of artificial indentation

Table 6-8 shows the summary of diameter measurement of artificial indentation for nominal diameter of 1.5, 0.8, 0.4 and 0.24 mm. The arithmetic mean of the three times of repeated measurements, its standard deviation of the measurement, standard deviation between participants and average of standard deviation within institutes (see. 6.1) are indicated. Figure 6-4 shows the results of the standard deviation of diameter between institutes and average of standard deviation within institutes for each nominal diameter of artificial indentation.

Table 6-8: Results of diameter measurement of artificial indentation (unit, μm)

Participant	1.5 mm		0.8 mm		0.4 mm		0.24 mm	
	diameter	SD	diameter	SD	diameter	SD	diameter	SD
NMIJ	1498.74	0.14	799.42	0.05	399.46	0.07	240.15	0.20
NIM	1508.33	1.26	803.33	0.76	401.17	0.76	242.75	0.05
VNIIFTRI	1499.33	0.29	801.00	1.00	400.33	1.26	241.17	1.04
INRIM	1498.40	0.10	798.85	0.04	398.91	0.02	239.38	0.07
PTB	1498.42	0.09	799.19	0.04	399.6	0.07	240.35	0.03
NPL	1499.49	0.03	800.00	0.01	400.01	0.03	240.52	0.04
KRISS	1498.42	0.38	799.67	0.29	400.00	0.25	240.17	0.38
Summary	SDinst	SDmean	SDinst	SDmean	SDinst	SDmean	SDinst	SDmean
	3.63	0.51	1.54	0.49	0.72	0.57	1.07	0.43

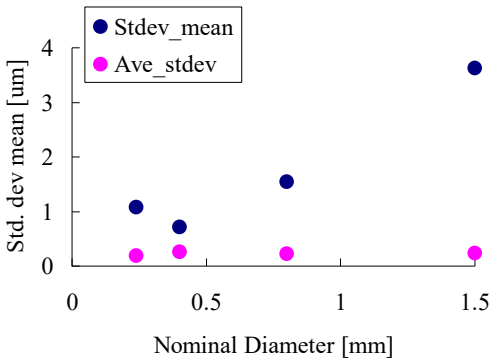

Fig. 6-4: Standard deviation of measured diameter between institutes and average of standard deviation within institutes.

7. Analysis

7.1 Determination of Reference Values

In this pilot study, the arithmetic mean was used as a reference values of each result of blocks. The uncertainties of the reference values was calculated as follows:

$$H_{ref} = \sum_i H_i / n \qquad (7.1)$$

$$u_{ref}^2 = \sum_i \left(H_i - H_{ref}\right)^2 / n = \sigma^2 / n \qquad (7.2)$$

where the H_i denotes measured Brinell hardness of block from i-th institute of the number of participants, n. The σ denotes the standard deviation of the H_i. All reported results adopted to calculate the reference values and the uncertainty of reference value.

The equivalence of the measurement is evaluated by En value, calculated from deviation from reference value and expanded uncertainties.

$$En = \left(H_i - H_{ref}\right) / \sqrt{\left(U_i^2 + U_{ref}^2\right)} \qquad (7.3)$$

7.2 Results of Brinell hardness of blocks

The strong correlation between measured Brinell hardness and diameter measurement of reference was found in the process of analyzing as mentioned in 6.2 and Appendix C. It is strongly suggested that the main cause of it is comes from the difference of optical measurement system among institutes, such as Numerical Aperture (N.A.) of objective lens and illumination of the measurement system.

After the draft of report was circulated, the N.A. dependence of indent diameter is investigated. There are two institute reported the N.A. dependence of the measured diameter and the both results show the similar tendency (Appendix D). INRIM reported detailed measurement and correction, the results was shown in figure 7-1. INRIM also reported a function to express the apparent diameter depending on N.A. of objective lens.

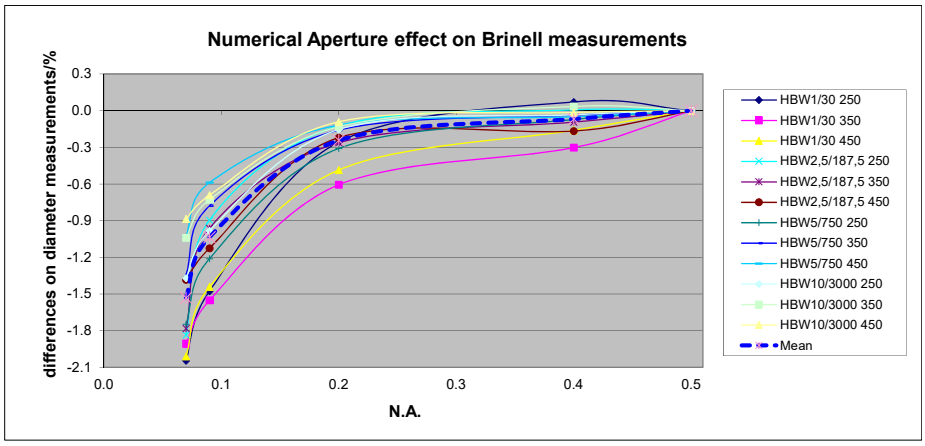

Fig. 7-1 Numerical aperture effect on Brinell diameter measurement reported by INRIM.

Finally, we indicate the results with following manner.

a) Results originally reported: Original results (without correction).

b) Results corrected by corrected result to reduce the N.A. effect.

The Corrected results (b) was adopted in the result of this pilot study.

The correction was applied to the measured dimeter using the function proposed by INRIM:

$$d_{\text{correction}} = C_{NA3}NA^3 + C_{NA2}NA^2 + C_{NA}NA + C_H H + C_L L + C_B D + C \quad [\%]. \quad (7.4)$$

Where the *NA:* numerical aperture of objective lens that used to diameter measurement of Brinell indent, H is the nominal hardness, L is the load in F [N]/9.80665, and D is the diameter of the indenter ball in mm, respectively. The coefficients of the function are shown in table 7-1.

Table 7-1 Coefficients of the correction function.

NA3	NA2	NA	H	F	B	C
65.09104	-70.6407	24.76834	0.000494	-0.00025	0.124558	-3.35459

Table 7-2 Numerical aperture of objective lens used the indentation dimeter measurement

Participant	250HBW			350HBW				450HBW			
	1/30	2.5/187.5	5/750	1/30	2.5/187.5	5/750	10/3000	1/30	2.5/187.5	5/750	10/3000
NMIJ	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
NIM	-	0.25	0.1	-	0.25	0.1	0.1	-	0.25	0.1	0.1
VNIIFTRI	0.17	0.11	0.11	0.17	0.11	0.11	0.11	0.17	0.11	0.11	0.11
INRM	0.09	0.07	0.07	0.09	0.07	0.07	0.07	0.09	0.07	0.07	0.07
PTB	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
NPL	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
KRISS	0.65	0.65	0.65	0.65	0.65	0.65	0.25	0.65	0.65	0.65	0.25

The NA correction is not applied to the institute that used N.A. larger than or equal 0.4. The measurement points that is not applying the correction are indicated by underlined in the table.

7.3 The original results.

The reported hardness from institutes are shown in Table 7-3 and fig. 7-2 for 250 HBW, Table 7-4 and fig. 7-3 for 350 HBW and Table 7-5 and fig. 7-4 for 250 HBW. The reported hardness, expanded uncertainties, deviation from Reference value and En are indicated in the tables, respectively.

7.4 The hardness corrected by diameter measurement results.

In this pilot study correlation between measured Brinell hardness and diameter of reference indentation was found as already described in section 7.2. Again, the correction was done only for hardness measured using N.A.< 0.4. The results applied the N.A. correction are shown in Table 7-6 and fig. 7-5 for 250 HBW, Table 7-7 and fig. 7-6 for 350 HBW and Table 7-8 and fig. 7-7 for 450 HBW.

In this pilot study report, the corrected values are adopted as the final result in accordance with the discussion in CIPM Working group on Hardness.

Comparison Result, without correction (Original reported values)

Table 7-3a Result for 250 HBW 1/30:

RV 250.0 HBW, U_Ref. (*k*=2): 3.22 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	253.28	2.39	3.27	0.48
NIM	-	-	-	-
VNIIFTRI	247.83	3.02	-2.17	0.30
INRIM	243.89	2.50	-6.11	0.88
PTB	248.44	2.45	-1.56	0.23
KRISS	254.03	1.45	4.03	0.61
NPL	252.54	2.99	2.54	0.36

Table 7-3b Result for 250 HBW 2.5/187.5:

RV 254.55 HBW, U_ref (k=2): 3.69 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	258.12	2.08	3.57	0.46
NIM	256.80	1.24	2.25	0.30
VNIIFTRI	253.26	1.47	-1.29	0.17
INRIM	244.54	2.30	-10.01	1.29
PTB	254.18	1.52	-0.37	0.05
KRISS	255.71	1.33	1.16	0.16
NPL	259.24	1.43	4.69	0.62

Table 7-3c Result for 250 HBW 5/750:

RV 248.40 HBW, U_Ref (*k*=2): 2.78 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	250.40	2.08	2.00	0.34
NIM	250.38	1.02	1.98	0.35
VNIIFTRI	249.99	1.40	1.59	0.28
INRIM	240.30	2.30	-8.10	1.35
PTB	247.87	1.96	-0.53	0.09
KRISS	249.93	1.40	1.54	0.27
NPL	249.91	0.96	1.51	0.27

Comparison Result, without correction (Original reported values)

Table 7-4a Result for 350 HBW 1/30:

RV 358.39 HBW, U_Ref (*k*=2): 1.80 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	361.01	3.79	2.61	0.50
NIM	-	-	-	-
VNIIFTRI	358.69	5.70	0.30	0.04
INRIM	354.82	3.50	-3.58	0.71
PTB	358.06	3.54	-0.33	0.07
KRISS	360.31	1.89	1.91	0.47
NPL	357.47	4.76	-0.92	0.15

Table 7-4b Result for 350 HBW 2.5/187.5:

RV 353.95 HBW U_Ref (*k*=2): 3.11 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	357.68	2.34	3.73	0.56
NIM	354.45	2.64	0.50	0.07
VNIIFTRI	348.16	2.90	-5.79	0.84
INRIM	348.41	3.20	-5.54	0.79
PTB	354.37	2.12	0.42	0.06
KRISS	356.81	1.86	2.86	0.44
NPL	357.77	2.69	3.82	0.56

Table 7-4c Result for 350 HBW 5/750:

RV 359.20 HBW U_Ref (*k*=2): 2.52 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	361.62	1.85	2.41	0.45
NIM	357.32	1.80	-1.89	0.35
VNIIFTRI	360.44	2.32	1.23	0.22
INRIM	352.63	3.10	-6.58	1.11
PTB	359.17	2.74	-0.03	0.01
KRISS	362.22	1.88	3.02	0.56
NPL	361.04	1.08	1.84	0.36

Table 7-4b Result for 350 HBW 10/3000:

RV: 357.35 HBW U_Ref (*k*=2): 2.36 HBW Block A

*RV: 356.44 HBW U_Ref (*k*=2): 1.71 HBW *Block B

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	360.80	2.05	3.45	0.67
NIM	357.71	0.86	0.35	0.07
VNIIFTRI	358.78	2.20	1.43	0.27
INRIM	354.44	3.10	-2.91	0.51
PTB	355.03	2.12	-2.32	0.45
KRISS*	357.26	1.86	0.82	0.21
NPL*	354.73	1.75	-1.71	0.45
NMIJ*	357.33	2.01	0.89	0.22

Comparison Result, without correction (Original reported values)

Table 7-5a Result for 450 HBW 1/30:

RV: 448.72 HBW, U_Ref (*k*=2): 1.38 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	450.42	4.45	1.71	0.33
NIM	-	-	-	-
VNIIFTRI	-	-	-	-
INRIM	447.41	4.50	-1.31	0.25
PTB	449.65	4.47	0.93	0.18
KRISS	449.29	2.39	0.57	0.16
NPL	446.81	6.49	-1.91	0.27

Table 7-5b Result for 450 HBW 2.5/187.5:

RV: 452.25 HBW U_Ref (*k*=2): 2.42 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	453.34	2.95	1.09	0.19
NIM	452.56	3.24	0.31	0.05
VNIIFTRI	446.88	3.84	-5.37	0.87
INRIM	448.88	4.10	-3.37	0.53
PTB	453.55	2.81	1.30	0.23
KRISS	454.97	2.34	2.72	0.51
NPL	455.57	2.78	3.32	0.59

Table 7-5c Result for 450 HBW 5/750:

RV: 453.22 HBW U_Ref (*k*=2): 1.73 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	454.82	1.59	1.61	0.42
NIM	452.33	2.62	-0.89	0.20
VNIIFTRI	451.01	2.90	-2.20	0.49
INRIM	449.62	4.00	-3.59	0.68
PTB	453.80	3.58	0.58	0.12
KRISS	455.38	2.33	2.17	0.52
NPL	455.54	1.53	2.33	0.61

Table 7-5d Result for 450 HBW 10/3000:

RV: 454.86 HBW U_Ref (*k*=2): 0.71 HBW Block A

*RV: 454.42 HBW U_Ref (*k*=2): 0.61 HBW *Block B

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	455.83	1.76	0.97	0.43
NIM	454.42	1.28	-0.44	0.23
VNIIFTRI	454.94	2.72	0.08	0.03
INRIM	453.77	3.90	-1.09	0.26
PTB	455.33	2.68	0.47	0.16
KRISS*	454.97	2.34	0.55	0.21
NPL*	453.92	1.13	-0.50	0.30
NMIJ*	454.37	1.89	-0.05	0.02

Comparison Result, without correction (Original reported values)

For 250HBW (without correction)

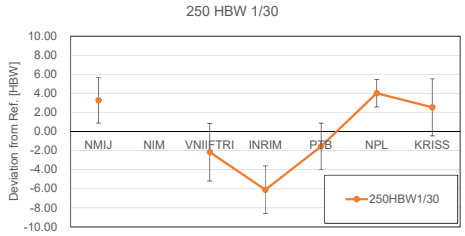

Fig. 7-2a: Deviation of the data from the reference value, 250HBW1/30.
RV: 250.00 HBW1/30 ± 3.22 HBW (*k*=2).

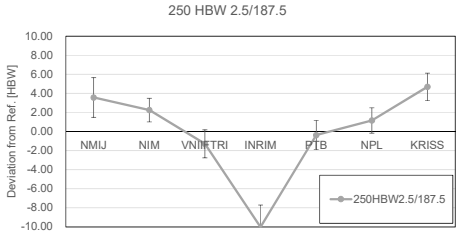

Fig. 7-2b: Deviation of the data from the reference value, 250HBW2.5/187.5.
RV: 254.55 HBW2.5/187.5 ± 3.69 HBW (*k*=2).

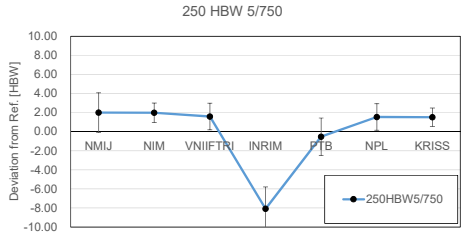

Fig. 7-2c: Deviation of the data from the reference value, 250 HBW5/750.
KCRV: 248.40 HBW 5/750 ± 2.78 HBW (*k*=2).

For 350HBW (without correction)

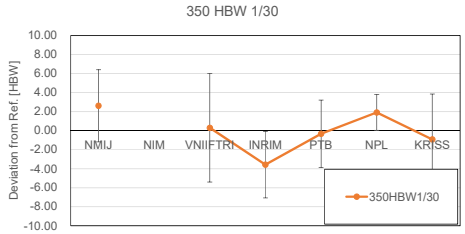

Fig. 7-3a: Deviation of the data from the reference value, 350HBW1/30.value, 350HBW1/30.
KCRV: 358.39 HBW1/30 ±1.80 HBW (*k*=2).

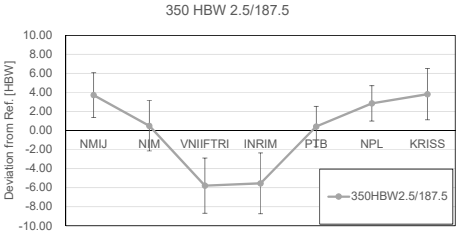

Fig. 7-3b: Deviation of the data from the reference

KCRV: 353.95 HBW2.5/187.5 ±3.11HBW (*k*=2).

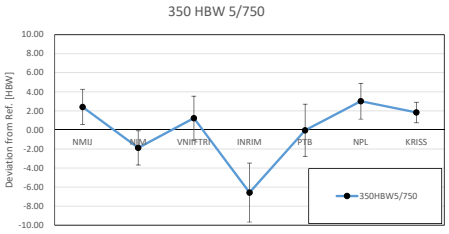

Fig. 7-3c: Deviation of the data from the reference value, 350HBW5/750.
KCRV: 359.20 HBW2.5/187.5 ±2.52HBW (*k*=2).

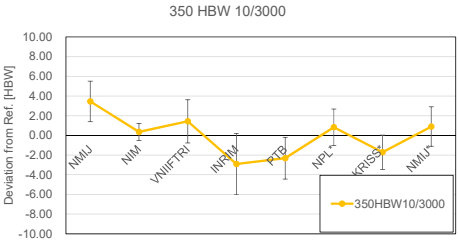

Fig. 7-3d: Deviation of the data from the reference value, 350HBW10/3000.
KCRV: 357.35 HBW 2.5/187.5 ±2.36HBW (*k*=2) for A
KCRV: 356.44 HBW 2.5/187.5 ±1.71HBW (*k*=2) for B

For 450HBW (without correction)

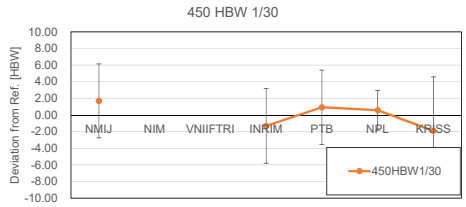

Fig. 7-4a: Deviation of the data from the reference value, 450HBW1/30.

KCRV: 448.72 HBW 1/30 ±1.38HBW (*k*=2).

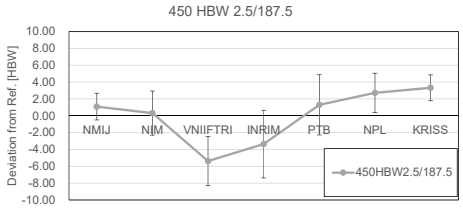

Fig. 7-4b: Deviation of the data from the reference value, 450HBW2.5/187.5.

KCRV: 452.25 HBW 2.5/187.5 ±2.42HBW(*k*=2).

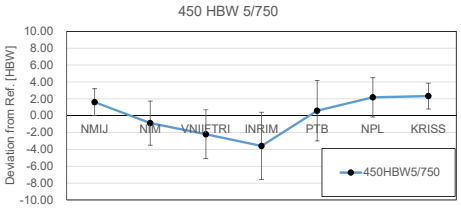

Fig. 7-4c: Deviation of the data from the reference value, 450HBW5/750.

KCRV: 453.22 HBW 5/750 ±1.73HBW (*k*=2).

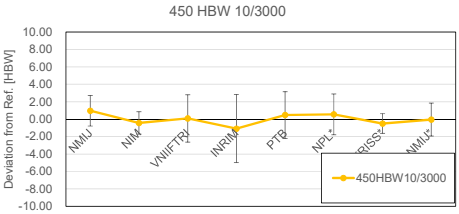

Fig. 7-4d: Deviation of the data from the reference value, 450HBW10/3000.

KCRV: 454.86 HBW10/3000 ±0.71HBW (*k*=2) for A

KCRV: 454.42 HBW10/3000 ±0.61HBW (*k*=2) for B

Comparison Result, with NA correction

Table 7-6a NA effect corrected results for 250 HBW 1/30:

RV: 252.20 HBW, U_Ref. (*k*=2): 1.05 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	253.28	2.39	1.08	0.34
NIM	-	-	-	-
VNIIFTRI	251.13	3.02	-1.07	0.29
INRIM	251.33	2.50	-0.87	0.27
PTB	250.90	2.45	-1.30	0.40
KRISS	254.03	1.45	1.83	0.72
NPL	252.54	2.99	0.34	0.09

Table 7-6b NA effect corrected results for 250 HBW 2.5/187.5

RV: 256.89 HBW, U_ref (k=2): 1.70 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	258.12	2.08	1.23	0.31
NIM	257.73	1.24	0.84	0.23
VNIIFTRI	258.75	1.47	1.86	0.50
INRIM	252.79	2.30	-4.10	1.00
PTB	255.88	1.52	-1.01	0.27
KRISS	255.71	1.33	-1.17	0.32
NPL	259.24	1.43	2.36	0.64

Table 7-6c NA effect corrected results for 250 HBW 5/750

RV: 250.91 HBW, U_Ref (*k*=2): 2.25 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|*En*|
NMIJ	250.40	2.08	-0.51	0.10
NIM	255.53	1.02	4.62	1.00
VNIIFTRI	254.47	1.40	3.57	0.76
INRIM	247.49	2.30	-3.42	0.68
PTB	248.62	1.96	-2.29	0.47
KRISS	249.93	1.40	-0.97	0.21
NPL	249.91	0.96	-1.00	0.22

Comparison Result, with NA correction, continued

Table 7-7a NA effect corrected results for 350 HBW 1/30

RV: 361.35 HBW, U_Ref (*k*=2): 2.11 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|En|
NMIJ	361.01	3.79	-0.34	0.06
NIM	-	-	-	-
VNIIFTRI	363.03	5.70	1.68	0.24
INRIM	365.12	3.50	3.76	0.69
PTB	361.18	3.54	-0.17	0.03
KRISS	360.31	1.89	-1.05	0.23
NPL	357.47	4.76	-3.88	0.61

Table 7-7b NA corrected results for 350 HBW 2.5/187.5

RV: 356.97 HBW U_Ref (*k*=2): 1.17 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|En|
NMIJ	357.68	2.34	0.70	0.21
NIM	355.34	2.64	-1.63	0.46
VNIIFTRI	355.24	2.90	-1.73	0.47
INRIM	359.64	3.20	2.66	0.67
PTB	356.34	2.12	-0.63	0.20
KRISS	356.81	1.86	-0.17	0.06
NPL	357.77	2.69	0.80	0.22

Table 7-7c NA corrected results for 350 HBW 5/750

RV 362.58 HBW U_Ref (*k*=2): 1.64 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|En|
NMIJ	361.62	1.85	-0.96	0.26
NIM	364.20	1.80	1.62	0.43
VNIIFTRI	366.44	2.32	3.86	0.96
INRIM	362.67	3.10	0.09	0.02
PTB	359.88	2.74	-2.70	0.63
KRISS	362.22	1.88	-0.36	0.10
NPL	361.04	1.08	-1.54	0.45

Table 7-7d NA corrected results for 350 HBW 10/3000

RV: 361.73 HBW U_Ref (*k*=2): 3.47 HBW Block A

*RV: 356.79 HBW U_Ref (*k*=2): 1.71 HBW Block B*

Institute	Hardness	*U* (*k*=2)	Deviation	|En|
NMIJ	360.80	2.05	-0.93	0.13
NIM	364.15	0.86	2.42	0.35
VNIIFTRI	364.31	2.20	2.58	0.35
INRIM	364.09	3.10	2.36	0.31
PTB	355.29	2.12	-6.44	0.89
KRISS*	357.60	1.86	0.82	0.21
NPL*	355.08	1.75	-1.71	0.44
NMIJ*	357.68	2.01	0.89	0.22

Comparison Result, with NA correction, continued

Table 7-8a NA corrected results for 450 HBW 1/30

RV: 451.88 HBW, U_Ref (*k*=2): 4.45 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|En|
NMIJ	450.42	4.45	-1.46	0.15
NIM	-	-	-	-
VNIIFTRI	-	-	-	-
INRIM	459.83	4.50	7.94	0.80
PTB	453.06	4.47	1.18	0.12
KRISS	449.29	2.39	-2.59	0.28
NPL	446.81	6.49	-5.08	0.46

Table 7-8b NA corrected results for 450 HBW 2.5/187.5

RV: 455.84 HBW U_Ref (*k*=2): 2.43 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|En|
NMIJ	453.34	2.95	-2.50	0.65
NIM	453.22	3.24	-2.62	0.65
VNIIFTRI	455.43	3.84	-0.41	0.09
INRIM	462.77	4.10	6.93	1.45
PTB	455.58	2.81	-0.26	0.07
KRISS	454.97	2.34	-0.87	0.26
NPL	455.57	2.78	-0.27	0.07

Table 7-8c NA corrected results for 450 HBW 5/750

RV: 457.19 HBW U_Ref (*k*=2): 2.27 HBW

Institute	Hardness	*U* (*k*=2)	Deviation	|En|
NMIJ	454.82	1.59	-2.36	0.49
NIM	460.49	2.62	3.31	0.63
VNIIFTRI	457.99	2.90	0.81	0.15
INRIM	461.86	4.00	4.67	0.77
PTB	454.21	3.58	-2.98	0.52
KRISS	455.38	2.33	-1.80	0.35
NPL	455.54	1.53	-1.65	0.34

Table 7-8d NA corrected results for 450 HBW 10/3000

RV: 460.01 HBW U_Ref (*k*=2): 3.94 HBW Block A

*RV: 455.11 HBW U_Ref (*k*=2): 0.61 HBW Block B

Institute	Hardness	*U* (*k*=2)	Deviation	|En|
NMIJ	455.83	1.76	-4.18	0.52
NIM	462.06	1.28	2.05	0.26
VNIIFTRI	461.42	2.72	1.41	0.17
INRIM	465.55	3.90	5.54	0.63
PTB	455.19	2.68	-4.82	0.58
KRISS*	455.67	2.34	0.55	0.23
NPL*	454.61	1.13	-0.50	0.39
NMIJ*	455.06	1.89	-0.05	0.03

For 250HBW (with NA correction)

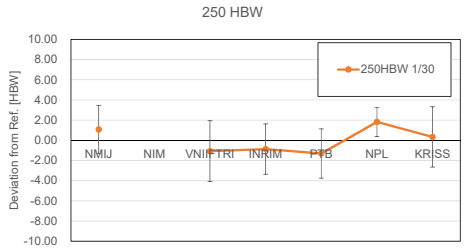

Fig. 7-5a: Deviation of the data from the reference value, 250HBW1/30.
RV: 252.20 HBW1/30 ± 1.05 HBW (*k*=2).

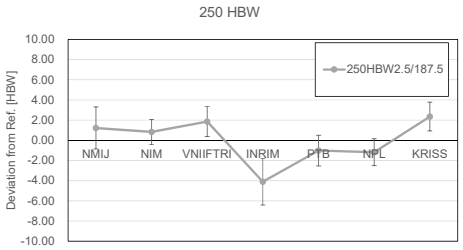

Fig. 7-5b: Deviation of the data from the reference value, 250HBW2.5/187.5.
RV: 256.89 HBW2.5/187.5 ± 1.70 HBW (*k*=2).

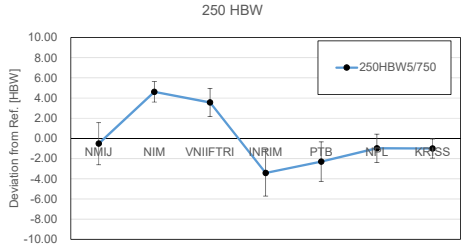

Fig. 7-5c: Deviation of the data from the reference value, 250 HBW5/750.
KCRV: 250.91 HBW 5/750 ± 2.25 HBW (*k*=2).

For 350HBW (with NA correction)

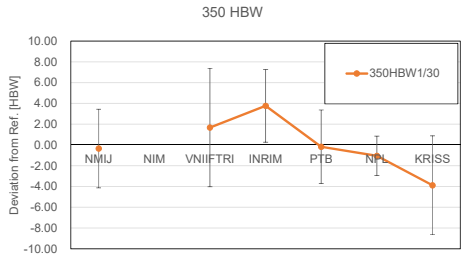

Fig. 7-6a: Deviation of the data from the reference value, 350HBW1/30.value, 350HBW1/30.
KCRV: 361.35 HBW1/30 ±2.11 HBW (*k*=2).

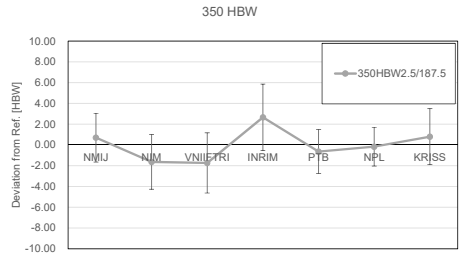

Fig. 7-6b: Deviation of the data from the reference
KCRV: 356.97 HBW2.5/187.5 ±1.17HBW (*k*=2).

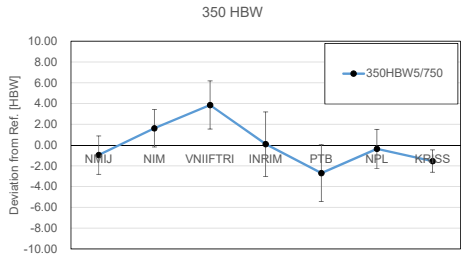

Fig. 7-6c: Deviation of the data from the reference value, 350HBW5/750.
KCRV: 362.58 HBW2.5/187.5 ±1.64HBW (*k*=2).

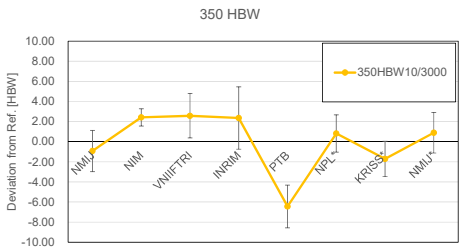

Fig. 7-6d: Deviation of the data from the reference value, 350HBW10/3000.
KCRV: 361.73 HBW 2.5/187.5 ±3.47HBW (*k*=2) for A
KCRV: 356.79 HBW 2.5/187.5 ±1.71HBW (*k*=2) for B

For 450HBW (with NA correction)

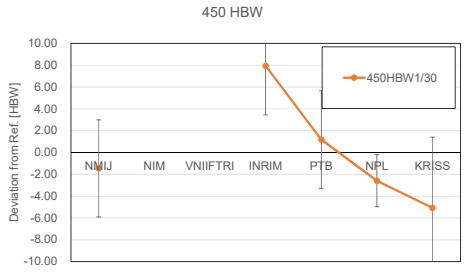

Fig. 7-7a: Deviation of the data from the reference value, 450HBW1/30.

KCRV: 451.88 HBW 1/30 ±4.45 HBW (*k*=2).

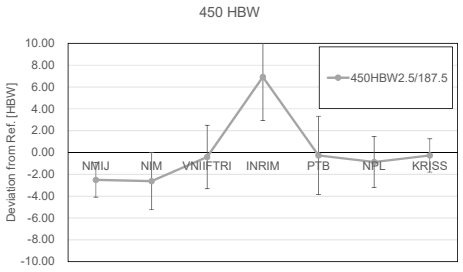

Fig. 7-7b: Deviation of the data from the reference value, 450HBW2.5/187.5.

KCRV: 455.84 HBW 2.5/187.5 ±2.43 HBW(*k*=2).

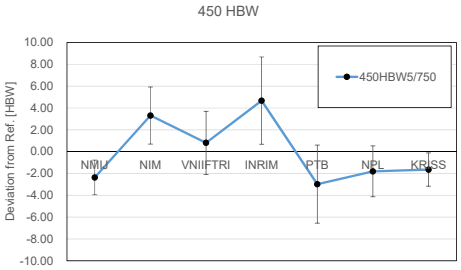

Fig. 7-7c: Deviation of the data from the reference value, 450HBW5/750.

KCRV: 457.19 HBW 5/750 ±2.27HBW (*k*=2).

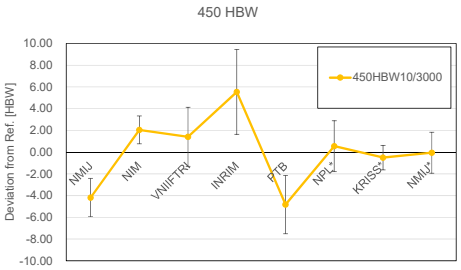

Fig. 7-7d: Deviation of the data from the reference value, 450HBW10/3000.

KCRV: 460.01 HBW10/3000 ±3.94HBW (*k*=2) for A

KCRV: 455.11 HBW10/3000 ±0.61HBW (*k*=2) for B

8. Summary:

This report is the pilot study report of Brinell hardness comparison. The item of comparisons are 250 HBW, 350 HBW, and 450 HBW, with scales 1/30, 2.5/187.5, 5/750 and 10/3000. Final results and variation of the participants are shown in Figures from 7-5 to 7-7 and Tables from 7-6 to 7-8. In the results, correction proposed by INRIM is applied to the results using objective lens, N.A. < 0.4.

References:

[1] *The essential points of the CIPM MRA*, BIPM
(available at http://www.bipm.org/en/convention/mra/objectives.html)

[2] *Guidelines for CIPM key comparisons* with modification 2003, BIPM, (1999).
(available at http://www.bipm.org/utils/en/pdf/guidelines.pdf)

[3] EA 10/16; *EA Guidelines on the Estimation of Uncertainty in Hardness Measurements*, European co-operation for accreditation (2002).
(http://www.european-accreditation.org/pdf/EA-10-16rev00.pdf)

[4] ISO 6506-3:1999 "Metallic materials –Brinell hardness test– Part 3: Calibration of reference blocks".

[5] *Technical supplement to the arrangement*, BIPM, (2003).
(available at http://www.bipm.org/utils/en/pdf/mra_techsuppl2003.pdf)

[6] M.G.. Cox, "The evaluation of key comparison data", Metrologia, **39**, 589(2002).

[7] R.N. Kachker, R.U. Datla and A.C. Parr, *Statistical analysis of CIPM key comparisons based on the ISO Guide*, Metrologia, **41**, 340 (2004).

Appendix A: Reported results and uncertainties

In this appendix, the individual result of reported measured values and uncertainties for Brinell hardness measurement are indicated.

Content

Report from:

Results and uncertainty report –INRIM– **INRIM 1/9**

Measurement results

Results for Reference and False indentations

Measurement result of measuremet of the length of Reference indents

reference Block	ID of the Block	Hardness (HBW)	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Temp (°C)
250	93241	1.0/30	387.05	387.04	387.07	386.44	386.45	386.40	387.05	386.43	386.74	(22±0.5)°C
	93243	2.5/187.5	960.47	960.37	960.37	962.28	962.20	962.17	960.40	962.22	961.31	(22±0.5)°C
	93242	5/750	1948.38	1948.12	1948.46	1949.64	1949.55	1949.75	1948.32	1949.65	1948.98	(22±0.5)°C
350	94041	1.0/30	323.29	323.28	323.30	323.25	323.25	323.26	323.29	323.25	323.27	(22±0.5)°C
	94043	2.5/187.5	813.22	813.26	813.21	813.15	813.22	813.24	813.23	813.20	813.22	(22±0.5)°C
	94042	5/750	1615.61	1615.49	1615.50	1615.91	1615.98	1616.06	1615.53	1615.98	1615.76	(22±0.5)°C
	94037	10/3000	3221.11	3221.13	3221.25	3222.45	3222.72	3222.80	3221.16	3222.66	3221.91	(22±0.5)°C
450	95008	1.0/30	289.01	289.02	289.00	288.49	288.51	288.49	289.01	288.50	288.75	(22±0.5)°C
	95011	2.5/187.5	720.58	720.59	720.56	720.63	720.67	720.65	720.58	720.65	720.61	(22±0.5)°C
	95010	5/750	1438.40	1438.30	1438.34	1438.62	1438.51	1438.58	1438.35	1438.57	1438.46	(22±0.5)°C
	95004	10/3000	2870.59	2870.68	2870.72	2868.14	2868.02	2868.10	2870.66	2868.09	2869.38	(22±0.5)°C

Measurement result of measuremet of the length of "False Indentation"

Nominal Diameter	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	(22±0.5)° C
1.5	1498.84	1498.93	1498.98	1497.74	1497.92	1498.01	1498.92	1497.89	1498.40	(22±0.5)°C
0.8	798.80	799.01	799.05	798.81	798.75	798.65	798.95	798.74	798.85	(22±0.5)°C
0.4	398.95	398.90	398.86	398.84	398.95	398.93	398.90	398.91	398.91	(22±0.5)°C
0.24	239.51	239.34	239.29	239.38	239.29	239.44	239.38	239.37	239.38	(22±0.5)°C

Results for 250HBW1/30, 250HBW2.5/187.5 and 250HBW5/750

INRIM 2/9

Specimen
250 HBW

Block ID.	93241

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
b7	1.0/30	1	389.80	389.81	389.83	390.01	389.99	389.97	389.81	389.99	389.90	241.32	(22±0.5)°C
e3		2	386.85	386.82	386.85	387.62	387.58	387.60	386.84	387.60	387.22	244.81	(22±0.5)°C
e6		3	387.86	387.86	387.88	387.78	387.78	387.79	387.87	387.78	387.83	244.02	(22±0.5)°C
h10		4	387.26	387.26	387.32	387.78	387.78	387.79	387.28	387.78	387.53	244.40	(22±0.5)°C
i4		5	386.94	386.93	386.93	387.34	387.34	387.40	386.93	387.36	387.15	244.91	(22±0.5)°C

Block ID.	93243

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
b7	2.5/187.5	1	972.97	972.94	972.94	973.08	973.09	973.05	972.95	973.07	973.01	242.22	(22±0.5)°C
e3		2	968.76	968.72	968.76	968.56	968.49	968.55	968.75	968.53	968.64	244.50	(22±0.5)°C
e6		3	966.70	966.63	966.60	967.97	968.00	967.91	966.64	967.96	967.30	245.21	(22±0.5)°C
h10		4	967.84	967.85	967.85	969.38	969.29	969.32	967.85	969.33	968.59	244.53	(22±0.5)°C
i4		5	965.76	965.78	965.78	965.01	965.02	965.01	965.77	965.01	965.39	246.22	(22±0.5)°C

Block ID.	93242

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
b7	5/750	1	1960.76	1960.37	1960.72	1955.47	1955.40	1955.62	1960.62	1955.50	1958.06	239.12	(22±0.5)°C
e3		2	1948.08	1947.70	1947.74	1948.08	1947.75	1947.72	1947.84	1947.85	1947.85	241.75	(22±0.5)°C
e6		3	1954.86	1955.02	1954.84	1955.94	1955.75	1955.80	1954.91	1955.83	1955.37	239.81	(22±0.5)°C
h10		4	1954.10	1954.46	1954.42	1957.66	1957.72	1957.92	1954.33	1957.77	1956.05	239.64	(22±0.5)°C
i4		5	1951.95	1951.86	1951.72	1948.18	1948.17	1948.51	1951.84	1948.29	1950.07	241.17	(22±0.5)°C

Results for 350HBW1/30, 350HBW2.5/187.5, 350HBW5/750 and 350HBW10/3000

INRIM 3/9

Specimen
350 HBW

Block ID.	94041

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
b7	1.0/30	1	324.62	324.61	324.62	324.55	324.57	324.57	324.62	324.56	324.59	352.73	(22±0.5)°C
e3		2	323.46	323.46	323.44	324.49	324.45	324.51	323.45	324.48	323.97	354.12	(22±0.5)°C
e6		3	324.43	324.46	324.47	324.16	324.14	324.16	324.45	324.15	324.30	353.37	(22±0.5)°C
h10		4	323.34	323.36	323.34	323.66	323.70	323.69	323.35	323.68	323.52	355.14	(22±0.5)°C
i4		5	321.74	321.73	321.72	322.14	322.18	322.15	321.73	322.16	321.94	358.72	(22±0.5)°C

Block ID.	94043

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
b7	2.5/187.5	1	816.66	816.66	816.67	817.21	817.17	817.11	816.66	817.16	816.91	347.91	(22±0.5)°C
e3		2	815.89	815.91	815.94	817.64	817.57	817.54	815.91	817.58	816.75	348.06	(22±0.5)°C
e6		3	816.68	816.67	816.69	816.48	816.40	816.43	816.68	816.44	816.56	348.23	(22±0.5)°C
h10		4	814.71	814.69	814.70	815.43	815.45	815.50	814.70	815.46	815.08	349.53	(22±0.5)°C
i4		5	815.66	815.63	815.72	817.28	817.25	817.23	815.67	817.25	816.46	348.31	(22±0.5)°C

Block ID.	94042

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
b7	5/750	1	1624.26	1624.24	1624.16	1623.04	1623.11	1623.17	1624.22	1623.11	1623.66	352.41	(22±0.5)°C
e3		2	1626.54	1626.72	1626.74	1625.19	1625.02	1625.03	1626.67	1625.08	1625.87	351.43	(22±0.5)°C
e6		3	1624.85	1624.90	1624.95	1622.91	1623.01	1623.06	1624.90	1622.99	1623.95	352.28	(22±0.5)°C
h10		4	1620.27	1619.96	1619.98	1621.35	1621.50	1621.42	1620.07	1621.42	1620.75	353.72	(22±0.5)°C
i4		5	1622.30	1622.01	1621.95	1621.06	1621.44	1621.38	1622.09	1621.29	1621.69	353.29	(22±0.5)°C

Block ID.	94037

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
b2	10/3000	1	3245.68	3245.80	3245.79	3247.65	3247.53	3247.62	3245.76	3247.60	3246.68	352.56	(22±0.5)°C
b4		2	3245.13	3245.38	3245.28	3243.98	3244.04	3243.92	3245.26	3243.98	3244.62	353.02	(22±0.5)°C
d2		3	3239.70	3239.71	3239.82	3236.13	3236.01	3235.97	3239.74	3236.04	3237.89	354.53	(22±0.5)°C
d6		4	3239.01	3239.07	3239.17	3238.95	3238.95	3239.09	3239.08	3239.00	3239.04	354.27	(22±0.5)°C
f4		5	3224.18	3224.34	3224.25	3221.99	3222.36	3222.13	3224.26	3222.16	3223.21	357.86	(22±0.5)°C

Results for 450HBW1/30, 450HBW2.5/187.5, 450HBW5/750 and 450HBW10/3000

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Specimen
450 HBW

Block ID.	95008

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
b7	1.0/30	1	288.67	288.67	288.64	288.67	288.73	288.71	288.66	288.70	288.68	448.59	(22±0.5)°C
e3		2	289.66	289.67	289.63	289.62	289.57	289.63	289.65	289.61	289.63	445.59	(22±0.5)°C
e6		3	289.70	289.68	289.70	289.75	289.78	289.73	289.69	289.75	289.72	445.30	(22±0.5)°C
h10		4	288.44	288.42	288.44	288.49	288.54	288.50	288.43	288.51	288.47	449.26	(22±0.5)°C
i4		5	289.21	289.22	289.24	288.30	288.30	288.32	289.22	288.31	288.77	448.32	(22±0.5)°C

Block ID.	95011

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
b7	2.5/187.5	1	721.97	721.96	721.96	721.81	721.76	721.91	721.96	721.83	721.90	448.35	(22±0.5)°C
e3		2	722.86	722.87	722.91	721.81	721.86	721.82	722.88	721.83	722.36	447.76	(22±0.5)°C
e6		3	722.36	722.31	722.31	721.24	721.27	721.20	722.33	721.24	721.78	448.49	(22±0.5)°C
h10		4	720.66	720.65	720.60	720.39	720.33	720.41	720.64	720.38	720.51	450.11	(22±0.5)°C
i4		5	721.06	721.03	721.09	720.60	720.60	720.61	721.06	720.60	720.83	449.70	(22±0.5)°C

Block ID.	95010

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
b7	5/750	1	1444.78	1445.15	1445.13	1443.16	1443.25	1443.24	1445.02	1443.22	1444.12	448.14	(22±0.5)°C
e3		2	1442.45	1442.71	1442.70	1441.89	1441.83	1441.86	1442.62	1441.86	1442.24	449.33	(22±0.5)°C
e6		3	1443.39	1443.31	1443.41	1442.42	1442.44	1442.41	1443.37	1442.42	1442.90	448.91	(22±0.5)°C
h10		4	1441.69	1441.51	1441.45	1441.06	1441.21	1441.24	1441.55	1441.17	1441.36	449.89	(22±0.5)°C
i4		5	1437.43	1437.63	1437.59	1438.89	1439.18	1439.23	1437.55	1439.10	1438.33	451.84	(22±0.5)°C

Block ID.	95004

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
b2	10/3000	1	2875.47	2875.52	2875.62	2871.25	2871.28	2871.34	2875.54	2871.29	2873.41	452.88	(22±0.5)°C
b4		2	2872.02	2871.84	2871.89	2870.78	2870.76	2870.66	2871.92	2870.73	2871.33	453.55	(22±0.5)°C
d2		3	2873.78	2873.62	2873.56	2869.74	2869.72	2869.75	2873.65	2869.74	2871.70	453.43	(22±0.5)°C
d6		4	2868.02	2868.01	2867.95	2867.46	2867.35	2867.27	2867.99	2867.36	2867.68	454.73	(22±0.5)°C
f4		5	2868.94	2868.90	2868.96	2869.27	2869.28	2869.18	2868.93	2869.24	2869.09	454.27	(22±0.5)°C

Uncertainty report –INRIM– **INRIM 5/9**

Brief description of the measurement system

Brinell key comparison 2003

Name of Institute
IMGC-CNR

Test Details

Instrument

Instrument type	Identifier
dead weight	IMGC-DN40I01 and Amsler 835-1

Measuring device

Device type	Identifier
Aut. Optical Meas. System (CNR patent)	AVAMS2

Uncertainty of the instruments

Hardness scale	uF (N)	uL (mm)	Dia. of Indenter (mm)
1,0/30	$1\cdot10^{-5}$	$1\cdot10^{-4}+(2\cdot d/1000)$	0.001
2,5/187,5	$1\cdot10^{-5}$	$1\cdot10^{-4}+(2\cdot d/1000)$	0.001
5,0/750	$1\cdot10^{-5}$	$1\cdot10^{-4}+(2\cdot d/1000)$	0.002
10/3000	$1\cdot10^{-5}$	$1\cdot10^{-4}+(2\cdot d/1000)$	0.003

d = indentation diameter/mm

Comments

The approximated formula for the calculation of the uncertainty of the realization of the Brinell scales in IMGC is the following: $U(p=95\%)/\% = 1 + 2\,(d/\text{mm})/(H/\text{HBW})$

To this uncertainty, the standard deviation of the measurements (of mean value) must be combined.

More detailed evaluation of uncertainty is in the attached file (IMGC_Brinell_Unc.XLS)

Summary of uncertainty tables

Evaluation of IMGC uncertainty (Realization of Brinell scales)

Scale	Hardness/HB	*st. unc.*	Exp. Uncertainty		Approx. Formula
		u/HB	*U/HB*	*U*/%	*U*/% = 1+ 2 *d*/*H*
			(confidence level p=95%)		
HBW1/30	250.0	1.2	2.5	1.0	1.0
	350.0	1.7	3.5	1.0	1.0
	450.0	2.2	4.5	1.0	1.0
HBW2,5/187,5	250.0	1.1	2.3	0.9	1.0
	350.0	1.5	3.2	0.9	1.0
	450.0	2.0	4.1	0.9	1.0
HBW5/750	250.0	1.1	2.3	0.9	1.0
	350.0	1.5	3.1	0.9	1.0
	450.0	1.9	4.0	0.9	1.0
HBW10/3000	350.0	1.5	3.1	0.9	1.0
	450.0	1.9	3.9	0.9	1.0

Evaluation of IMGC uncertainty (CCM-KC.2 Brinell measurements)

Scale	Hardness/HB	st. unc.	st. dev.	cov. fact.	*st. unc.*	Exp. Uncertainty		Approx. Formula
		u/HB	*/HB*	*k*	*u*/HB	*U/HB*	*U*/%	*U*/% = 1+ 2 *d*/*H*
						(confidence level p=95%)		
HBW1/30	250.0	1.2	0.7	2.1	1.4	2.9	1.2%	1.2%
	350.0	1.7	0.3	2.1	1.7	3.5	1.0%	1.0%
	450.0	2.2	0.4	2.1	2.2	4.6	1.0%	1.0%
HBW2,5/187,5	250.0	1.1	0.7	2.1	1.3	2.7	1.1%	1.2%
	350.0	1.5	1.1	2.1	1.9	4.0	1.1%	1.2%
	450.0	2.0	0.8	2.1	2.1	4.4	1.0%	1.1%
HBW5/750	250.0	1.1	0.5	2.1	1.2	2.5	1.0%	1.1%
	350.0	1.5	0.4	2.1	1.5	3.2	0.9%	1.0%
	450.0	1.9	0.6	2.1	2.0	4.2	0.9%	1.0%
HBW10/3000	350.0	1.5	0.9	2.1	1.7	3.6	1.0%	1.2%
	450.0	1.9	0.3	2.1	1.9	4.0	0.9%	1.0%

Uncertainty report for Hardness scale 1/30

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				Type A	Type B					
Influencing quantity X_i	**Symbol**	**Unit**	**Value**	s_i	a_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force	***F***	N	**294.20**	2.9E-03		8.7E-06	8.7E-01	6.5E-06	8	5.3E-12
Indentation diameter	***d***	mm	**0.3834**	8.7E-04		7.5E-07	-1.4E+03	1.4E+00	19	1.0E-01
Ball diameter	***D***	mm	**1.000**		1.0E-03	3.3E-07	2.1E+01	1.4E-04	30	6.7E-10
Test force application time	t_1	s	**7.0**		1.0E+00	3.3E-01	1.2E-01	4.7E-03	30	7.5E-07
Test force duration time	t_2	s	**12.5**		2.5E+00	2.1E+00	-1.2E-01	3.0E-02	30	2.9E-05
Total								1.4E+00		1.0E-01
Combined standard uncertainty *u (H)*								1.2E+00	ν_{eff}	19
Confidence level								95%		
Coverage factor								2.1		
Expanded standard uncertainty *U (H)*								**2.5**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$								**1.0**	**%**	**1.0**
Hardness	**250.0**	**HBW**								

			F	*d*	*D*
		Δ	*x*+*Δ*	*x*+*Δ*	*x*+*Δ*
F	294.2	0.00294	294.2	294.2	294.2
d	0.383	0.00087	0.3834	0.3842	0.3834
D	1.000	0.00100	1.000	1.000	1.001
HV	250.0		250.0	248.8	250.0
ΔHV			0.00	-1.17	0.02
ΔHV/HV			1.0E-05	-4.7E-03	8.3E-05
$c_i = \Delta HV/\Delta x$			8.5E-01	-1.4E+03	2.1E+01

				Type A	Type B					
Influencing quantity X_i	**Symbol**	**Unit**	**Value**	s_i	a_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force	***F***	N	**294.20**	2.9E-03		8.7E-06	1.2E+00	1.3E-05	8	2.0E-11
Indentation diameter	***d***	mm	**0.3258**	7.5E-04		5.6E-07	-2.2E+03	2.7E+00	19	4.0E-01
Ball diameter	***D***	mm	**1.000**		1.0E-03	3.3E-07	2.0E+01	1.4E-04	30	6.1E-10
Test force application time	t_1	s	**7.0**		1.0E+00	3.3E-01	1.4E-01	6.6E-03	30	1.5E-06
Test force duration time	t_2	s	**12.5**		2.5E+00	2.1E+00	-1.0E-01	2.3E-02	30	1.7E-05
Total								2.8E+00		4.0E-01
Combined standard uncertainty *u (H)*								1.7E+00	ν_{eff}	19
Confidence level								95%		
Coverage factor								2.1		
Expanded standard uncertainty *U (H)*								**3.5**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$								**1.0**	**%**	**1.0**
Hardness	**350.0**	**HBW**								

			F	*d*	*D*
		Δ	*x*+*Δ*	*x*+*Δ*	*x*+*Δ*
F	294.2	0.00294	294.2	294.2	294.2
d	0.326	0.00075	0.3258	0.3266	0.3258
D	1.000	0.00100	1.000	1.000	1.001
HV	350.0		350.0	348.4	350.1
ΔHV			0.00	-1.66	0.02
ΔHV/HV			1.0E-05	-4.8E-03	5.8E-05
$c_i = \Delta HV/\Delta x$			1.2E+00	-2.2E+03	2.0E+01

				Type A	Type B					
Influencing quantity X_i	**Symbol**	**Unit**	**Value**	s_i	a_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force	***F***	N	**294.20**	2.9E-03		8.7E-06	1.6E+00	2.1E-05	8	5.5E-11
Indentation diameter	***d***	mm	**0.2883**	6.8E-04		4.6E-07	-3.2E+03	4.6E+00	19	1.1E+00
Ball diameter	***D***	mm	**1.000**		1.0E-03	3.3E-07	2.0E+01	1.3E-04	30	5.8E-10
Test force application time	t_1	s	**7.0**		1.0E+00	3.3E-01	1.6E-01	8.8E-03	30	2.6E-06
Test force duration time	t_2	s	**12.5**		2.5E+00	2.1E+00	-9.0E-02	1.7E-02	30	9.5E-06
Total								4.7E+00		1.1E+00
Combined standard uncertainty *u (H)*								2.2E+00	ν_{eff}	19
Confidence level								95%		
Coverage factor								2.1		
Expanded standard uncertainty *U (H)*								**4.5**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$								**1.0**	**%**	**1.0**
Hardness	**450.0**	**HBW**								

			F	*d*	*D*
		Δ	*x*+*Δ*	*x*+*Δ*	*x*+*Δ*
F	294.2	0.00294	294.2	294.2	294.2
d	0.288	0.00068	0.2883	0.2889	0.2883
D	1.000	0.00100	1.000	1.000	1.001
HV	450.0		450.0	447.8	450.0
ΔHV			0.00	-2.15	0.02
ΔHV/HV			1.0E-05	-4.8E-03	4.4E-05
$c_i = \Delta HV/\Delta x$			1.5E+00	-3.2E+03	2.0E+01

Uncertainty report for Hardness scale 2.5/187.5

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				Type A	Type B					
Influencing quantity X_i	**Symbol**	**Unit**	**Value**	s_i	a_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force	***F***	N	**1838.7**	1.8E-02		3.4E-04	1.4E-01	6.5E-06	8	5.3E-12
Indentation diameter	***d***	mm	**0.9584**	2.0E-03		4.1E-06	-5.4E+02	1.2E+00	19	7.5E-02
Ball diameter	***D***	mm	**2.500**		1.0E-03	3.3E-07	8.3E+00	2.3E-05	30	1.7E-11
Test force application time	t_1	s	**7.0**		1.0E+00	3.3E-01	1.2E-01	4.7E-03	30	7.5E-07
Test force duration time	t_2	s	**12.5**		2.5E+00	2.1E+00	-1.2E-01	3.0E-02	30	2.9E-05
Total								1.2E+00		7.5E-02
Combined standard uncertainty *u (H)*								1.1E+00	ν_{eff}	20
Confidence level								95%		
Coverage factor								2.1		
Expanded standard uncertainty *U (H)*								**2.3**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$								**0.9**	**%**	**1.0**
Hardness	**250.0**	**HBW**								

			F	*d*	*D*
		Δ	*x*+*Δ*	*x*+*Δ*	*x*+*Δ*
F	1838.7	0.01839	1838.8	1838.7	1838.7
d	0.958	0.00202	0.9584	0.9604	0.9584
D	2.500	0.00100	2.500	2.500	2.501
HV	250.0		250.0	248.9	250.0
ΔHV			0.00	-1.09	0.01
ΔHV/HV			1.0E-05	-4.4E-03	3.3E-05
$c_i = \Delta HV/\Delta x$			1.4E-01	-5.4E+02	8.3E+00

				Type A	Type B					
Influencing quantity X_i	**Symbol**	**Unit**	**Value**	s_i	a_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force	***F***	N	**1838.7**	1.8E-02		3.4E-04	1.9E-01	1.3E-05	8	2.0E-11
Indentation diameter	***d***	mm	**0.8145**	1.7E-03		3.0E-06	-8.8E+02	2.3E+00	19	2.8E-01
Ball diameter	***D***	mm	**2.500**		1.0E-03	3.3E-07	8.1E+00	2.2E-05	30	1.6E-11
Test force application time	t_1	s	**7.0**		1.0E+00	3.3E-01	1.4E-01	6.6E-03	30	1.5E-06
Test force duration time	t_2	s	**12.5**		2.5E+00	2.1E+00	-1.0E-01	2.3E-02	30	1.7E-05
Total								2.4E+00		2.8E-01
Combined standard uncertainty *u (H)*								1.5E+00	ν_{eff}	19
Confidence level								95%		
Coverage factor								2.1		
Expanded standard uncertainty *U (H)*								**3.2**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$								**0.9**	**%**	**1.0**
Hardness	**350.0**	**HBW**								

			F	*d*	*D*
		Δ	*x*+*Δ*	*x*+*Δ*	*x*+*Δ*
F	1838.7	0.01839	1838.8	1838.7	1838.7
d	0.815	0.00173	0.8145	0.8162	0.8145
D	2.500	0.00100	2.500	2.500	2.501
HV	350.0		350.0	348.5	350.0
ΔHV			0.00	-1.52	0.01
ΔHV/HV			1.0E-05	-4.4E-03	2.3E-05
$c_i = \Delta HV/\Delta x$			1.9E-01	-8.8E+02	8.1E+00

				Type A	Type B					
Influencing quantity X_i	**Symbol**	**Unit**	**Value**	s_i	a_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force	***F***	N	**1838.7**	1.8E-02		3.4E-04	2.5E-01	2.1E-05	8	5.5E-11
Indentation diameter	***d***	mm	**0.7206**	1.5E-03		2.4E-06	-1.3E+03	3.8E+00	19	7.8E-01
Ball diameter	***D***	mm	**2.500**		1.0E-03	3.3E-07	8.0E+00	2.1E-05	30	1.5E-11
Test force application time	t_1	s	**7.0**		1.0E+00	3.3E-01	1.6E-01	8.8E-03	30	2.6E-06
Test force duration time	t_2	s	**12.5**		2.5E+00	2.1E+00	-9.0E-02	1.7E-02	30	9.5E-06
Total								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**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$								**0.9**	**%**	**1.0**
Hardness	**450.0**	**HBW**								

			F	*d*	*D*
		Δ	*x*+*Δ*	*x*+*Δ*	*x*+*Δ*
F	1838.7	0.01839	1838.8	1838.7	1838.7
d	0.721	0.00154	0.7206	0.7221	0.7206
D	2.500	0.00100	2.500	2.500	2.501
HV	450.0		450.0	448.0	450.0
ΔHV			0.00	-1.96	0.01
ΔHV/HV			1.0E-05	-4.4E-03	1.8E-05
$c_i = \Delta HV/\Delta x$			2.4E-01	-1.3E+03	8.0E+00

Uncertainty report for Hardness scale 5/750

INRIM 8/9

				Type A	Type B					
Influencing quantity X_i	**Symbol**	**Unit**	**Value**	s_i	a_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force	***F***	N	**7355.0**	7.4E-02		5.4E-03	3.5E-02	6.5E-06	8	5.3E-12
Indentation diameter	***d***	mm	**1.9169**	3.9E-03		1.5E-05	-2.7E+02	1.1E+00	19	6.8E-02
Ball diameter	***D***	mm	**5.000**		2.0E-03	1.3E-06	4.1E+00	2.3E-05	30	1.7E-11
Test force application time	t_1	s	**7.0**		1.0E+00	3.3E-01	1.2E-01	4.7E-03	30	7.5E-07
Test force duration time	t_2	s	**12.5**		2.5E+00	2.1E+00	-1.2E-01	3.0E-02	30	2.9E-05
Total								1.2E+00		6.8E-02
Combined standard uncertainty *u (H)*								1.1E+00	ν_{eff}	20
Confidence level								95%		
Coverage factor								2.1		
Expanded standard uncertainty *U (H)*								**2.3**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$								**0.9**	**%**	**1.0**
Hardness	**250.0**	**HBW**								

			F	*d*	*D*
		Δ	*x*+*Δ*	*x*+*Δ*	*x*+*Δ*
F	7355.0	0.07355	7355.1	7355.0	7355.0
d	1.917	0.00393	1.9169	1.9208	1.9169
D	5.000	0.00200	5.000	5.000	5.002
HV	250.0		250.0	248.9	250.0
ΔHV			0.00	-1.07	0.01
ΔHV/HV			1.0E-05	-4.3E-03	3.3E-05
$c_i = \Delta HV/\Delta x$			3.4E-02	-2.7E+02	4.1E+00

				Type A	Type B					
Influencing quantity X_i	**Symbol**	**Unit**	**Value**	s_i	a_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force	***F***	N	**7355.0**	7.4E-02		5.4E-03	4.9E-02	1.3E-05	8	2.0E-11
Indentation diameter	***d***	mm	**1.6290**	3.4E-03		1.1E-05	-4.4E+02	2.2E+00	19	2.5E-01
Ball diameter	***D***	mm	**5.000**		2.0E-03	1.3E-06	4.0E+00	2.2E-05	30	1.6E-11
Test force application time	t_1	s	**7.0**		1.0E+00	3.3E-01	1.4E-01	6.6E-03	30	1.5E-06
Test force duration time	t_2	s	**12.5**		2.5E+00	2.1E+00	-1.0E-01	2.3E-02	30	1.7E-05
Total								2.2E+00		2.5E-01
Combined standard uncertainty *u (H)*								1.5E+00	ν_{eff}	19
Confidence level								95%		
Coverage factor								2.1		
Expanded standard uncertainty *U (H)*								**3.1**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$								**0.9**	**%**	**1.0**
Hardness	**350.0**	**HBW**								

			F	*d*	*D*
		Δ	*x*+*Δ*	*x*+*Δ*	*x*+*Δ*
F	7355.0	0.07355	7355.1	7355.0	7355.0
d	1.629	0.00336	1.6290	1.6324	1.6290
D	5.000	0.00200	5.000	5.000	5.002
HV	350.0		350.0	348.6	350.0
ΔHV			0.00	-1.48	0.01
ΔHV/HV			1.0E-05	-4.2E-03	2.3E-05
$c_i = \Delta HV/\Delta x$			4.8E-02	-4.4E+02	4.0E+00

				Type A	Type B					
Influencing quantity X_i	**Symbol**	**Unit**	**Value**	s_i	a_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force	***F***	N	**7355.0**	7.4E-02		5.4E-03	6.2E-02	2.1E-05	8	5.5E-11
Indentation diameter	***d***	mm	**1.4412**	3.0E-03		8.9E-06	-6.4E+02	3.6E+00	19	6.8E-01
Ball diameter	***D***	mm	**5.000**		2.0E-03	1.3E-06	4.0E+00	2.1E-05	30	1.5E-11
Test force application time	t_1	s	**7.0**		1.0E+00	3.3E-01	1.6E-01	8.8E-03	30	2.6E-06
Test force duration time	t_2	s	**12.5**		2.5E+00	2.1E+00	-9.0E-02	1.7E-02	30	9.5E-06
Total								3.6E+00		6.8E-01
Combined standard uncertainty *u (H)*								1.9E+00	ν_{eff}	19
Confidence level								95%		
Coverage factor								2.1		
Expanded standard uncertainty *U (H)*								**4.0**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$								**0.9**	**%**	**1.0**
Hardness	**450.0**	**HBW**								

			F	*d*	*D*
		Δ	*x*+*Δ*	*x*+*Δ*	*x*+*Δ*
F	7355.0	0.07355	7355.1	7355.0	7355.0
d	1.441	0.00298	1.4412	1.4442	1.4412
D	5.000	0.00200	5.000	5.000	5.002
HV	450.0		450.0	448.1	450.0
ΔHV			0.00	-1.90	0.01
ΔHV/HV			1.0E-05	-4.2E-03	1.8E-05
$c_i = \Delta HV/\Delta x$			6.1E-02	-6.4E+02	4.0E+00

Uncertainty report for Hardness scale 10/3000

INRIM 9/9

				Type A	Type B									F	d
Influencing quantity X_i	**Symbol**	**Unit**	**Value**	s_i	a_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ξ_i	$u_i^4(y)/\xi_i$			ξ	$x+\xi$	$x+\xi$
Test force	***F***	N	**29420**	2.9E-01		8.7E-02	1.2E-02	1.3E-05	8	2.0E-11	*F*	29420.0	0.29420	29420.2	29420.0
Indentation diameter	***d***	mm	**3.2580**	6.6E-03		4.4E-05	-2.2E+02	2.1E+00	19	2.4E-01	*d*	3.258	0.00662	3.2580	3.2646
Ball diameter	***D***	mm	**10.000**		3.0E-03	3.0E-06	2.0E+00	1.2E-05	30	5.0E-12	*D*	10.000	0.00300	10.000	10.000
Test force application time	t_1	s	**7.0**		1.0E+00	3.3E-01	1.4E-01	6.6E-03	30	1.5E-06	*HV*	350.0		350.0	348.6
Test force duration time	t_2	s	**12.5**		2.5E+00	2.1E+00	-1.0E-01	2.3E-02	30	1.7E-05	ξ *HV*			0.00	-1.46
Total								2.2E+00		2.4E-01	ξ *HV/HV*			1.0E-05	-4.2E-03
Combined standard uncertainty *u (H)*								1.5E+00	ξ_{eff}	19	$c_i = \xi$ *HV*/ξ *x*			1.2E-02	-2.2E+02
Confidence level								95%							
Coverage factor								2.1							
Expanded standard uncertainty *U (H)*								**3.1**	**HBW**						
Relative Expanded standard uncertainty U_{rel} *(H)*								**0.9**	**%**	**1.0**					
Hardness	**350.0**	**HBW**													

				Type A	Type B									F	d
Influencing quantity X_i	**Symbol**	**Unit**	**Value**	s_i	a_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ξ_i	$u_i^4(y)/\xi_i$			ξ	$x+\xi$	$x+\xi$
Test force	***F***	N	**29420**	2.9E-01		8.7E-02	1.6E-02	2.1E-05	8	5.5E-11	*F*	29420.0	0.29420	29420.2	29420.0
Indentation diameter	***d***	mm	**2.8825**	5.9E-03		3.4E-05	-3.2E+02	3.5E+00	19	6.4E-01	*d*	2.883	0.00587	2.8825	2.8884
Ball diameter	***D***	mm	**10.000**		3.0E-03	3.0E-06	2.0E+00	1.2E-05	30	4.7E-12	*D*	10.000	0.00300	10.000	10.000
Test force application time	t_1	s	**7.0**		1.0E+00	3.3E-01	1.6E-01	8.8E-03	30	2.6E-06	*HV*	450.0		450.0	448.1
Test force duration time	t_2	s	**12.5**		2.5E+00	2.1E+00	-9.0E-02	1.7E-02	30	9.5E-06	ξ *HV*			0.00	-1.87
Total								3.5E+00		6.4E-01	ξ *HV/HV*			1.0E-05	-4.2E-03
Combined standard uncertainty *u (H)*								1.9E+00	ξ_{eff}	19	$c_i = \xi$ *HV*/ξ *x*			1.5E-02	-3.2E+02
Confidence level								95%							
Coverage factor								2.1							
Expanded standard uncertainty *U (H)*								**3.9**	**HBW**						
Relative Expanded standard uncertainty U_{rel} *(H)*								**0.9**	**%**	**1.0**					
Hardness	**450.0**	**HBW**													

END –INRIM–

Results and uncertainty report –KRISS– **KRISS 1/11**

Measurement results

Results for Reference and False indentations

Measurement result of measuremet of the length of Reference indents

reference Block	ID of the Block	Hardness (HBW)	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Temp (ºC)
250	93241	1.0/30	0.383	0.383	0.3825	0.382	0.3815	0.382	0.3828	0.3818	0.3823	23 ºC
	93243	2.5/187.5	0.9435	0.9435	0.9440	0.9425	0.9430	0.9425	0.9432	0.9427	0.9429	
	93242	5/750	1.9150	1.9140	1.9160	1.9125	1.9140	1.9125	1.9150	1.9130	1.9140	
350	94041	1.0/30	0.321	0.321	0.3215	0.3195	0.319	0.3185	0.3201	0.3190	0.3195	23 ºC
	94043	2.5/187.5	0.8065	0.8065	0.806	0.8055	0.8055	0.8045	0.8058	0.8052	0.8055	
	94042	5/750	1.6030	1.6040	1.6035	1.6000	1.6005	1.6015	1.6021	1.6007	1.6014	
	94037	10/3000	3.2015	3.2020	3.2015	3.2015	3.2005	3.2005	3.2013	3.2008	3.2010	
450	95008	1.0/30	0.2885	0.2880	0.2885	0.2875	0.2870	0.2875	0.2883	0.2873	0.2878	23 ºC
	95011	2.5/187.5	0.7170	0.7170	0.7165	0.7160	0.7165	0.7170	0.7167	0.7165	0.7166	
	95010	5/750	1.4335	1.4340	1.4345	1.4340	1.4340	1.4335	1.4339	1.4338	1.4339	
	95004	10/3000	2.8575	2.8595	2.8565	2.8560	2.8565	2.8560	2.8578	2.8562	2.8570	

Measurement result of measuremet
of the length of "False Indentation"

Nominal Diameter	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Temp (ºC)
1.5	1.4990	1.4990	1.4985	1.4980	1.4985	1.4975	1.4988	1.4980	1.4984	23 ºC
0.8	0.7995	0.8000	0.7995	0.7995	0.8000	0.7995	0.7997	0.7997	0.7997	
0.4	0.4000	0.4005	0.4000	0.3995	0.4000	0.4000	0.4002	0.3998	0.4000	
0.24	0.2405	0.2400	0.2395	0.2405	0.2405	0.2400	0.2400	0.2403	0.2402	

Results for 250HBW1/30, 250HBW2.5/187.5 and 250HBW5/750 KRISS 2/11

Specimen
250 HBW

Block ID.	93241

Test identifier	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
d5	1.0/30	1	0.3825	0.3825	0.3830	0.3820	0.3825	0.3825	0.3827	0.3823	0.3825	251.3	23 ºC
e9		2	0.3830	0.3830	0.3830	0.3820	0.3825	0.3825	0.3830	0.3823	0.3827	251.0	
f4		3	0.3805	0.3805	0.3810	0.3805	0.3805	0.3810	0.3807	0.3807	0.3807	253.8	
i3		4	0.3810	0.3815	0.3810	0.3805	0.3810	0.3805	0.3812	0.3807	0.3809	253.5	
i8		5	0.3815	0.3815	0.3815	0.3805	0.3810	0.3810	0.3815	0.3808	0.3812	253.1	

Block ID.	93243

Test identifier	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
d5	2.5/187.5	1	0.9420	0.9425	0.9420	0.9425	0.9420	0.9425	0.9422	0.9423	0.9423	259.1	23 ºC
e9		2	0.9430	0.9430	0.9430	0.9420	0.9420	0.9425	0.9430	0.9422	0.9426	258.9	
f4		3	0.9405	0.9410	0.9410	0.9405	0.9400	0.9395	0.9408	0.9400	0.9404	260.2	
i3		4	0.9410	0.9410	0.9405	0.9400	0.9405	0.9400	0.9408	0.9402	0.9405	260.1	
i8		5	0.9450	0.9450	0.9445	0.9445	0.9435	0.9435	0.9448	0.9438	0.9443	257.9	

Block ID.	93242

Test identifier	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
d5	5/750	1	1.9205	1.9205	1.9210	1.9200	1.9205	1.9205	1.9207	1.9203	1.9205	249.1	23 ºC
e9		2	1.9210	1.9215	1.9210	1.9195	1.9195	1.9195	1.9212	1.9195	1.9203	249.1	
f4		3	1.9195	1.9195	1.9195	1.9175	1.9170	1.9175	1.9195	1.9173	1.9184	249.7	
i3		4	1.9145	1.9145	1.9135	1.9130	1.9140	1.9140	1.9142	1.9137	1.9139	250.9	
i8		5	1.9145	1.9145	1.9140	1.9140	1.9145	1.9155	1.9143	1.9147	1.9145	250.7	

Results for 350HBW1/30, 350HBW2.5/187.5, 350HBW5/750 and 350HBW10/3000 KRISS 3/11

Specimen
350 HBW

Block ID.	94041

Test identifier	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
d5	1.0/30	1	0.3240	0.3240	0.3240	0.3.230	0.3225	0.3225	0.3240	0.3225	0.3233	355.9	23 ºC
e9		2	0.3230	0.3225	0.3230	0.3225	0.3230	0.3225	0.3228	0.3227	0.3228	357.0	
f4		3	0.3240	0.3235	0.3240	0.3225	0.3225	0.3225	0.3238	0.3225	0.3232	356.1	
i3		4	0.3225	0.3225	0.3225	0.3210	0.3215	0.3220	0.3225	0.3215	0.3220	358.8	
i8		5	0.3215	0.3220	0.3220	0.3210	0.3215	0.3215	0.3218	0.3213	0.3216	359.7	

Block ID.	94043

Test identifier	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
d5	2.5/187.5	1	0.8105	0.8105	0.8100	0.8090	0.8095	0.8100	0.8103	0.8095	0.8099	354.3	23 ºC
e9		2	0.8060	0.8060	0.8060	0.8070	0.8070	0.8075	0.8060	0.8072	0.8066	357.3	
f4		3	0.8055	0.8055	0.8055	0.8065	0.8060	0.8060	0.8055	0.8062	0.8058	358.0	
i3		4	0.8045	0.8045	0.8045	0.8045	0.8040	0.8030	0.8045	0.8038	0.8042	359.5	
i8		5	0.8050	0.8050	0.8045	0.8025	0.8040	0.8030	0.8048	0.8032	0.8040	359.7	

Block ID.	94042

Test identifier	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
d5	5/750	1	1.6080	1.6075	1.6085	1.6045	1.6055	1.6055	1.6080	1.6052	1.6066	360.3	23 ºC
e9		2	1.6075	1.6075	1.6080	1.6050	1.6050	1.6045	1.6077	1.6048	1.6063	360.5	
f4		3	1.6045	1.6045	1.6045	1.6035	1.6040	1.603.5	1.6045	1.6038	1.6041	361.5	
i3		4	1.6050	1.6045	1.6045	1.6040	1.6040	1.6035	1.6047	1.6038	1.6043	361.4	
i8		5	1.603.5	1.6050	1.6045	1.6035	1.6040	1.6040	1.6048	1.6038	1.6043	361.4	

Block ID.	94038

Test identifier	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
b2	10/3000	1	3.2435	3.2415	3.244	3.2445	3.245	3.245	3.2430	3.2448	3.2439	353.4	23 ºC
b4		2	3.2460	3.2460	3.2465	3.2455	3.2460	3.2460	3.2462	3.2458	3.2460	352.9	
d2		3	3.2370	3.2370	3.2370	3.2305	3.2305	3.2300	3.2370	3.2303	3.2337	355.7	
d6		4	3.2385	3.2395	3.2390	3.2410	3.2415	3.2400	3.2390	3.2408	3.2399	354.3	
f4		5	3.224	3.225	3.225	3.2265	3.226	3.2265	3.2247	3.2263	3.2255	357.5	

Results for 450HBW1/30, 450HBW2.5/187.5, 450HBW5/750 and 450HBW10/3000 KRISS 4/11

Specimen
450 HBW

Block ID.	95008

Test identifier	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
d5	1.0/30	1	0.2890	0.2890	0.2890	0.2890	0.2885	0.2890	0.2890	0.2888	0.2889	448.1	23 ºC
e9		2	0.2900	0.2900	0.2900	0.2895	0.2900	0.2900	0.2900	0.2898	0.2899	444.9	
f4		3	0.2895	0.2890	0.2895	0.2885	0.2890	0.2890	0.2893	0.2888	0.2891	447.5	
i3		4	0.2900	0.2895	0.2905	0.2900	0.2895	0.2895	0.2900	0.2897	0.2898	445.2	
i8		5	0.2895	0.2890	0.2890	0.2885	0.2885	0.2885	0.2892	0.2885	0.2888	448.3	

Block ID.	95011

Test identifier	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
d5	2.5/187.5	1	0.7175	0.7180	0.7180	0.7175	0.7170	0.7175	0.7178	0.7173	0.7176	454.1	23 ºC
e9		2	0.7170	0.7170	0.7170	0.7160	0.7160	0.7165	0.7170	0.7162	0.7166	455.4	
f4		3	0.7150	0.7155	0.7150	0.7155	0.7155	0.7155	0.7152	0.7155	0.7153	457.0	
i3		4	0.7165	0.7160	0.7165	0.7165	0.7170	0.7165	0.7163	0.7167	0.7165	455.5	
i8		5	0.7160	0.7165	0.7160	0.7160	0.7165	0.7165	0.7162	0.7163	0.7163	455.8	

Block ID.	95010

Test identifier	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
d5	5/750	1	1.4330	1.4335	1.4335	1.4340	1.4345	1.4345	1.4333	1.4343	1.4338	455.0	23 ºC
e9		2	1.4350	1.4350	1.4350	1.4340	1.4330	1.4330	1.4350	1.4333	1.4342	454.7	
f4		3	1.4340	1.4330	1.4330	1.4320	1.4315	1.4320	1.4333	1.4318	1.4326	455.8	
i3		4	1.4310	1.4310	1.4305	1.4300	1.4329	1.4295	1.4308	1.4308	1.4308	456.9	
i8		5	1.4330	1.4330	1.4330	1.4340	1.4330	1.4340	1.4330	1.4337	1.4333	455.3	

Block ID.	95005

Test identifier	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
b2	10/3000	1	2.8720	2.8710	2.8715	2.8735	2.8735	2.8740	2.8715	2.8737	2.8726	453.4	23 ºC
b4		2	2.8725	2.8730	2.8730	2.8745	2.8745	2.8740	2.8728	2.8743	2.8736	453.1	
d2		3	2.8740	2.8735	2.8740	2.8705	2.8705	2.8700	2.8738	2.8703	2.8721	453.5	
d6		4	2.8700	2.8700	2.8695	2.8710	2.8710	2.8715	2.8698	2.8712	2.8705	454.0	
f4		5	2.8655	2.8655	2.8655	2.8655	2.8670	2.8655	2.8655	2.8660	2.8658	455.6	

Uncertainty report –KRISS– KRISS 5/11

Brief description of the measurement system

Name of Institute
KRISS

Test Details

Instrument

Instrument type	Identifier
a lever amplified dead weight	Akashi SHT-5/ NO. 30003

Measuring device

Device type	Identifier
Optical microscope	Leica UWM (Germany)

Uncertainty of the instruments

Hardness scale	uF (N)	uL (mm)	Dia. of Indenter (mm)
1.0/30	0.018	0.001	0.0005
2.5/187.5	0.075	0.001	0.0005
5.0/750	1.031	0.001	0.0005
10/3000	2.648	0.001	0.0005

Please expand the uncertainty cell and define more detail for the measurement uncertainty ,if your institute calculate the uncertainty depending on the measured value.

Comment
The uncertainty of instruments is standard uncertainty.

Uncertainty report for 250HBW1/30

KRISS 6/11

Uncertainty budget for 250 HBW 1/30											
	source of uncertainty	estimated value	Unit	Limit value	Distribution type	Standard uncertainty	Unit	Sensitivity coefficient	Unit	uncertainty contribution, *u* (H), HBW	type
1	Test force	294.2	N	-	Normal	0.018	N	8.60E-01	HBW/N	1.53E-02	A
2	Diameter of the ball	1	mm	-	Normal	0.0005	mm	2.07E+01	HBW/mm	1.04E-02	A
3	Length measuring device	0.3816	mm	-	Normal	0.001	mm	-1.38E+03	HBW/mm	-1.38E+00	A
4	Test force application time	5	sec	1.0	Rectangular	0.577	sec	1.20E-01	HBW/sec	6.92E-02	B
5	Test force duration	10	sec	1.0	Rectangular	0.577	sec	-1.19E-01	HBW/sec	-6.85E-02	B
6	Uniformity of hardness	253	HBW	-	Normal	0.57	HBW	1	-	5.70E-01	A
Combined uncertainty u(HBW)										1.50	
Expanded uncertainty U(HBW) k=2										2.99	
Relative Expanded uncertainty U(HBW) k=2, %										1.18	

Uncertainty report for 250HBW2.5/187.5

Uncertainty budget for 250 HBW 2.5/187.5											
	source of uncertainty	estimated value	Unit	Limit value	Distribution type	Standard uncertainty	Unit	Sensitivity coefficient	Unit	uncertainty contribution, *u* (H), HBW	type
1	Test force	1839	N	-	Normal	0.075	N	1.41E-01	HBW/N	1.06E-02	A
2	Diameter of the ball	2.5	mm	-	Normal	0.0005	mm	8.24E+00	HBW/mm	4.12E-03	A
3	Length measuring device	0.9420	mm	-	Normal	0.001	mm	-5.72E+02	HBW/mm	-5.72E-01	A
4	Test force application time	5	sec	1.0	Rectangular	0.577	sec	1.21E-01	HBW/sec	6.99E-02	B
5	Test force duration	10	sec	1.0	Rectangular	0.577	sec	-1.18E-01	HBW/sec	-6.80E-02	B
6	Uniformity of hardness	259	HBW	-	Normal	0.42	HBW	1	-	4.20E-01	A
Combined uncertainty u(HBW)										0.72	
Expanded uncertainty U(HBW) k=2										1.43	
Relative Expanded uncertainty U(HBW) k=2, %										0.55	

Uncertainty report for 250HBW5/750

KRISS 7/11

Uncertainty budget for 250 HBW 5/750											
	source of uncertainty	estimated value	Unit	Limit value	Distribution type	Standard uncertainty	Unit	Sensitivity coefficient	Unit	uncertainty contribution, u(H), HBW	type
1	Test force	7355	N	-	Normal	1.031	N	3.40E-02	HBW/N	3.50E-02	A
2	Diameter of the ball	5	mm	-	Normal	0.0005	mm	4.14E+00	HBW/mm	2.07E-03	A
3	Length measuring device	1.9175	mm	-	Normal	0.001	mm	-2.72E+02	HBW/mm	-2.72E-01	A
4	Test force application time	5	sec	1.0	Rectangular	0.577	sec	1.19E-01	HBW/sec	6.88E-02	B
5	Test force duration	10	sec	1.0	Rectangular	0.577	sec	-1.19E-01	HBW/sec	-6.87E-02	B
6	Uniformity of hardness	250	HBW	-	Normal	0.38	HBW	1	-	3.80E-01	A
Combined uncertainty u(HBW)										0.48	
Expanded uncertainty U(HBW) k=2										0.96	
Relative Expanded uncertainty U(HBW) k=2, %										0.38	

Uncertainty report for 350HBW1/30

Uncertainty budget for 350 HBW 1/30											
	source of uncertainty	estimated value	Unit	Limit value	Distribution type	Standard uncertainty	Unit	Sensitivity coefficient	Unit	uncertainty contribution, u(H), HBW	type
1	Test force	294.2	N	-	Normal	0.018	N	1.22E+00	HBW/N	2.17E-02	A
2	Diameter of the ball	1	mm	-	Normal	0.0005	mm	2.08E+01	HBW/mm	1.04E-02	A
3	Length measuring device	0.3266	mm	-	Normal	0.001	mm	-2.26E+03	HBW/mm	-2.26E+00	A
4	Test force application time	5	sec	1.0	Rectangular	0.577	sec	1.43E-01	HBW/sec	8.24E-02	B
5	Test force duration	10	sec	1.0	Rectangular	0.577	sec	-1.03E-01	HBW/sec	-5.97E-02	B
6	Uniformity of hardness	358	HBW	-	Normal	0.75	HBW	1	-	7.50E-01	A
Combined uncertainty u(HBW)										2.38	
Expanded uncertainty U(HBW) k=2										4.76	
Relative Expanded uncertainty U(HBW) k=2, %										1.33	

Uncertainty report for 350HBW2.5/187.5

KRISS 8/11

Uncertainty budget for 350 HBW 2.5/187.5											
	source of uncertainty	estimated value	Unit	Limit value	Distribution type	Standard uncertainty	Unit	Sensitivity coefficient	Unit	uncertainty contribution, *u* (H), HBW	type
1	Test force	1839	N	-	Normal	0.075	N	1.95E-01	HBW/N	1.46E-02	A
2	Diameter of the ball	2.5	mm	-	Normal	0.0005	mm	8.08E+00	HBW/mm	4.04E-03	A
3	Length measuring device	0.8061	mm	-	Normal	0.001	mm	-9.13E+02	HBW/mm	-9.13E-01	A
4	Test force application time	5	sec	1.0	Rectangular	0.577	sec	1.43E-01	HBW/sec	8.24E-02	B
5	Test force duration	10	sec	1.0	Rectangular	0.577	sec	-1.03E-01	HBW/sec	-5.97E-02	B
6	Uniformity of hardness	358	HBW	-	Normal	0.98	HBW	1	-	9.80E-01	A
Combined uncertainty u(HBW)										1.34	
Expanded uncertainty U(HBW) k=2										2.69	
Relative Expanded uncertainty U(HBW) k=2, %										0.75	

Uncertainty report for 350HBW5/750

Uncertainty budget for 350 HBW 5/750											
	source of uncertainty	estimated value	Unit	Limit value	Distribution type	Standard uncertainty	Unit	Sensitivity coefficient	Unit	uncertainty contribution, *u* (H), HBW	type
1	Test force	7355	N	-	Normal	1.031	N	4.91E-02	HBW/N	5.06E-02	A
2	Diameter of the ball	5	mm	-	Normal	0.0005	mm	4.03E+00	HBW/mm	2.02E-03	A
3	Length measuring device	1.6051	mm	-	Normal	0.001	mm	-4.62E+02	HBW/mm	-4.62E-01	A
4	Test force application time	5	sec	1.0	Rectangular	0.577	sec	1.43E-01	HBW/sec	8.27E-02	B
5	Test force duration	10	sec	1.0	Rectangular	0.577	sec	-1.03E-01	HBW/sec	-5.94E-02	B
6	Uniformity of hardness	361	HBW	-	Normal	0.25	HBW	1	-	2.50E-01	A
Combined uncertainty u(HBW)										0.54	
Expanded uncertainty U(HBW) k=2										1.08	
Relative Expanded uncertainty U(HBW) k=2, %										0.30	

Uncertainty report for 350HBW10/3000

KRISS 9/11

Uncertainty budget for 350 HBW 10/3000											
	source of uncertainty	estimated value	Unit	Limit value	Distribution type	Standard uncertainty	Unit	Sensitivity coefficient	Unit	uncertainty contribution, *u* (H), HBW	type
1	Test force	29420	N	-	Normal	2.648	N	1.21E-02	HBW/N	3.20E-02	A
2	Diameter of the ball	10	mm	-	Normal	0.0005	mm	2.02E+00	HBW/mm	1.01E-03	A
3	Length measuring device	3.2387	mm	-	Normal	0.001	mm	-2.25E+02	HBW/mm	-2.25E-01	A
4	Test force application time	5	sec	1.0	Rectangular	0.577	sec	1.42E-01	HBW/sec	8.20E-02	B
5	Test force duration	10	sec	1.0	Rectangular	0.577	sec	-1.04E-01	HBW/sec	-5.99E-02	B
6	Uniformity of hardness	355	HBW	-	Normal	0.84	HBW	1	-	8.40E-01	A
Combined uncertainty u(HBW)										0.88	
Expanded uncertainty U(HBW) k=2										1.75	
Relative Expanded uncertainty U(HBW) k=2, %										0.49	

Uncertainty report for 450HBW1/30

Uncertainty budget for 450 HBW 1/30											
	source of uncertainty	estimated value	Unit	Limit value	Distribution type	Standard uncertainty	Unit	Sensitivity coefficient	Unit	uncertainty contribution, *u* (H), HBW	type
1	Test force	294.2	N	-	Normal	0.018	N	1.52E+00	HBW/N	2.70E-02	A
2	Diameter of the ball	1	mm	-	Normal	0.0005	mm	2.00E+01	HBW/mm	9.98E-03	A
3	Length measuring device	0.2893	mm	-	Normal	0.001	mm	-3.16E+03	HBW/mm	-3.16E+00	A
4	Test force application time	5	sec	1.0	Rectangular	0.577	sec	1.62E-01	HBW/sec	9.35E-02	B
5	Test force duration	10	sec	1.0	Rectangular	0.577	sec	-9.04E-02	HBW/sec	-5.22E-02	B
6	Uniformity of hardness	447	HBW	-	Normal	0.73	HBW	1	-	7.30E-01	A
Combined uncertainty u(HBW)										3.24	
Expanded uncertainty U(HBW) k=2										6.49	
Relative Expanded uncertainty U(HBW) k=2, %										1.45	

Uncertainty report for 450HBW2.5/187.5

KRISS 10/11

Uncertainty budget for 450 HBW 2.5/187.5											
	source of uncertainty	estimated value	Unit	Limit value	Distribution type	Standard uncertainty	Unit	Sensitivity coefficient	Unit	uncertainty contribution, *u* (H), HBW	type
1	Test force	1839	N	-	Normal	0.075	N	2.48E-01	HBW/N	1.86E-02	A
2	Diameter of the ball	2.5	mm	-	Normal	0.0005	mm	7.98E+00	HBW/mm	3.99E-03	A
3	Length measuring device	0.7164	mm	-	Normal	0.001	mm	-1.30E+03	HBW/mm	-1.30E+00	A
4	Test force application time	5	sec	1.0	Rectangular	0.577	sec	1.64E-01	HBW/sec	9.47E-02	B
5	Test force duration	10	sec	1.0	Rectangular	0.577	sec	-8.91E-02	HBW/sec	-5.14E-02	B
6	Uniformity of hardness	456	HBW	-	Normal	0.47	HBW	1	-	4.70E-01	A
Combined uncertainty u(HBW)										1.39	
Expanded uncertainty U(HBW) k=2										2.78	
Relative Expanded uncertainty U(HBW) k=2, %										0.61	

Uncertainty report for 450HBW5/750

Uncertainty budget for 450 HBW 5/750											
	source of uncertainty	estimated value	Unit	Limit value	Distribution type	Standard uncertainty	Unit	Sensitivity coefficient	Unit	uncertainty contribution, *u* (H), HBW	type
1	Test force	7355	N	-	Normal	1.031	N	6.20E-02	HBW/N	6.39E-02	A
2	Diameter of the ball	5	mm	-	Normal	0.0005	mm	4.05E+00	HBW/mm	2.03E-03	A
3	Length measuring device	1.4430	mm	-	Normal	0.001	mm	-6.46E+02	HBW/mm	-6.46E-01	A
4	Test force application time	5	sec	1.0	Rectangular	0.577	sec	1.64E-01	HBW/sec	9.47E-02	B
5	Test force duration	10	sec	1.0	Rectangular	0.577	sec	-8.91E-02	HBW/sec	-5.14E-02	B
6	Uniformity of hardness	456	HBW	-	Normal	0.39	HBW	1	-	3.90E-01	A
Combined uncertainty u(HBW)										0.76	
Expanded uncertainty U(HBW) k=2										1.53	
Relative Expanded uncertainty U(HBW) k=2, %										0.34	

Uncertainty report for 450HBW10/3000

KRISS 11/11

Uncertainty budget for 450 HBW 10/3000											
	source of uncertainty	estimated value	Unit	Limit value	Distribution type	Standard uncertainty	Unit	Sensitivity coefficient	Unit	uncertainty contribution, *u* (H), HBW	type
1	Test force	29420	N	-	Normal	2.648	N	1.54E-02	HBW/N	4.09E-02	A
2	Diameter of the ball	10	mm	-	Normal	0.0005	mm	2.00E+00	HBW/mm	9.98E-04	A
3	Length measuring device	2.8709	mm	-	Normal	0.001	mm	-3.23E+02	HBW/mm	-3.23E-01	A
4	Test force application time	5	sec	1.0	Rectangular	0.577	sec	1.64E-01	HBW/sec	9.44E-02	B
5	Test force duration	10	sec	1.0	Rectangular	0.577	sec	-8.94E-02	HBW/sec	-5.16E-02	B
6	Uniformity of hardness	454	HBW	-	Normal	0.45	HBW	1	-	4.50E-01	A
Combined uncertainty u(HBW)										0.57	
Expanded uncertainty U(HBW) k=2										1.13	
Relative Expanded uncertainty U(HBW) k=2, %										0.25	

End –KRISS–

Results and uncertainty report –NIM– **NIM 1/11**

Measurement results

Results for Reference and False indentations

Measurement result of measuremet of the length of Reference indents

reference Block	ID of the Block	Hardness (HBW)	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Temp (°C)
250	93241	1.0/30	0.3841	0.3841	0.3845	0.3847	0.3849	0.3851	0.3842	0.3849	0.3846	19.7
	93243	2.5/187.5	0.945	0.945	0.945	0.941	0.940	0.940	0.945	0.940	0.943	19.9
	93242	5/750	1.910	1.911	1.909	1.905	1.900	1.899	1.910	1.901	1.906	19.1
350	94041	1.0/30	0.3236	0.3233	0.3233	0.3243	0.3240	0.3240	0.3234	0.3241	0.3238	19.7
	94043	2.5/187.5	0.807	0.804	0.808	0.806	0.806	0.807	0.806	0.806	0.806	19.9
	94042	5/750	1.603	1.610	1.609	1.609	1.606	1.606	1.607	1.607	1.607	19.1
	94037	10/3000	3.210	3.212	3.211	3.210	3.210	3.211	3.211	3.210	3.211	20.2
450	95008	1.0/30	0.2901	0.2899	0.2899	0.2899	0.2897	0.2895	0.2900	0.2897	0.2898	19.7
	95011	2.5/187.5	0.718	0.718	0.718	0.719	0.718	0.719	0.718	0.719	0.718	19.9
	95010	5/750	1.440	1.439	1.439	1.440	1.439	1.440	1.439	1.440	1.440	19.1
	95004	10/3000	2.864	2.862	2.863	2.861	2.863	2.862	2.863	2.862	2.863	20.2

Measurement result of measuremet of the length of "False Indentation"

Nominal Diameter	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Temp (°C)
1.5	1.503	1.501	1.507	1.514	1.513	1.512	1.504	1.513	1.508	19.1
0.8	0.802	0.800	0.802	0.806	0.805	0.805	0.801	0.805	0.803	19.1
0.4	0.400	0.400	0.399	0.401	0.404	0.403	0.400	0.403	0.401	19.1
0.24	0.2427	0.2427	0.2427	0.2428	0.2427	0.2429	0.2427	0.2428	0.2428	19.7

Results for 250HBW1/30, 250HBW2.5/187.5 and 250HBW5/750

NIM 2/11

Specimen
250 HBW

Block ID.	93241

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
D7	1.0/30	1	0.3848	0.3844	0.3846	0.3837	0.3834	0.3838	0.3846	0.3836	0.3841	249	19.7
F3		2	0.3838	0.3839	0.3838	0.3834	0.3831	0.3834	0.3838	0.3833	0.3836	250	19.7
G2		3	0.3824	0.3826	0.3826	0.3823	0.3823	0.3824	0.3825	0.3823	0.3824	251	19.7
G9		4	0.3823	0.3819	0.3817	0.3817	0.3821	0.3820	0.3820	0.3819	0.3820	252	19.7
J5		5	0.3809	0.3809	0.3808	0.3819	0.3817	0.3819	0.3809	0.3818	0.3814	253	19.7

Block ID.	93243

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
D7	2.5/187.5	1	0.952	0.954	0.952	0.958	0.957	0.957	0.953	0.957	0.955	252	19.9
F3		2	0.943	0.941	0.942	0.948	0.947	0.948	0.942	0.948	0.945	257	19.9
G2		3	0.940	0.942	0.941	0.946	0.947	0.947	0.941	0.947	0.944	258	19.9
G9		4	0.950	0.951	0.951	0.948	0.947	0.949	0.951	0.948	0.949	255	19.9
J5		5	0.938	0.938	0.939	0.936	0.937	0.938	0.938	0.937	0.938	261	19.9

Block ID.	93242

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
D7	5/750	1	1.917	1.921	1.918	1.920	1.918	1.920	1.919	1.919	1.919	249	19.1
F3		2	1.926	1.922	1.926	1.920	1.920	1.921	1.925	1.920	1.923	248	19.1
G2		3	1.922	1.926	1.926	1.919	1.919	1.918	1.925	1.919	1.922	249	19.1
G9		4	1.911	1.910	1.915	1.911	1.908	1.912	1.912	1.910	1.911	252	19.1
J5		5	1.905	1.903	1.901	1.902	1.901	1.903	1.903	1.902	1.903	254	19.1

Results for 350HBW1/30, 350HBW2.5/187.5, 350HBW5/750 and 350HBW10/3000

NIM 3/11

Specimen
350 HBW

Block ID.	94041

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
D7	1.0/30	1	0.3262	0.3260	0.3260	0.3269	0.3268	0.3268	0.3261	0.3268	0.3265	348	19.7
F3		2	0.3247	0.3249	0.3248	0.3240	0.3242	0.3244	0.3248	0.3242	0.3245	353	19.7
G2		3	0.3240	0.3240	0.3240	0.3246	0.3243	0.3246	0.3240	0.3245	0.3243	353	19.7
G9		4	0.3262	0.3258	0.3259	0.3256	0.3258	0.3253	0.3260	0.3256	0.3258	350	19.7
J5		5	0.3228	0.3233	0.3230	0.3235	0.3236	0.3232	0.3230	0.3234	0.3232	356	19.7

Block ID.	94043

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
D7	2.5/187.5	1	0.810	0.810	0.810	0.816	0.814	0.812	0.810	0.814	0.812	352	19.9
F3		2	0.809	0.809	0.810	0.810	0.809	0.809	0.809	0.809	0.809	355	19.9
G2		3	0.809	0.811	0.810	0.811	0.812	0.815	0.810	0.813	0.811	353	19.9
G9		4	0.810	0.810	0.809	0.808	0.808	0.806	0.810	0.807	0.809	355	19.9
J5		5	0.804	0.804	0.805	0.809	0.810	0.808	0.804	0.809	0.807	357	19.9

Block ID.	94042

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
D7	5/750	1	1.610	1.613	1.610	1.610	1.608	1.613	1.611	1.610	1.611	358	19.1
F3		2	1.618	1.618	1.617	1.620	1.620	1.619	1.618	1.620	1.619	355	19.1
G2		3	1.618	1.619	1.618	1.609	1.613	1.609	1.618	1.610	1.614	357	19.1
G9		4	1.610	1.609	1.607	1.616	1.618	1.619	1.609	1.618	1.613	357	19.1
J5		5	1.605	1.608	1.602	1.606	1.611	1.611	1.605	1.609	1.607	360	19.1

Block ID.	94037

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
A2	10/3000	1	3.234	3.239	3.234	3.232	3.232	3.231	3.236	3.232	3.234	355	20.2
C5		2	3.223	3.220	3.225	3.223	3.224	3.224	3.223	3.224	3.223	358	20.2
D1		3	3.222	3.220	3.225	3.224	3.225	3.223	3.222	3.224	3.223	358	20.2
D3		4	3.223	3.223	3.220	3.220	3.223	3.225	3.222	3.223	3.222	358	20.2
E5		5	3.215	3.218	3.215	3.218	3.217	3.219	3.216	3.218	3.217	359	20.2

Results for 450HBW1/30, 450HBW2.5/187.5, 450HBW5/750 and 450HBW10/3000

NIM 4/11

Specimen
450 HBW

Block ID.	95008

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
D7	1.0/30	1	0.2890	0.2891	0.2892	0.2909	0.2909	0.2909	0.2891	0.2909	0.2900	444	19.7
F3		2	0.2919	0.2917	0.2917	0.2919	0.2917	0.2914	0.2918	0.2917	0.2917	439	19.7
G2		3	0.2908	0.2907	0.2904	0.2901	0.2901	0.2904	0.2906	0.2902	0.2904	443	19.7
G9		4	0.2909	0.2914	0.2911	0.2897	0.2899	0.2897	0.2911	0.2898	0.2905	443	19.7
J5		5	0.2910	0.2911	0.2908	0.2911	0.2911	0.2910	0.2910	0.2911	0.2910	441	19.7

Block ID.	95011

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
D7/D6	2.5/187.5	1	0.719	0.719	0.719	0.721	0.721	0.721	0.719	0.721	0.720	451	19.9
F3		2	0.719	0.719	0.719	0.719	0.718	0.717	0.719	0.718	0.719	455	19.9
G2		3	0.720	0.719	0.720	0.717	0.719	0.720	0.720	0.719	0.719	452	19.9
G9		4	0.717	0.717	0.718	0.718	0.719	0.718	0.717	0.718	0.718	455	19.9
J5		5	0.719	0.719	0.718	0.716	0.716	0.717	0.719	0.716	0.718	453	19.9

Block ID.	95010

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
D7	5/750	1	1.442	1.441	1.441	1.433	1.438	1.434	1.441	1.435	1.438	452	19.1
F3		2	1.437	1.437	1.437	1.443	1.440	1.440	1.437	1.441	1.439	451	19.1
G2		3	1.436	1.436	1.437	1.439	1.438	1.435	1.436	1.437	1.437	453	19.1
G9		4	1.438	1.437	1.438	1.442	1.445	1.442	1.438	1.443	1.440	451	19.1
J5		5	1.436	1.438	1.432	1.430	1.432	1.433	1.435	1.432	1.434	455	19.1

Block ID.	95004

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
A2	10/3000	1	2.869	2.870	2.868	2.871	2.870	2.869	2.869	2.870	2.870	454	20.2
C5		2	2.869	2.869	2.869	2.872	2.867	2.870	2.869	2.870	2.869	454	20.2
D1		3	2.870	2.872	2.872	2.873	2.875	2.869	2.871	2.872	2.872	453	20.2
D3		4	2.866	2.868	2.865	2.867	2.867	2.868	2.866	2.867	2.867	455	20.2
E5		5	2.867	2.863	2.862	2.865	2.870	2.867	2.864	2.867	2.866	455	20.2

Uncertainty report –NIM– **NIM 5/11**

Brief description of the measurement system

Brinell key comparison 2003

Name of Institute
NIM

Test Details

Instrument

Instrument type	Identifier
dead weight	NIM No. 82898

Measuring device

Device type	Identifier
optical microscope	CARLZEISS NIM No.76402

Uncertainty of the instruments

Hardness scale	uF (N)	uL (mm)	Dia. of Indenter (mm)
1.0/30	0.19	0.0005	0.9994
2.5/187.5	0.56	0.0018	2.4992
5.0/750	2.94	0.0020	4.9983
10/3000	8.83	0.0020	10.0001

Comment

Uncertainty report for 250HBW1/30

NIM 6/11

Block ID.93241 250HBW1/30

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	294.2	N	-	Normal	0.095	N	8.49E-01	HBW/N	8.07E-02	B
2	Length measuring device	Length measuring device	/	mm	-	Normal	2.00E-04	mm	-1.37E+03	HBW/mm	2.75E-01	B
3		Repeatability of readings	0	mm	-	Normal	1.80E-04	mm	-1.37E+03	HBW/mm	2.47E-01	A
4	Indenter geometry	Diameter of the ball	1	mm	1.00E-03	Rectangle	5.00E-04	mm	-20.65	HBW/mm	-1.03E-02	B
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	0.289	sec	0.12	HBW/sec	3.46E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	0.289	sec	-0.12	HBW/sec	3.46E-02	B
7	Uniformity of Blocks	-	251	HBW	-	Normal		HBW	1	-	0.00E+00	A
...	....	....	....	....	....	....	....	....	....	....	....	....
combined standard uncertainty, u [HBW]											0.38	
expanded combined standard uncertainty, U [HBW] (k=2)											0.8	

Uncertainty report for 250HBW2.5/187.5

Block ID:93243 250HBW2.5/187.5

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	1839	N	-	Normal	0.28	N	1.35E-01	HBW/N	3.78E-02	B
2	Length measuring device	Length measuring device	/	mm	-	Normal	9.00E-04	mm	-5.46E+02	HBW/mm	4.91E-01	B
3		Repeatability of readings	0	mm	-	Normal	6.70E-04	mm	-5.46E+02	HBW/mm	3.66E-01	A
4	Indenter geometry	Diameter of the ball	2.5	mm	1.00E-03	Rectangle	5.00E-04	mm	-8.38	HBW/mm	-4.19E-03	B
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	0.289	sec	0.12	HBW/sec	3.46E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	0.289	sec	-0.12	HBW/sec	3.46E-02	B
7	Uniformity of Blocks	-	257	HBW	-	Normal		HBW	1	-	0.00E+00	A
...	....	....	....	....	....	....	....	....	....	....	....	....
combined standard uncertainty, u [HBW]											0.62	
expanded combined standard uncertainty, U [HBW] (k=2)											1.2	

Uncertainty report for 250HBW5/750

NIM 7/11

Block ID:93242 250HBW5/750

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	7355	N	-	Normal	1.47	N	3.32E-02	HBW/N	4.87E-02	B
2	Length measuring device	Length measuring device	/	mm	-	Normal	1.00E-03	mm	-2.76E+02	HBW/mm	2.76E-01	B
3		Repeatability of readings	0	mm	-	Normal	1.53E-03	mm	-2.76E+02	HBW/mm	4.22E-01	A
4	Indenter geometry	Diameter of the ball	5	mm	2.00E-03	Rectangle	1.00E-03	mm	-4.19	HBW/mm	-4.19E-03	B
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	0.289	sec	0.12	HBW/sec	3.46E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	0.289	sec	-0.12	HBW/sec	3.46E-02	B
7	Uniformity of Blocks	-	250	HBW	-	Normal		HBW	1	-	0.00E+00	A
...	….	….	….	….	….	….	….	….	….	….	….	….
combined standard uncertainty, u [HBW]											0.51	
expanded combined standard uncertainty, U [HBW] (k=2)											1.0	

Uncertainty report for 350HBW1/30

Block ID 94041 350HBW1/30

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	294.2	N	-	Normal	0.10	N	1.19E+00	HBW/N	1.13E-01	B
2	Length measuring device	Length measuring device	/	mm	-	Normal	5.00E-04	mm	-2.22E+03	HBW/mm	1.11E+00	B
3		Repeatability of readings	0	mm	-	Normal	1.45E-04	mm	-2.22E+03	HBW/mm	3.22E-01	A
4	Indenter geometry	Diameter of the ball	1	mm	1.00E-03	Rectangle	5.00E-04	mm	-19.758	HBW/mm	-9.88E-03	B
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	0.289	sec	0.14	HBW/sec	4.04E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	0.289	sec	-0.11	HBW/sec	3.18E-02	B
7	Uniformity of Blocks	-	352	HBW	-	Normal		HBW		-	0.00E+00	A
...	….	….	….	….	….	….	….	….	….	….	….	….
combined standard uncertainty, u [HBW]											1.16	
expanded combined standard uncertainty, U [HBW] (k=2)											2.3	

Uncertainty report for 350HBW2.5/187.5

NIM 8/11

Block ID 94043 350HBW2.5/187.5

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	1839	N	-	Normal	0.28	N	1.89E-01	HBW/N	5.29E-02	B
2	Length measuring device	Length measuring device	/	mm	-	Normal	9.00E-04	mm	-8.79E+02	HBW/mm	7.91E-01	B
3		Repeatability of readings	0	mm	-	Normal	1.20E-03	mm	-8.79E+02	HBW/mm	1.06E+00	A
4	Indenter geometry	Diameter of the ball	2.5	mm	1.00E-03	Rectangle	5.00E-04	mm	-8.148	HBW/mm	-4.07E-03	B
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	0.289	sec	0.14	HBW/sec	4.04E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	0.289	sec	-0.11	HBW/sec	3.18E-02	B
7	Uniformity of Blocks	-	354	HBW	-	Normal		HBW		-	0.00E+00	A
...	....	....	....	....	....	....	....	....	....	....	....	....
combined standard uncertainty, u [HBW]											1.32	
expanded combined standard uncertainty, U [HBW] (k=2)											2.6	

Uncertainty report for 350HBW5/750

Block ID 94042 350HBW5/750

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	7355	N	-	Normal	1.47	N	4.64E-02	HBW/N	6.82E-02	B
2	Length measuring device	Length measuring device	/	mm	-	Normal	1.00E-03	mm	-4.46E+02	HBW/mm	4.46E-01	B
3		Repeatability of readings	0	mm	-	Normal	1.73E-03	mm	-4.46E+02	HBW/mm	7.73E-01	A
4	Indenter geometry	Diameter of the ball	5	mm	2.00E-03	Rectangle	1.00E-03	mm	-4.07	HBW/mm	-4.07E-03	B
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	0.289	sec	0.14	HBW/sec	4.04E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	0.289	sec	-0.11	HBW/sec	3.18E-02	B
7	Uniformity of Blocks	-	357	HBW	-	Normal		HBW		-	0.00E+00	A
...	....	....	....	....	....	....	....	....	....	....	....	....
combined standard uncertainty, u [HBW]											0.90	
expanded combined standard uncertainty, U [HBW] (k=2)											1.8	

Uncertainty report for 350HBW10/3000

NIM 9/11

Block ID 94037 350HBW10/3000

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	29421	N	-	Normal	4.415	N	1.36E-02	HBW/N	5.99E-02	B
2	Length measuring device	Length measuring device	/	mm	-	Normal	1.00E-03	mm	-2.17E+02	HBW/mm	2.17E-01	B
3		Repeatability of readings	0	mm	-	Normal	1.67E-03	mm	-2.17E+02	HBW/mm	3.62E-01	A
4	Indenter geometry	Diameter of the ball	10	mm	3.00E-03	Rectangle	1.50E-03	mm	-1.9758	HBW/mm	-2.96E-03	B
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	0.289	sec	0.14	HBW/sec	4.04E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	0.289	sec	-0.11	HBW/sec	3.18E-02	B
7	Uniformity of Blocks	-	358	HBW	-	Normal		HBW		-	0.00E+00	A
...	....	....	....	....	....	....	....	....	....	....	....	....
combined standard uncertainty, u [HBW]											0.43	
expanded combined standard uncertainty, U [HBW] (k=2)											0.9	

Uncertainty report for 450HBW1/30

Block ID 95008 450HBW1/30

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	294.2	N	-	Normal	0.095	N	1.53E+00	HBW/N	1.45E-01	B
2	Length measuring device	Length measuring device	/	mm	-	Normal	2.00E-04	mm	3.19E+03	HBW/mm	6.38E-01	B
3		Repeatability of readings	0	mm	-	Normal	1.45E-04	mm	3.19E+03	HBW/mm	4.63E-01	A
4	Indenter geometry	Diameter of the ball	1	mm	1.00E-03	Rectangle	5.00E-04	mm	-19.058	HBW/mm	-9.53E-03	B
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	0.289	sec	0.16	HBW/sec	4.62E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	0.289	sec	-0.09	HBW/sec	2.60E-02	B
7	Uniformity of Blocks	-	442	HBW	-	Normal		HBW		-	0.00E+00	A
...	....	....	....	....	....	....	....	....	....	....	....	....
combined standard uncertainty, u [HBW]											0.80	
expanded combined standard uncertainty, U [HBW] (k=2)											1.6	

Uncertainty report for 450HBW2.5/187.5

NIM 10/11

Block ID:95011 450HBW2.5/187.5

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	1839	N	-	Normal	0.28	N	2.43E-01	HBW/N	6.81E-02	B
2	Length measuring device	Length measuring device	/	mm	-	Normal	9.00E-04	mm	-1.26E+03	HBW/mm	1.14E+00	B
3		Repeatability of readings	0	mm	-	Normal	8.82E-04	mm	-1.26E+03	HBW/mm	1.12E+00	A
4	Indenter geometry	Diameter of the ball	2.5	mm	1.00E-03	Rectangle	5.00E-04	mm	-8.0283	HBW/mm	-4.01E-03	B
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	0.289	sec	0.16	HBW/sec	4.62E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	0.289	sec	-0.09	HBW/sec	2.60E-02	B
7	Uniformity of Blocks	-	453	HBW	-	Normal		HBW		-	0.00E+00	A
...	....	....	....	....	....	....	....	....	....	....	....	....
combined standard uncertainty, u [HBW]											1.60	
expanded combined standard uncertainty, U [HBW] (k=2)											3.2	

Uncertainty report for 450HBW5/750

Block ID :95010 450HBW5/750

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	7355	N	-	Normal	1.47	N	5.97E-02	HBW/N	8.77E-02	B
2	Length measuring device	Length measuring device	/	mm	-	Normal	1.00E-03	mm	-6.42E+02	HBW/mm	6.42E-01	B
3		Repeatability of readings	0	mm	-	Normal	1.76E-03	mm	-6.42E+02	HBW/mm	1.13E+00	A
4	Indenter geometry	Diameter of the ball	5	mm	2.00E-03	Rectangle	1.00E-03	mm	-4.0142	HBW/mm	-4.01E-03	B
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	0.289	sec	0.16	HBW/sec	4.62E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	0.289	sec	-0.09	HBW/sec	2.60E-02	B
7	Uniformity of Blocks	-	452	HBW	-	Normal		HBW		-	0.00E+00	A
...	....	....	....	....	....	....	....	....	....	....	....	....
combined standard uncertainty, u [HBW]											1.31	
expanded combined standard uncertainty, U [HBW] (k=2)											2.6	

Uncertainty report for 450HBW10/3000

NIM 11/11

Block ID :95004 450HBW10/3000

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	29421	N	-	Normal	4.415	N	1.74E-02	HBW/N	7.70E-02	B
2	Length measuring device	Length measuring device	/	mm	-	Normal	1.00E-03	mm	-3.11E+02	HBW/mm	3.11E-01	B
3		Repeatability of readings	0	mm	-	Normal	1.76E-03	mm	-3.11E+02	HBW/mm	5.49E-01	A
4	Indenter geometry	Diameter of the ball	10	mm	3.00E-03	Rectangle	1.50E-03	mm	-1.9058	HBW/mm	-2.86E-03	B
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	0.289	sec	0.16	HBW/sec	4.62E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	0.289	sec	-0.09	HBW/sec	2.60E-02	B
7	Uniformity of Blocks	-	454	HBW	-	Normal		HBW	1	-	0.00E+00	A
...	....	....	....	....	....	....	....	....	....	....	....	....
combined standard uncertainty, u [HBW]											0.64	
expanded combined standard uncertainty, U [HBW] (k=2)											1.3	

End of –NIM–

Results and uncertainty report –NPL– **NPL 1/9**

Measurement results

Results for Reference indentations

Measurement result of measurement of the length of Reference indents

reference Block	Hardness (HBW)	dh1 (μm)	dh2 (μm)	dh3 (μm)	dv1 (μm)	dv2 (μm)	dv3 (μm)	dh mean (μm)	dv mean (μm)	d (μm)	Temp (°C)
250	1.0/30	382.9	382.79	382.8	382.74	382.7	382.76	382.83	382.73	382.78	20.4°-20.6°
	2.5/187.5	949.31	949.25	949.45	944.29	944.74	944.55	949.34	944.53	946.93	20.4°-20.6°
	5/750	1915.35	1915.07	1915.26	1905.9	1904.46	1905.7	1915.23	1905.35	1910.29	20.4°-20.6°
350	1.0/30	321.8	321.65	321.86	320.35	320.45	320.44	321.77	320.41	321.09	20.4°-20.6°
	2.5/187.5	806.98	806.67	806.97	806.74	806.7	806.42	806.87	806.62	806.75	20.4°-20.6°
	5/750	1603.33	1603.05	1603.81	1602.93	1602.8	1602.96	1603.4	1602.9	1603.15	20.4°-20.6°
	10/3000	3201.8	3202.25	3202.1	3203.1	3203.31	3202.8	3202.05	3203.07	3202.56	20.4°-20.6°
450	1.0/30	288.7	288.61	288.61	288.27	288.5	288.49	288.64	288.42	288.53	20.4°-20.6°
	2.5/187.5	718.2	718.31	718.22	717.2	717.7	717.69	718.24	717.53	717.89	20.4°-20.6°
	5/750	1434.5	1434.8	1435	1433.7	1433.93	1433.97	1434.77	1433.87	1434.32	20.4°-20.6°
	10/3000	2862.2	2862.4	2862	2861.6	2861.92	2861.3	2862.2	2861.61	2861.9	20.4°-20.6°

Results for False indentations

Dummy indentations were all measured using the x 40 and x 1.25 lenses.

Results:

	Horizontal [μm]			Vertical [μm]		
	1	2	3	1	2	3
A	1500.2	1500.19	1500.16	1498.7	1498.8	1498.87
B	799.98	800	800.03	800	799.99	799.99
C	400.23	400.14	400.1	399.8	399.93	399.86
D	240.5	240.49	240.6	240.5	240.49	240.51

Results for 250HBW1/30, 250HBW2.5/187.5 and 250HBW5/750

NPL 2/8

Specimen
250 HBW

Block ID.	93241

Test identifiler	hardness scale	No. of test	dh1 (μm)	dh2 (μm)	dh3 (μm)	dv1 (μm)	dv2 (μm)	dv3 (μm)	dh mean (μm)	dv mean (μm)	d (μm)	Hardness (HBW)	Temp (°C)
D3	1.0/30	1	381.35	381.06	381.13	381.04	381.1	381.25	381.18	381.13	381.155	253.07	20.4°-20.6°
D6		2	381.2	380.95	380.8	380.62	380.54	380.7	380.98	380.62	380.8	253.56	20.4°-20.6°
D8		3	381.77	381.85	381.6	381	380.78	380.82	381.74	380.87	381.3	252.86	20.4°-20.6°
G3		4	379.52	379.65	379.42	380.15	380.27	380.13	379.53	380.18	379.86	254.87	20.4°-20.6°
H7		5	379.62	379.85	379.65	378.5	378.78	378.85	379.71	378.71	379.21	255.78	20.4°-20.6°

Block ID.	93249

Test identifiler	hardness scale	No. of test	dh1 (μm)	dh2 (μm)	dh3 (μm)	dv1 (μm)	dv2 (μm)	dv3 (μm)	dh mean (μm)	dv mean (μm)	d (μm)	Hardness (HBW)	Temp (°C)
D3	2.5/187.5	1	949.56	949.1	949.26	951.3	950.9	950.6	949.31	950.93	950.12	254.64	20.4°-20.6°
D6		2	949.7	949.51	949.42	948.64	948.71	948.57	949.54	948.64	949.74	255.22	20.4°-20.6°
D8		3	950.55	950.61	950.9	948.75	948.65	949	950.69	948.8	945.74	254.85	20.4°-20.6°
G3		4	944.92	944.6	945.1	946.66	946	946.3	944.87	946.32	945.6	257.18	20.4°-20.6°
H6		5	946.8	946.8	946.35	946.3	946.4	946.26	946.65	946.32	946.49	256.68	20.4°-20.6°

Block ID.	93242

Test identifiler	hardness scale	No. of test	dh1 (μm)	dh2 (μm)	dh3 (μm)	dv1 (μm)	dv2 (μm)	dv3 (μm)	dh mean (μm)	dv mean (μm)	d (μm)	Hardness (HBW)	Temp (°C)
D3	5/750	1	1918.2	1918.26	1918.7	1922.6	1923.2	1923	1918.39	1922.93	1920.66	249	20.4°-20.6°
D6		2	1919.13	1919.28	1919.02	1920.1	1919.74	1919.73	1919.14	1919.86	1919.5	249.32	20.4°-20.6°
D8		3	1917.9	1917.05	1917.2	1916.03	1915.84	1915.85	1917.38	1915.91	1916.65	250.09	20.4°-20.6°
G3		4	1914.4	1914.74	1914.78	1915.4	1915.07	1915.7	1914.64	1915.39	1915.02	250.53	20.4°-20.6°
H7		5	1914.4	1914.62	1914.48	1914.08	1914.15	1914.1	1914.5	1914.11	1914.31	250.73	20.4°-20.6°

Results for 350HBW1/30, 350HBW2.5/187.5, 350HBW5/750 and 350HBW10/3000

NPL 3/8

Specimen
350 HBW

Block ID.	94041

Test identifiler	hardness scale	No. of test	dh1 (μm)	dh2 (μm)	dh3 (μm)	dv1 (μm)	dv2 (μm)	dv3 (μm)	dh mean (μm)	dv mean (μm)	d (μm)	Hardness (HBW)	Temp (°C)
D3	1.0/30	1	322.28	322.34	322.15	321.6	321.6	321.65	322.26	321.62	321.94	358.83	20.4°-20.6°
D6		2	321.2	321.4	321.4	321.65	321.5	321.57	321.33	321.57	321.45	359.95	20.4°-20.6°
D8		3	321.9	321.8	321.75	320.33	320.11	320.6	321.82	320.68	321.25	360.42	20.4°-20.6°
G3		4	320.34	320.33	320.36	320.88	320.85	320.91	320.34	320.88	320.61	361.89	20.4°-20.6°
H7		5	321.07	320.96	321.11	321.4	321.46	321.42	321.05	321.43	321.24	360.44	20.4°-20.6°

Block ID.	94043

Test identifiler	hardness scale	No. of test	dh1 (μm)	dh2 (μm)	dh3 (μm)	dv1 (μm)	dv2 (μm)	dv3 (μm)	dh mean (μm)	dv mean (μm)	d (μm)	Hardness (HBW)	Temp (°C)
D3	2.5/187.5	1	809.63	809.67	809.67	808.81	808.77	808.98	809.66	808.85	809.26	354.87	20.4°-20.6°
D6		2	807.11	807.12	807.4	807.2	807.35	807.4	807.21	807.32	807.26	356.67	20.4°-20.6°
D8		3	806.21	806.25	806.15	807.04	806.75	806.8	806.2	806.86	806.53	357.34	20.4°-20.6°
G3		4	806.52	806.68	806.85	806.5	806.5	806.2	806.68	806.4	806.54	357.33	20.4°-20.6°
H7		5	805.65	805.98	805.75	806.17	806.25	806.23	805.79	806.22	806.01	357.82	20.4°-20.6°

Block ID.	94042

Test identifiler	hardness scale	No. of test	dh1 (μm)	dh2 (μm)	dh3 (μm)	dv1 (μm)	dv2 (μm)	dv3 (μm)	dh mean (μm)	dv mean (μm)	d (μm)	Hardness (HBW)	Temp (°C)
D3	5/750	1	1604.07	1603.87	1603.85	1604.64	1604.58	1604.84	1603.93	1604.69	1604.31	361.31	20.4°
D6		2	1603.82	1603.46	1603.73	1603.25	1603.36	1603.23	1603.67	1603.28	1603.48	361.7	
D8		3	1603.94	1603.4	1603.72	1599.5	1599.55	1599.4	1603.69	1599.48	1601.59	362.58	To
G3		4	1599.92	1599.78	1599.97	1603.11	1603.22	1603.15	1599.89	1603.16	1601.53	362.6	
H7		5	1601.25	1601.38	1601.42	1600.25	1600.4	1600.47	1601.35	1600.37	1600.86	362.91	20.6°

Block ID.	94038

Test identifiler	hardness scale	No. of test	dh1 (μm)	dh2 (μm)	dh3 (μm)	dv1 (μm)	dv2 (μm)	dv3 (μm)	dh mean (μm)	dv mean (μm)	d (μm)	Hardness (HBW)	Temp (°C)
A2	10/3000	1	3235.4	3235.3	3235.35	3234.7	3234.6	3234.6	3235.35	3234.64	3235	355.28	20.4°
C5		2	3228.5	3228.2	3228.5	3230.25	3230.6	3230.1	3228.4	3230.32	3229.36	356.56	
D1		3	3219.83	3220.1	3220.15	3220.15	3220.53	3219.95	3220.03	3220.21	3220.12	358.66	To
D3		4	3226.9	3226.7	3227	3224.4	3224.7	3224.9	3226.87	3224.67	3225.77	357.37	
E5		5	3220.8	3220.9	3220.8	3221.5	3221.35	3221.4	3220.83	3221.42	3221.13	358.43	20.6°

Results for 450HBW1/30, 450HBW2.5/187.5, 450HBW5/750 and 450HBW10/3000

NPL 4/8

Specimen
450 HBW

Block ID.	95008

Test identifiler	hardness scale	No. of test	dh1 (μm)	dh2 (μm)	dh3 (μm)	dv1 (μm)	dv2 (μm)	dv3 (μm)	dh mean (μm)	dv mean (μm)	d (μm)	Hardness (HBW)	Temp (°C)
D3	1.0/30	1	288.02	287.7	287.73	288.35	288.61	288.67	287.82	288.54	288.18	450.31	20.4°-20.6°
D6		2	288.45	288.61	288.36	287.93	288.12	288.19	288.47	288.08	288.28	450	20.4°-20.6°
D8		3	288.34	288.47	288.4	288.7	288.68	288.48	288.4	288.62	288.51	449.25	20.4°-20.6°
G3		4	289.3	289.35	289.2	288.35	288.31	288.37	289.28	288.34	288.81	448.3	20.4°-20.6°
H7		5	288.84	288.73	288.79	288.65	288.63	288.66	288.79	288.65	288.72	448.6	20.4°-20.6°

Block ID.	95011

Test identifiler	hardness scale	No. of test	dh1 (μm)	dh2 (μm)	dh3 (μm)	dv1 (μm)	dv2 (μm)	dv3 (μm)	dh mean (μm)	dv mean (μm)	d (μm)	Hardness (HBW)	Temp (°C)
D3	2.5/187.5	1	718.4	718.28	718.36	718	718.14	718.12	718.35	718.09	718.22	453.24	20.4°
A6		2	716.46	716.5	716.36	716.29	716.1	716.4	716.44	716.26	716.35	455.66	
D8		3	716.03	716.21	716.15	716.25	716.2	716.25	716.13	716.23	716.18	455.88	To
G3		4	716.03	716.78	716.4	716.95	716.73	716.45	716.4	716.71	716.56	455.39	
H7		5	717.2	716.9	716.7	717.02	717.48	717.27	716.93	717.26	717.1	454.69	20.6°

Block ID.	95010

Test identifiler	hardness scale	No. of test	dh1 (μm)	dh2 (μm)	dh3 (μm)	dv1 (μm)	dv2 (μm)	dv3 (μm)	dh mean (μm)	dv mean (μm)	d (μm)	Hardness (HBW)	Temp (°C)
D3	5/750	1	1432.75	1432.95	1433.4	1433.84	1433.8	1433.67	1433.03	1433.77	1433.4	455.14	20.4°
D6		2	1433.65	1433.76	1433.92	1433.51	1433.26	1432.96	1433.78	1433.24	1433.51	455.07	
D8		3	1434.82	1434.86	1434.66	1435.12	1434.99	1434.6	1434.78	1434.9	1434.84	454.21	To
G3		4	1431.4	1432.33	1432.06	1430.66	1430.94	1430.92	1431.93	1430.84	1431.39	456.45	
H7		5	1432.37	1432.3	1432.4	1431.7	1431.88	1431.5	1432.36	1431.69	1432.03	456.04	20.6°

Block ID.	95005

Test identifiler	hardness scale	No. of test	dh1 (μm)	dh2 (μm)	dh3 (μm)	dv1 (μm)	dv2 (μm)	dv3 (μm)	dh mean (μm)	dv mean (μm)	d (μm)	Hardness (HBW)	Temp (°C)
A2	10/3000	1	2868.36	2868.3	2868.78	2868.25	2868.02	2868.72	2868.48	2868.33	2868.41	454.62	20.4°
C5		2	2868.5	2868.6	2868.7	2868.03	2868.1	2868.08	2868.6	2868.07	2868.34	455.64	
D1		3	2868.4	2868.17	2868.7	2868	2868.25	2868	2868.42	2868.08	2868.25	454.67	To
D3		4	2868.68	2868.4	2868.15	2868.2	2868.7	2868.2	2868.41	2868.37	2868.39	454.62	
E5		5	2866.25	2866.83	2866.65	2865.64	2866.04	2866.15	2866.58	2865.94	2866.26	455.32	20.6°

Uncertainty report –NPL– **NPL 5/8**

Brief description of the measurement system

Brinell key comparison 2003

Partner Number

Test Details

Instrument

Instrument type	Identifier
30 kN Instron	5567 H1571

Measuring device

Device type	Identifier
Gal indent software	

The work was carried out using NPL's 1.5 kN hardness machine, for the HBW 1/30 scale; which is based on the Instron RT2000 hardness machine, with a laser interferometer depth sensor.
The HBW 2.5/187.5, 10/3000 and 5/750 tests were carried out using NPL's 30 kN hardness machine based on an Intron 5567 tensile/compression testing machine. This machine also has a Heidenhain depth measurement sensor.
Both machines are interfaced to their own PC-driven control system based upon Instron's Merlin and Wavemaker software product, which uses generalised wavefoms for closed loop control. The servo design provides control of the applied forces, via loadcell control, and indenter motion.
The indentation measurement system consists of a Reichert-Jung (Polyvar Met) microscope with CCD camera to image the indentation, and an interferometer to measure the stage movement.
A range of lenses were used for measuring the indentations, (not including the x 10 internal magnification), the details of these are given below:

Scale	Primary lens	Secondary lens
2.5/187.5	X 40 (NA=0.75)	X 1.25
5/750	X 40 (NA=0.75)	X 0.8
10/3000	X 40 (NA=0.75)	X 0.8
1.0/30	X 40 (NA=0.75)	X 1.25

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Dummy indentations were all measured using the x 40 and x 1.25 lenses.

Results:

	Horizontal [μm]			Vertical [μm]		
	1	2	3	1	2	3
A	1500.20	1500.19	1500.16	1498.70	1498.80	1498.87
B	799.98	800.00	800.03	800.00	799.99	799.99
C	400.23	400.14	400.10	399.8	399.93	399.86
D	240.50	240.49	240.60	240.50	240.49	240.51

Machine Calibration:

Force Calibration:

The force calibration included the nominal test forces for each scale to be calibrated against the NPL deadweight machine via a reference loadcell. The calibration showed the machine to operate with an error of -0.013%, 0.010% & - 0.005% for 1.879 kN, 7.355 kN & 29.42 kN consecutively. There was also a 0.039% uncertainty in the stability of the force, for the worst of these forces.

Time Calibration:

The time recording was found to have an uncertainty of 0.15 seconds across the 60 second testing cycle, via calibration against a calibrated stop clock.

Indentation measuring equipment Calibration:

The laser from the interferometer measuring system was calibrated. A calibrated stage graticule was then used within the system to ensure the laser measurement was accurate showing an error of less than 0.5 μm across 0.1 mm, 0.01 mm & 1.0 mm.

Uncertainty report for hardness scale HBW1/30

NPL 7/8

HB 1/30

Quantity	Source of uncertainty	Value	Divisor	Standard Uncertainty	Sensitivity Coefficients / Ci (Block hardness in HB)			Uncertainty in hardness u(xi).Ci / HB		
x_i				$u(x_i)$						
					100	300	500	100	300	500
F (N)	Test force	0.421	2	**0.21**	3.40E-01	1.00E+00	1.70E+00	**0.072**	**0.215**	**0.358**
D (mm)	Diameter of Indenter	0.001	√3	**0.00058**	-9.40E+00	-8.20E+00	-8.00E+00	**-0.005**	**-0.005**	**-0.005**
d (%)	Measurement of indent	0.25	2	**0.125**	-2.20E+00	-6.20E+00	-1.00E+01	**-0.279**	**-0.775**	**-1.275**
t_1 (s)	Test force application time	0.025	1	**0.025**	8.70E-02	1.30E-01	1.80E-01	**0.002**	**0.003**	**0.004**
t_2 (s)	Test force duration time	0.025	1	**0.025**	-1.50E-01	-1.20E-01	-8.50E-02	**-0.004**	**-0.003**	**-0.002**
					Standard uncertainty			0.29	0.8	1.32
					Expanded uncertainty, k=2			0.58	1.61	2.65
					Uncertatinty [%]			0.58%	0.54%	0.53%

Uncertainty report for hardness scale HBW2.5/187.5

HB 2.5/187.5

Quantity	Source of uncertainty	Value	Divisor	Standard Uncertainty	Sensitivity Coefficients / Ci (Block hardness in HB)			Uncertainty in hardness u(xi).Ci / HB		
x_i				$u(x_i)$						
					255	357	455	255	357	455
F (N)	Test force	1.067	2	**0.53**	1.40E-01	1.90E-01	2.50E-01	**0.074**	**0.104**	**0.132**
D (mm)	Diameter of Indenter	0.001	√3	**0.00058**	-6.90E+00	-9.70E+00	-7.20E+00	**-0.004**	**-0.006**	**-0.004**
d (%)	Measurement of indent	0.25	2	**0.125**	-5.30E+00	-7.40E+00	-9.30E+00	**-0.659**	**-0.923**	**-1.16**
t_1 (s)	Test force application time	0.025	1	**0.025**	1.20E-01	1.40E-01	1.70E-01	**0.003**	**0.004**	**0.004**
t_2 (s)	Test force duration time	0.025	1	**0.025**	-1.20E-01	-1.10E-01	-9.20E-02	**-0.003**	**-0.003**	**-0.002**
					Standard uncertainty			0.66	0.93	1.17
					Expanded uncertainty, k=2			1.33	1.86	2.34
					Uncertatinty [%]			0.52%	0.52%	0.51%

Uncertainty report for hardness scale HBW5/750

NPL 8/8

HB 5/750

Quantity	Source of uncertainty	Value	Divisor	Standard Uncertainty	Sensitivity Coefficients / Ci (Block hardness in HB)			Uncertainty in hardness u(xi).Ci / HB		
x_i				$u(x_i)$						
					250	362	455	250	362	455
F (N)	Test force	4.266	2	**2.13**	3.40E-02	4.90E-02	6.20E-02	**0.073**	**0.105**	**0.132**
D (mm)	Diameter of Indenter	0.002	√3	**0.00115**	-1.20E+01	-4.90E+00	-3.60E+00	**-0.014**	**-0.006**	**-0.004**
d (%)	Measurement of indent	0.25	2	**0.125**	-5.60E+00	-7.50E+00	-9.30E+00	**-0.698**	**-0.936**	**-1.16**
t_1 (s)	Test force application time	0.025	1	**0.025**	1.20E-01	1.40E-01	1.70E-01	**0.003**	**0.004**	**0.004**
t_2 (s)	Test force duration time	0.025	1	**0.025**	-1.20E-01	-1.10E-01	-9.20E-02	**-0.003**	**-0.003**	**-0.002**
					Standard uncertainty			0.7	0.94	1.17
					Expanded uncertainty, k=2			1.4	1.88	2.33
					Uncertatinty [%]			0.56%	0.52%	0.51%

Uncertainty report for hardness scale HBW10/3000

HB 10/3000

Quantity	Source of uncertainty	Value	Divisor	Standard Uncertainty	Sensitivity Coefficients / Ci (Block hardness in HB)		Uncertainty in hardness u(xi).Ci / HB	
x_i				$u(x_i)$				
					357	455	357	455
F (N)	Test force	17.06	2	**8.53**	1.20E-02	1.50E-02	**0.104**	**0.132**
D (mm)	Diameter of Indenter	0.003	√3	**0.00173**	-2.40E+00	-1.80E+00	**-0.004**	**-0.003**
d (%)	Measurement of indent	0.25	2	**0.125**	-7.40E+00	-9.30E+00	**-0.923**	**-1.16**
t_1 (s)	Test force application time	0.025	1	**0.025**	1.40E-01	1.70E-01	**0.004**	**0.004**
t_2 (s)	Test force duration time	0.025	1	**0.025**	-1.10E-01	-9.20E-02	**-0.003**	**-0.002**
					Standard uncertainty		0.93	1.17
					Expanded uncertainty, k=2		1.86	2.34
					Uncertatinty [%]		0.52%	0.51%

END –NPL–

Results and uncertainty report –PTB– **PTB 1/11**

Measurement results

Results for Reference and False indentations

Measurement result of measuremet of the length of Reference indents

reference Block	ID of the Block	Hardness (HBW)	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Temp (ºC)
250	93241	1.0/30	0.3831	0.3830	0.3832	0.3814	0.3813	0.3815	0.38310	0.38140	0.38225	20+/-0.3
	93243	2.5/187.5	0.9372	0.9374	0.9373	0.9386	0.9385	0.9386	0.93730	0.93857	0.93793	(this temperature range is
	93242	5/750	1.9138	1.9140	1.9140	1.9058	1.9056	1.9059	1.91393	1.90577	1.90985	valid for all measurements)
350	94041	1.0/30	0.3209	0.3210	0.3211	0.3206	0.3207	0.3206	0.32098	0.32062	0.32080	20
	94043	2.5/187.5	0.8090	0.8086	0.8088	0.8072	0.8072	0.8071	0.80880	0.80717	0.80798	
	94042	5/750	1.6055	1.6051	1.6054	1.6039	1.6043	1.6041	1.60530	1.60408	1.60469	
	94037	10/3000	3.2058	3.2056	3.2060	3.2037	3.2037	3.2040	3.20580	3.20380	3.20480	
450	95008	1.0/30	0.2890	0.2888	0.2890	0.2871	0.2874	0.2870	0.28892	0.28715	0.28803	20
	95011	2.5/187.5	0.7184	0.7187	0.7184	0.7187	0.7187	0.7187	0.71850	0.71868	0.71859	
	95010	5/750	1.4371	1.4372	1.4371	1.4376	1.4373	1.4372	1.43713	1.43737	1.43725	
	95004	10/3000	2.8635	2.8635	2.8633	2.8622	2.8621	2.8619	2.86340	2.86205	2.86273	

Measurement result of measuremet of the length of "False Indentation"

Nominal Diameter	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Temp (ºC)
1.5	1.4994	1.4994	1.4995	1.4975	1.4973	1.4975	1.49942	1.49742	1.49842	20
0.8	0.7995	0.7993	0.7995	0.7990	0.7991	0.7990	0.79940	0.79898	0.79919	
0.4	0.3999	0.3997	0.3998	0.3993	0.3994	0.3996	0.39980	0.39940	0.39960	
0.24	0.2405	0.2404	0.2404	0.2403	0.2403	0.2404	0.24040	0.24030	0.24035	

Results for 250HBW1/30, 250HBW2.5/187.5 and 250HBW5/750

PTB 2/11

Specimen
250 HBW

Block ID.	93241

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
B8	1.0/30	1	0.3856	0.3857	0.3856	0.3855	0.3855	0.3855	0.38560	0.38545	0.38553	247.1	20
E2		2	0.3854	0.3854	0.3855	0.3859	0.3860	0.3858	0.38542	0.38587	0.38564	246.9	
F7		3	0.3842	0.3843	0.3845	0.3850	0.3847	0.3847	0.38432	0.38478	0.38455	248.4	
H5		4	0.3838	0.3840	0.3840	0.3824	0.3824	0.3827	0.38392	0.38247	0.38319	250.2	
H9		5	0.3831	0.3832	0.3831	0.3841	0.3840	0.3841	0.38312	0.38407	0.38359	249.7	

Block ID.	93243

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
B8	2.5/187.5	1	0.9528	0.9530	0.9531	0.9538	0.9536	0.9535	0.95297	0.95360	0.95328	252.8	20
E2		2	0.9509	0.9510	0.9510	0.9493	0.9490	0.9494	0.95093	0.94922	0.95008	254.6	
F7		3	0.9512	0.9512	0.9513	0.9511	0.9512	0.9510	0.95122	0.95107	0.95114	254.0	
H5		4	0.9489	0.9489	0.9488	0.9472	0.9471	0.9471	0.94885	0.94710	0.94798	255.7	
H9		5	0.9515	0.9515	0.9514	0.9512	0.9514	0.9514	0.95143	0.95130	0.95137	253.8	

Block ID.	93242

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
B8	5/750	1	1.9316	1.9316	1.9316	1.9285	1.9285	1.9286	1.93158	1.92850	1.93004	246.4	20
E2		2	1.9278	1.9279	1.9275	1.9290	1.9292	1.9294	1.92773	1.92920	1.92847	246.8	
F7		3	1.9217	1.9220	1.9218	1.9218	1.9222	1.9221	1.92182	1.92203	1.92193	248.6	
H5		4	1.9193	1.9195	1.9195	1.9218	1.9220	1.9217	1.91942	1.92183	1.92063	248.9	
H9		5	1.9218	1.9219	1.9219	1.9225	1.9222	1.9224	1.92187	1.92235	1.92211	248.5	

Results for 350HBW1/30, 350HBW2.5/187.5, 350HBW5/750 and 350HBW10/3000

PTB 3/11

Specimen
350 HBW

Block ID.	94041

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
B8	1.0/30	1	0.3226	0.3226	0.3224	0.3222	0.3223	0.3224	0.32248	0.32228	0.32238	357.7	20
E2		2	0.3247	0.3247	0.3246	0.3235	0.3233	0.3236	0.32467	0.32347	0.32407	353.9	
F7		3	0.3221	0.3221	0.3222	0.3224	0.3223	0.3221	0.32210	0.32225	0.32218	358.2	
H5		4	0.3208	0.3211	0.3210	0.3209	0.3209	0.3210	0.32095	0.32093	0.32094	361.0	
H9		5	0.3210	0.3211	0.3211	0.3222	0.3222	0.3223	0.32102	0.32220	0.32161	359.5	

Block ID.	94043

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
B8	2.5/187.5	1	0.8100	0.8101	0.8103	0.8102	0.8099	0.8099	0.81013	0.81000	0.81007	354.0	20
E2		2	0.8106	0.8103	0.8102	0.8110	0.8107	0.8109	0.81037	0.81087	0.81062	353.5	
F7		3	0.8091	0.8092	0.8089	0.8113	0.8115	0.8114	0.80905	0.81135	0.81020	353.9	
H5		4	0.8092	0.8094	0.8090	0.8091	0.8089	0.8089	0.80918	0.80897	0.80908	354.9	
H9		5	0.8086	0.8084	0.8086	0.8079	0.8080	0.8082	0.80853	0.80803	0.80828	355.6	

Block ID.	94042

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
B8	5/750	1	1.6080	1.6078	1.6078	1.6093	1.6089	1.6091	1.60783	1.60907	1.60845	359.3	20
E2		2	1.6114	1.6115	1.6116	1.6116	1.6119	1.6118	1.61150	1.61177	1.61163	357.8	
F7		3	1.6092	1.6095	1.6094	1.6086	1.6086	1.6086	1.60932	1.60858	1.60895	359.1	
H5		4	1.6050	1.6053	1.6050	1.6109	1.6105	1.6109	1.60508	1.61075	1.60792	359.5	
H9		5	1.6061	1.6057	1.6059	1.6077	1.6076	1.6074	1.60588	1.60752	1.60670	360.1	

Block ID.	94037

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (°C)
A4	10/3000	1	3.2567	3.2570	3.2567	3.2492	3.2493	3.2494	3.25678	3.24927	3.25303	351.1	20
C3		2	3.2427	3.2427	3.2426	3.2386	3.2383	3.2385	3.24262	3.23845	3.24053	353.9	
C6		3	3.2390	3.2387	3.2391	3.2368	3.2367	3.2367	3.23890	3.23670	3.23780	354.5	
E2		4	3.2294	3.2292	3.2293	3.2237	3.2240	3.2240	3.22928	3.22390	3.22659	357.1	
F5		5	3.2222	3.2221	3.2220	3.2190	3.2190	3.2193	3.22205	3.21908	3.22057	358.5	

Results for 450HBW1/30, 450HBW2.5/187.5, 450HBW5/750 and 450HBW10/3000

PTB 4/11

Specimen
450 HBW

Block ID.	95008

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
B8	1.0/30	1	0.2875	0.2876	0.2871	0.2860	0.2862	0.2860	0.28740	0.28602	0.28671	454.9	20
E2		2	0.2890	0.2889	0.2889	0.2876	0.2874	0.2874	0.28888	0.28743	0.28816	450.3	
F7		3	0.2884	0.2885	0.2887	0.2887	0.2889	0.2887	0.28850	0.28872	0.28861	448.8	
H5		4	0.2890	0.2889	0.2889	0.2890	0.2890	0.2890	0.28892	0.28895	0.28893	447.8	
H9		5	0.2894	0.2896	0.2896	0.2893	0.2892	0.2893	0.28948	0.28922	0.28935	446.5	

Block ID.	95011

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
B8	2.5/187.5	1	0.7181	0.7178	0.7178	0.7189	0.7187	0.7188	0.71788	0.71877	0.71833	452.9	20
E2		2	0.7195	0.7196	0.7195	0.7163	0.7161	0.7162	0.71953	0.71620	0.71787	453.5	
F7		3	0.7170	0.7168	0.7168	0.7182	0.7183	0.7183	0.71687	0.71827	0.71757	453.9	
H5		4	0.7193	0.7190	0.7193	0.7192	0.7195	0.7196	0.71918	0.71943	0.71931	451.6	
H9		5	0.7169	0.7170	0.7170	0.7151	0.7155	0.7153	0.71697	0.71527	0.71612	455.8	

Block ID.	95010

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
B8	5/750	1	1.4362	1.4366	1.4366	1.4345	1.4344	1.4344	1.43642	1.43442	1.43542	453.7	20
E2		2	1.4353	1.4350	1.4350	1.4352	1.4352	1.4354	1.43508	1.43523	1.43516	453.9	
F7		3	1.4359	1.4361	1.4363	1.4348	1.4347	1.4347	1.43607	1.43473	1.43540	453.7	
H5		4	1.4347	1.4345	1.4348	1.4353	1.4352	1.4354	1.43462	1.43525	1.43493	454.0	
H9		5	1.4350	1.4347	1.4348	1.4362	1.4361	1.4362	1.43478	1.43617	1.43548	453.7	

Block ID.	95004

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
A4	10/3000	1	2.8690	2.8698	2.8694	2.8667	2.8668	2.8668	2.86937	2.86673	2.86805	454.6	20
C3		2	2.8665	2.8665	2.8662	2.8655	2.8653	2.8656	2.86640	2.86547	2.86593	455.3	
C6		3	2.8647	2.8643	2.8645	2.8638	2.8640	2.8638	2.86450	2.86387	2.86418	455.9	
E2		4	2.8691	2.8690	2.8689	2.8660	2.8661	2.8661	2.86898	2.86603	2.86751	454.8	
F5		5	2.8640	2.8641	2.8641	2.8630	2.8629	2.8628	2.86403	2.86285	2.86344	456.1	

Uncertainty report –PTB– **PTB 5/11**

Brief description of the measurement system

Brinell key comparison 2003

Name of Institute
PTB

Test Details

Instrument

Instrument type	Identifier
dead weight	HNME VB187,5 / HNME B3000

Measuring device

Device type	Identifier
Microscope Leitz Libra 200	

Uncertainty of the instruments

Hardness scale	uF (N)	uL (mm)	Dia. of Indenter (mm)	Cycle time t, s
1.0/30	$5x10^{-5}$	0.3 µm	0.3 µm	0.2 s
2.5/187.5	$5x10^{-5}$	0.3 µm	0.3 µm	0.2 s
5.0/750	$5x10^{-5}$	0.3 µm	0.3 µm	0.2 s
10/3000	$5x10^{-5}$	0.3 µm	0.3 µm	0.2 s

Comment
1) The 3 reference indents ID 93243, 93242 and 94043 do not have an ideal shape. ID 93243 is deformed over half the circumference. ID 93242 is not round, and ID 94043 is scratched and det We have added photos of the mentioned indents. 2) In one field of our test indents we have already found an indent. Therefore we have made in this field ours as the second indent. 3) The inhomogeneity of the hardness distribution of the blocks in some cases is rather large. This can be seen from the hardness variation over the 5 indents on one block.

Summary of uncertainty tables

Summary of uncertainties, in HBW

Hardness scale	250 HBW	350 HBW	450 HBW
HBW 1/30	2.45	3.54	4.47
HBW 2,5/187,5	1.52	2.12	2.81
HBW 5/750	1.96	2.74	3.58
HBW 10/3000	1.50	2.12	2.68

Uncertainty report for 250HBW1/30

PTB 6/11

Hardness scale 250 HBW 1/30							
Influencing quantity	Meas. Deviation	Distrib. type	Stand. Uncertainty	Sensitivity coeff.	Contrib. To comb. stand. unc.		
Test force F		N	0.002942	0.849762067	0.0025	0.00000625	
Indentation diam d		N	0.0009	1359.364178	1.22342776	1.49677548	
Indent. Ball diam D		N	0.0003	-1.573565826	-0.00047207	2.2285E-07	
Test force appl. Time t_a		N	0.2	0.119195	0.023839	0.0005683	
Test force dur. Time t_d		N	0.2	-0.11905	-0.02381	0.00056692	
Combined standard uncertainty						1.22389426	
Expanded standard uncertainty						2.45	HBW
Calculation of sensitivity coefficients							
F, N	294.2	cF, HBW/N	0.849762067				
D, mm	1	cd, HBW/mm	1359.364178				
d, mm	0.383	cD, HBW/mm	-1.573565826				
H, HBW	250	cta, HBW/s	0.119195				
		ctd, HBW/s	-0.11905				

Uncertainty report for 350HBW1/30

Hardness scale 350 HBW 1/30							
Influencing quantity	Meas. Deviation	Distrib. type	Stand. Uncertainty	Sensitivity coeff.	Contrib. To comb. stand. unc.		
Test force F		N	0.002942	1.189666893	0.0035	0.00001225	
Indentation diam d		N	0.0008	2209.28069	1.767424552	3.12378955	
Indent. Ball diam D		N	0.0003	-1.104924005	-0.000331477	1.0988E-07	
Test force appl. Time t_a		N	0.2	0.140925	0.028185	0.00079439	
Test force dur. Time t_d		N	0.2	-0.10451	-0.020902	0.00043689	
Combined standard uncertainty						1.76777634	
Expanded standard uncertainty						3.54	HBW
Calculation of sensitivity coefficients							
F, N	294.2	cF, HBW/N	1.189666893				
D, mm	1	cd, HBW/mm	2209.28069				
d, mm	0.326	cD, HBW/mm	-1.104924005				
H, HBW	350	cta, HBW/s	0.140925				
		ctd, HBW/s	-0.10451				

Uncertainty report for 450HBW1/30

PTB 7/11

Hardness scale 450 HBW 1/30							
Influencing quantity	Meas. Deviation	Distrib. type	Stand. Uncertainty	Sensitivity coeff.	Contrib. To comb. stand. unc.		
Test force F		N	0.002942	1.52957172	0.0045	0.00002025	
Indentation diam d		N	0.0007	3194.131562	2.235892094	4.99921345	
Indent. Ball diam D		N	0.0003	-0.843573894	-0.000253072	6.4046E-08	
Test force appl. Time t_a		N	0.2	0.162655	0.032531	0.00105827	
Test force dur. Time t_d		N	0.2	-0.08997	-0.017994	0.00032378	
Combined standard uncertainty						2.23620567	
Expanded standard uncertainty						4.47	HBW
Calculation of sensitivity coefficients							
F, N	294.2	cF, HBW/N	1.52957172				
D, mm	1	cd, HBW/mm	3194.131562				
d, mm	0.288	cD, HBW/mm	-0.843573894				
H, HBW	450	cta, HBW/s	0.162655				
		ctd, HBW/s	-0.08997				

Uncertainty report for 250HBW2.5/187.5

Hardness scale 250 HBW 2,5/187,5							
Influencing quantity	Meas. Deviation	Distrib. type	Stand. Uncertainty	Sensitivity coeff.	Contrib. To comb. stand. unc.		
Test force F		N	0.0183	0.136612022	0.0025	0.00000625	
Indentation diam d		N	0.0014	543.7456713	0.76124394	0.57949234	
Indent. Ball diam D		N	0.0003	-1.573565826	-0.00047207	2.2285E-07	
Test force appl. Time t_a		N	0.2	0.119195	0.023839	0.0005683	
Test force dur. Time t_d		N	0.2	-0.11905	-0.02381	0.00056692	
Combined standard uncertainty						0.76199345	
Expanded standard uncertainty						1.52	HBW
Calculation of sensitivity coefficients							
F, N	1830	cF, HBW/N	0.136612022				
D, mm	2.5	cd, HBW/mm	543.7456713				
d, mm	0.9575	cD, HBW/mm	-1.573565826				
H, HBW	250	cta, HBW/s	0.119195				
		ctd, HBW/s	-0.11905				

Uncertainty report for 350HBW2.5/187.5

PTB 8/11

Hardness scale 350 HBW 2,5/187,5							
Influencing quantity	Meas. Deviation	Distrib. type	Stand. Uncertainty	Sensitivity coeff.	Contrib. To comb. stand. unc.		
Test force F		N	0.0183	0.191256831	0.0035	0.00001225	
Indentation diam d		N	0.0012	883.7122759	1.060454731	1.12456424	
Indent. Ball diam D		N	0.0003	-1.104924005	-0.000331477	1.0988E-07	
Test force appl. Time t_a		N	0.2	0.140925	0.028185	0.00079439	
Test force dur. Time t_d		N	0.2	-0.10451	-0.020902	0.00043689	
Combined standard uncertainty						1.06104094	
Expanded standard uncertainty						2.12	HBW
Calculation of sensitivity coefficients							
F, N	1830	cF, HBW/N	0.191256831				
D, mm	2.5	cd, HBW/mm	883.7122759				
d, mm	0.815	cD, HBW/mm	-1.104924005				
H, HBW	350	cta, HBW/s	0.140925				
		ctd, HBW/s	-0.10451				

Uncertainty report for 450HBW2.5/187.5

Hardness scale 450 HBW 2,5/187,5							
Influencing quantity	Meas. Deviation	Distrib. type	Stand. Uncertainty	Sensitivity coeff.	Contrib. To comb. stand. unc.		
Test force F		N	0.0183	0.245901639	0.0045	0.00002025	
Indentation diam d		N	0.0011	1277.652625	1.405417887	1.97519944	
Indent. Ball diam D		N	0.0003	-0.843573894	-0.000253072	6.4046E-08	
Test force appl. Time t_a		N	0.2	0.162655	0.032531	0.00105827	
Test force dur. Time t_d		N	0.2	-0.08997	-0.017994	0.00032378	
Combined standard uncertainty						1.40591671	
Expanded standard uncertainty						2.81	HBW
Calculation of sensitivity coefficients							
F, N	1830	cF, HBW/N	0.245901639				
D, mm	2.5	cd, HBW/mm	1277.652625				
d, mm	0.72	cD, HBW/mm	-0.843573894				
H, HBW	450	cta, HBW/s	0.162655				
		ctd, HBW/s	-0.08997				

Uncertainty report for 250HBW5/750

PTB 9/11

Hardness scale 250 HBW 5/750							
Influencing quantity	Meas. Deviation	Distrib. type	Stand. Uncertainty	Sensitivity coeff.	Contrib. To comb. stand. unc.		
Test force F		N	0.07355	0.033990483	0.0025	0.00000625	
Indentation diam d		N	0.0036	271.8728356	0.978742208	0.95793631	
Indent. Ball diam D		N	0.0003	-1.573565826	-0.00047207	2.2285E-07	
Test force appl. Time t_a		N	0.2	0.119195	0.023839	0.0005683	
Test force dur. Time t_d		N	0.2	-0.11905	-0.02381	0.00056692	
Combined standard uncertainty						0.97932528	
Expanded standard uncertainty						1.96	HBW
Calculation of sensitivity coefficients							
F, N	7355	cF, HBW/N	0.033990483				
D, mm	5	cd, HBW/mm	271.8728356				
d, mm	1.915	cD, HBW/mm	-1.573565826				
H, HBW	250	cta, HBW/s	0.119195				
		ctd, HBW/s	-0.11905				

Uncertainty report for 350HBW5/750

Hardness scale 350 HBW 5/750							
Influencing quantity	Meas. Deviation	Distrib. type	Stand. Uncertainty	Sensitivity coeff.	Contrib. To comb. stand. unc.		
Test force F		N	0.07355	0.047586676	0.0035	0.00001225	
Indentation diam d		N	0.0031	441.856138	1.369754028	1.8762261	
Indent. Ball diam D		N	0.0003	-1.104924005	-0.000331477	1.0988E-07	
Test force appl. Time t_a		N	0.2	0.140925	0.028185	0.00079439	
Test force dur. Time t_d		N	0.2	-0.10451	-0.020902	0.00043689	
Combined standard uncertainty						1.37020792	
Expanded standard uncertainty						2.74	HBW
Calculation of sensitivity coefficients							
F, N	7355	cF, HBW/N	0.047586676				
D, mm	5	cd, HBW/mm	441.856138				
d, mm	1.63	cD, HBW/mm	-1.104924005				
H, HBW	350	cta, HBW/s	0.140925				
		ctd, HBW/s	-0.10451				

Uncertainty report for 450HBW5/750

PTB 10/11

Hardness scale 450 HBW 5/750							
Influencing quantity	Meas. Deviation	Distrib. type	Stand. Uncertainty	Sensitivity coeff.	Contrib. To comb. stand. unc.		
Test force F		N	0.07355	0.061182869	0.0045	0.00002025	
Indentation diam d		N	0.0028	638.8263124	1.788713675	3.19949661	
Indent. Ball diam D		N	0.0003	-0.843573894	-0.000253072	6.4046E-08	
Test force appl. Time t_a		N	0.2	0.162655	0.032531	0.00105827	
Test force dur. Time t_d		N	0.2	-0.08997	-0.017994	0.00032378	
Combined standard uncertainty						1.78910564	
Expanded standard uncertainty						3.58	HBW
Calculation of sensitivity coefficients							
F, N	7355	cF, HBW/N	0.061182869				
D, mm	5	cd, HBW/mm	638.8263124				
d, mm	1.44	cD, HBW/mm	-0.843573894				
H, HBW	450	cta	0.162655				
		ctd	-0.08997				

Uncertainty report for 250HBW10/3000

Scale: 250 HBW10/3000							
Influencing quantity	Meas. Deviation	Distrib. type	Stand. Uncertainty	Sensitivity coeff.	Contrib. To comb. stand. unc.		
Test force F		N	0.2941995	0.008497635	0.0025	0.00000625	
Indentation diam d		N	0.0055	135.9364178	0.747650298	0.55898097	
Indent. Ball diam D		N	0.0003	-1.573565826	-0.00047207	2.2285E-07	
Test force appl. Time t_a		N	0.2	0.119195	0.023839	0.0005683	
Test force dur. Time t_d		N	0.2	-0.11905	-0.02381	0.00056692	
Combined standard uncertainty						0.74841343	
Expanded standard uncertainty						1.50	HBW
Calculation of sensitivity coefficients							
F, N	29419.95	cF, HBW/N	0.008497635				
D, mm	10	cd, HBW/mm	135.9364178				
d, mm	3.83	cD, HBW/mm	-1.573565826				
H, HBW	250	cta, HBW/s	0.119195				
		ctd, HBW/s	-0.11905				

Uncertainty report for 350HBW10/3000

PTB 11/11

Scale: 350 HBW10/3000							
Influencing quantity	Meas. Deviation	Distrib. type	Stand. Uncertainty	Sensitivity coeff.	Contrib. To comb. stand. unc.		
Test force F		N	0.2941995	0.011896689	0.0035	0.00001225	
Indentation diam d		N	0.0048	220.928069	1.060454731	1.12456424	
Indent. Ball diam D		N	0.0003	-1.104924005	-0.000331477	1.0988E-07	
Test force appl. Time t_a		N	0.2	0.140925	0.028185	0.00079439	
Test force dur. Time t_d		N	0.2	-0.10451	-0.020902	0.00043689	
Combined standard uncertainty						1.06104094	
Expanded standard uncertainty						2.12	HBW
Calculation of sensitivity coefficients							
F, N	29419.95	cF, HBW/N	0.011896689				
D, mm	10	cd, HBW/mm	220.928069				
d, mm	3.26	cD, HBW/mm	-1.104924005				
H, HBW	350	cta, HBW/s	0.140925				
		ctd, HBW/s	-0.10451				

Uncertainty report for 450HBW10/3000

Hardness scale 450 HBW 10/3000							
Influencing quantity	Meas. Deviation	Distrib. type	Stand. Uncertainty	Sensitivity coeff.	Contrib. To comb. stand. unc.		
Test force F		N	0.2941995	0.015295743	0.0045	0.00002025	
Indentation diam d		N	0.0042	319.4131562	1.341535256	1.79971684	
Indent. Ball diam D		N	0.0003	-0.843573894	-0.000253072	6.4046E-08	
Test force appl. Time t_a		N	0.2	0.162655	0.032531	0.00105827	
Test force dur. Time t_d		N	0.2	-0.08997	-0.017994	0.00032378	
Combined standard uncertainty						1.34205783	
Expanded standard uncertainty						2.68	HBW
Calculation of sensitivity coefficients							
F, N	29419.95	cF, HBW/N	0.015295743				
D, mm	10	cd, HBW/mm	319.4131562				
d, mm	2.88	cD, HBW/mm	-0.843573894				
H, HBW	450	cta, HBW/s	0.162655				
		ctd, HBW/s	-0.08997				

End –PTB–

Results and uncertainty report –VNIIFTRI– **VNIIFTRI 1/10**

Measurement results

Results for Reference and False indentations

Measurement result of measuremet of the length of Reference indents

reference Block	Hardness (HBW)	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Temp (°C)
250	1/30	0,385	0,386	0,385	0,384	0,384	0,385	0,385	0,384	0,385	21,2
	2,5/187,5	0,947	0,948	0,946	0,948	0,945	0,948	0,147	0,947	0,947	22,3
	5/750	1,918	1,920	1,920	1,916	1,917	1,920	1,919	1,918	1,919	21,8
350	1/30	0,322	0,323	0,323	0,322	0,322	0,322	0,323	0,322	0,322	21,2
	2,5/187,5	0,810	0,815	0,813	0,812	0,812	0,810	0,813	0,811	0,812	22,3
	5/750	1,609	1,608	1,608	1,606	1,609	1,605	1,608	1,607	1,607	21,8
	10/3000	3,206	3,210	3,207	3,208	3,211	3,208	3,208	3,209	3,209	21,8
450	1/30	-	-	-	-	-	-	-	-	-	-
	2,5/187,5	0,721	0,722	0,722	0,722	0,723	0,722	0,722	0,722	0,722	22,3
	5/750	1,440	1,440	1,439	1,438	1,440	1,440	1,440	1,440	1,440	22,3
	10/3000	2,868	2,865	2,866	2,867	2,866	2,868	2,868	2,867	2,867	21,8

Measurement result of measuremet of the length of “False indentations“

Nominal diameter	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Temp (°C)
0,240	0,243	0,240	0,241	0,240	0,240	0,243	0,241	0,241	0,241	21,2
0,400	0,402	0,400	0,398	0,401	0,401	0,400	0,400	0,401	0,400	21,2
0,800	0,800	0,802	0,802	0,800	0,800	0,802	0,801	0,801	0,801	21,2
1,500	1,499	1,500	1,500	1,499	1,499	1,499	1,500	1,499	1,499	21,2

Results for 250HBW1/30, 250HBW2.5/187.5 and 250HBW5/750

VNIIFTRI 2/10

Specimen
250 HBW

Block ID.	93241

Test identifiler	Hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
C7	1/30	1	0,386	0,386	0,387	0,387	0,386	0,386	0,386	0,386	0,386	246,49	21,2
E4		2	0,386	0,384	0,385	0,385	0,384	0,385	0,385	0,385	0,385	247,83	21,2
G6		3	0,383	0,383	0,383	0,385	0,384	0,384	0,383	0,384	0,384	249,18	21,2
G10		4	0,386	0,385	0,384	0,385	0,385	0,385	0,385	0,385	0,385	247,83	21,2
J4		5	0,384	0,385	0,385	0,384	0,384	0,386	0,385	0,385	0,385	247,83	21,2

Block ID.	93243

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
C7	2,5/187,5	1	0,953	0,952	0,953	0,952	0,953	0,952	0,953	0,952	0,953	253,04	22,3
E4		2	0,952	0,953	0,952	0,954	0,953	0,953	0,952	0,953	0,953	253,04	22,3
G6		3	0,953	0,954	0,953	0,953	0,954	0,954	0,952	0,953	0,954	252,49	22,3
G10		4	0,953	0,954	0,953	0,952	0,954	0,954	0,953	0,953	0,953	253,04	22,3
J4		5	0,950	0,950	0,950	0,950	0,949	0,950	0,950	0,950	0,950	254,70	22,3

Block ID.	93242

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
C7	5/750	1	1920	1920	1918	1916	1916	1918	1919	1917	1918	249,72	21,8
E4		2	1913	1915	1916	1915	1917	1917	1915	1916	1916	250,26	21,8
G6		3	1920	1916	1916	1914	1918	1916	1917	1916	1917	249,99	21,8
G10		4	1920	1917	1918	1916	1918	1918	1918	1917	1918	249,72	21,8
J4		5	1917	1914	1915	1915	1917	1917	1915	1916	1916	250,26	21,8

Results for 350HBW1/30, 350HBW2.5/187.5, 350HBW5/750 and 350HBW10/3000

VNIIFTRI 3/10

Specimen
350 HBW

Block ID.	94041

Test identifiler	Hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
C7	1/30	1	0,323	0,324	0,323	0,324	0,324	0,323	0,323	0,324	0,323	356,41	21,2
E4		2	0,321	0,323	0,321	0,321	0,323	0,321	0,322	0,322	0,322	358,69	21,2
G6		3	0,321	0,321	0,321	0,322	0,323	0,321	0,321	0,322	0,322	358,69	21,2
G10		4	0,321	0,323	0,323	0,321	0,322	0,323	0,322	0,322	0,322	358,69	21,2
J4		5	0,321	0,323	0,321	0,321	0,322	0,321	0,322	0,321	0,321	360,99	21,2

Block ID.	94043

Test identifiler	Hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
C7	2,5/187,5	1	0,818	0,818	0,819	0,818	0,817	0,819	0,818	0,818	0,818	347,11	22,3
E4		2	0,819	0,819	0,820	0,819	0,819	0,820	0,819	0,819	0,819	346,24	22,3
G6		3	0,817	0,817	0,815	0,815	0,815	0,818	0,816	0,816	0,816	348,86	22,3
G10		4	0,813	0,816	0,815	0,815	0,815	0,817	0,815	0,816	0,816	348,86	22,3
J4		5	0,813	0,813	0,815	0,814	0,816	0,815	0,814	0,815	0,815	349,74	22,3

Block ID.	94042

Test identifiler	Hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
C7	5/750	1	1606	1603	1606	1605	1605	1603	1605	1605	1605	360,99	21,8
E4		2	1605	1606	1606	1608	1609	1609	1606	1609	1607	360,07	21,8
G6		3	1605	1602	1608	1608	1605	1604	1605	1606	1606	360,53	21,8
G10		4	1609	1608	1608	1608	1608	1605	1608	1607	1607	360,07	21,8
J4		5	1606	1605	1608	1604	1608	1603	1607	1605	1606	360,53	21,8

Block ID.	94037

Test identifiler	Hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
B3	10/3000	1	3224	3223	3226	3224	3224	3225	3224	3224	3224	357,77	21,8
B5		2	3225	3222	3227	3226	3226	3225	3225	3226	3225	357,55	21,8
D4		3	3216	3219	3220	3218	3216	3213	3218	3216	3217	359,38	21,8
E1		4	3216	3214	3215	3217	3216	3218	3215	3217	3216	359,61	21,8
F3		5	3215	3216	3215	3215	3218	3218	3215	3217	3216	359,61	21,8

Results for 450HBW2.5/187.5, 450HBW5/750 and 450HBW10/3000

VNIIFTRI 4/10

Specimen
450 HBW

Block ID.	95011

Test identifiler	Hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
C7	2,5/187,5	1	0,724	0,725	0,722	0,724	0,725	0,724	0,724	0,724	0,724	445,87	22,3
E4		2	0,724	0,724	0,723	0,723	0,723	0,724	0,724	0,723	0,723	447,13	22,3
G6		3	0,724	0,723	0,724	0,724	0,723	0,725	0,724	0,724	0,724	445,87	22,3
G10		4	0,725	0,722	0,723	0,723	0,722	0,723	0,723	0,723	0,723	447,13	22,3
J4		5	0,723	0,722	0,721	0,723	0,721	0,721	0,722	0,722	0,722	448,40	22,3

Block ID.	95010

Test identifiler	Hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
C7	5/750	1	1440	1440	1442	1440	1438	1438	1441	1439	1440	450,88	21,8
E4		2	1443	1442	1441	1441	1439	1441	1442	1440	1441	450,25	21,8
G6		3	1443	1441	1440	1437	1442	1439	1441	1439	1440	450,88	21,8
G10		4	1439	1443	1441	1438	1440	1440	1441	1439	1440	450,88	21,8
J4		5	1437	1438	1439	1439	1438	1438	1438	1438	1438	452,17	21,8

Block ID.	95004

Test identifiler	Hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
B3	10/3000	1	2868	2870	2870	2870	2866	2874	2869	2870	2869	454,42	21,8
B5		2	2864	2867	2864	2869	2867	2865	2865	2867	2866	455,40	21,8
D4		3	2864	2864	2866	2861	2869	2866	2865	2865	2865	455,72	21,8
E1		4	2866	2869	2869	2869	2871	2872	2868	2871	2869	454,42	21,8
F3		5	2869	2867	2867	2870	2866	2866	2868	2867	2868	454,75	21,8

***Not participated for 450HBW1/30**

Uncertainty report –VNIIFTRI– **VNIIFTRI 5/10**

Brief description of the measurement system

Partner Number
VNIIFTRI

Test Details

Instrumen t

Instrument type	Identifier
Direct loading	
1/30	TPO-2, Plant „Etalon“, S.Peterburg
2,5/187,5 5/750 10/3000	BRINELL

Measuring device

Device type	Identifier
1/30	Microscope with nominal division of scale equal to 0,8 mkm (production of the plant „LOMO“, S.-Peterburg)
2,5/187,5 5/750 10/3000	Microscope with nominal division of scale equal to 1,0 mkm BMI –1C (production of the plant „NLZ“, Novosibirsk)

Uncertainty of the instruments

Hardness scale	uF (N)	uL (mm)	Dia. of Indenter (mm)
1/30	0,03	0,0008	100,015
2,5/187,5	0,18	0,001	250,090
5/750	0,74	0,001	500,125
10/3000	2,94	0,001	1,000,021

Comments: The measurements results and the uncertainty evaluation at the level 450 HBW 1/30 are not given.

Uncertainty report for 250HBW1/30

VNIIFTRI 6/10

250 HBW 1/30

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	294,2	N		Normal	2,9 E-05	N	0,2	HBW/N	5,8 E-05	A
2	Length measuring device	Length measuring device	0,385	mm		Normal	8,0 E-04	mm	1,329 E+03	HBW/mm	1,06 E-01	A
3		Repeatability of readings		mm		Normal	3,3 E-04	mm	1,329 E+03	HBW/mm	4,39 E-01	B
4	Indenter geometry	Diameter of the ball	1,0	mm		Rectangle	1,5 E-04	mm	20,1	HBW/mm	3,0 E-03	A
5	Testing cycle	Force application time	8	sec	0,5	Rectangle	0,3	sec	1,18 E-01	HBW/sec	3,55 E-02	B
6		Test force duration	15	sec	0,5	Rectangle	0,3	sec	-1,12 E-01	HBW/sec	3,57 E-02	B
combined standard uncertainty, u [HBW]											1,51	
expanded combined standard uncertainty, U [HBW] (k=2)											3,02	

Uncertainty report for 250HBW2.5/187.5

250 HBW 2,5/187,5

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	1839,0	N		Normal	1,84 E-01	N	0,2	HBW/N	3,68 E-02	A
2	Length measuring device	Length measuring device	0,953	mm		Normal	1,0 E-03	mm	5,52 E+02	HBW/mm	5,52 E-01	A
3		Repeatability of readings		mm		Normal	0,307	mm	5,52 E+02	HBW/mm	1,69 E-01	B
4	Indenter geometry	Diameter of the ball	2,5	mm	1,0 E-03	Rectangle	9,0 E-04	mm	8,27	HBW/mm	7,44 E-03	A
5	Testing cycle	Force application time	8	sec	0,5	Rectangle	0,3	sec	1,19 E-01	HBW/sec	3,6 E-02	B
6		Test force duration	15	sec	0,5	Rectangle	0,2	sec	-1,19 E-01	HBW/sec	2,38 E-02	B
combined standard uncertainty, u [HBW]											0,735	
expanded combined standard uncertainty, U [HBW] (k=2)											1,47	

Uncertainty report for 250HBW5/750

VNIIFTRI 7/10

250 HBW 5/750

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	7355,0	N		Normal	0,74	N	0,2	HBW/N	1,48 E-01	A
2	Length measuring device	Length measuring device	1,92	mm		Normal	1,0 E-03	mm	2,7 E+02	HBW/mm	2,6 E-01	A
3		Repeatability of readings	0	mm		Normal	7,9 E-04	mm	2,7 E+02	HBW/mm	2,13 E-01	B
4	Indenter geometry	Diameter of the ball	5,0	mm	2,0 E-03	Rectangle	1,25 E-03	mm	4,12	HBW/mm	5,15 E-03	A
5	Testing cycle	Force application time	8	sec	0,5	Rectangle	0,3	sec	0,12	HBW/sec	3,5 E-02	B
6		Test force duration	15	sec	0,5	Rectangle	0,2	sec	-0,12	HBW/sec	2,4 E-02	B
combined standard uncertainty, u [HBW]											0,70	
expanded combined standard uncertainty, U [HBW] (k=2)											1,40	

Uncertainty report for 350HBW1/30

350 HBW 1/30

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	294,2	N		Normal	3,0 E-02	N	0,2	HBW/N	6,0 E-03	A
2	Length measuring device	Length measuring device	0,322	mm		Normal	8,0 E-04	mm	2,28 E+03	HBW/mm	1,8	A
3		Repeatability of readings		mm		Normal	4,2 E-04	mm	2,28 E+03	HBW/mm	9,58 E-01	B
4	Indenter geometry	Diameter of the ball	1,0	mm	1,0 E-03	Rectangle	9,0 E-04	mm	2,0 E+01	HBW/mm	1,8 E-02	A
5	Testing cycle	Force application time	8	sec		Rectangle	0,3	sec	1,4 E-01	HBW/sec	4,2 E-02	B
6		Test force duration	15	sec		Rectangle	0,3	sec	-1,0 E-01	HBW/sec	3,0 E-02	B
combined standard uncertainty, u [HBW]											2,85	
expanded combined standard uncertainty, U [HBW] (k=2)											5,7	

Uncertainty report for 350HBW2.5/187.5

VNIIFTRI 8/10

350 HBW 2,5/187,5

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	1839,0	N		Normal	1,84 E-01	N	0,2	HBW/N	3,68 E-02	A
2	Length measuring device	Length measuring device	0,817	mm		Normal	1,0 E-03	mm	8,75 E+02	HBW/mm	8,75 E-01	A
3		Repeatability of readings		mm		Normal	5,4 E-04	mm	8,75 E+02	HBW/mm	4,7 E-01	B
4	Indenter geometry	Diameter of the ball	2,5	mm	1,0 E-03	Rectangle	9,0 E-04	mm	8,03	HBW/mm	7,2 E-03	A
5	Testing cycle	Force application time	8	sec	0,5	Rectangle	0,3	sec	0,14	HBW/sec	4,2 E-02	B
6		Test force duration	15	sec	0,5	Rectangle	0,2	sec	-0,10	HBW/sec	2,1 E-02	B
combined standard uncertainty, u [HBW]											1,45	
expanded combined standard uncertainty, U [HBW] (k=2)											2,9	

Uncertainty report for 350HBW5/750

350 HBW 5/750

	source of uncertainty		Estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	7355,0	N		Normal	0,74	N	0,2	HBW/N	1,48 E-01	A
2	Length measuring device	Length measuring device	1,606	mm		Normal	1,0 E-03	mm	4,61 E+02	HBW/mm	4,61 E-01	A
3		Repeatability of readings	0	mm		Normal	1,07 E-03	mm	4,61 E+02	HBW/mm	4,93 E-01	B
4	Indenter geometry	Diameter of the ball	5,0	mm	2,0 E-03	Rectangle	1,25 E-03	mm	4,09	HBW/mm	5,11 E-03	A
5	Testing cycle	Force application time	8	sec	0,5	Rectangle	0,3	sec	0,14	HBW/sec	4,3 E-02	B
6		Test force duration	15	sec	0,5	Rectangle	0,2	sec	-0,10	HBW/sec	2,1 E-02	B
combined standard uncertainty, u [HBW]											1,16	
expanded combined standard uncertainty, U [HBW] (k=2)											2,32	

Uncertainty report for 350HBW10/3000

VNIIFTRI 9/10

350 HBW 10/3000

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	2942,0	N		Normal	2,942	N	0,2	HBW/N	5,88 E-01	A
2	Length measuring device	Length measuring device	3,220	mm		Normal	1,0 E-03	mm	2,29 E+02	HBW/mm	2,29 E-01	A
3		Repeatability of readings		mm		Normal	1,09 E-03	mm	2,29 E+02	HBW/mm	2,50 E-01	B
4	Indenter geometry	Diameter of the ball	10,0	mm	3,0 E-03	Rectangle	2,1 E-04	mm	2,02	HBW/mm	4,0 E-04	A
5	Testing cycle	Force application time	8	sec	0,5	Rectangle	0,3	sec	1,43 E-01	HBW/sec	4,29 E-02	B
6		Test force duration	15	sec	0,5	Rectangle	0,2	sec	-1,03 E-01	HBW/sec	2,06 E-02	B
combined standard uncertainty, u [HBW]											1,10	
expanded combined standard uncertainty, U [HBW] (k=2)											2,20	

Uncertainty report for 450HBW2.5/187.5

450 HBW 2,5/187,5

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	1839,0	N		Normal	1,84 E-01	N	0,2	HBW/N	3,68 E-02	A
2	Length measuring device	Length measuring device	0,723	mm		Normal	1,0 E-03	mm	1,26 E+03	HBW/mm	1,26	A
3		Repeatability of readings		mm		Normal	4,4 E-04	mm	1,26 E+03	HBW/mm	5,54 E-01	B
4	Indenter geometry	Diameter of the ball	2,5	mm	1,0 E-03	Rectangle	9,0 E-04	mm	7,97	HBW/mm	7,2 E-03	A
5	Testing cycle	Force application time	8	sec	0,5	Rectangle	0,3	sec	0,16	HBW/sec	4,8 E-02	B
6		Test force duration	15	sec	0,5	Rectangle	0,2	sec	-0,09	HBW/sec	1,8 E-02	B
combined standard uncertainty, u [HBW]											1,92	
expanded combined standard uncertainty, U [HBW] (k=2)											3,84	

Uncertainty report for 450HBW5/750

VNIIFTRI 10/10

450 HBW 5/750

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	7355,0	N		Normal	0,74	N	0,2	HBW/N	1,48 E-02	A
2	Length measuring device	Length measuring device	1,440	mm		Normal	1,0 E-03	mm	6,39 E+02	HBW/mm	6,39 E-01	A
3		Repeatability of readings	0	mm		Normal	0,93	mm	6,39 E+02	HBW/mm	5,94 E-01	B
4	Indenter geometry	Diameter of the ball	5,0	mm	2,0 E-03	Rectangle	1,25 E-03	mm	3,97	HBW/mm	4,9 E-03	A
5	Testing cycle	Force application time	8	sec	0,5	Rectangle	0,3	sec	0,16	HBW/sec	4,8 E-02	B
6		Test force duration	15	sec	0,5	Rectangle	0,2	sec	-0,09	HBW/sec	1,8 E-02	B
combined standard uncertainty, u [HBW]											1,45	
expanded combined standard uncertainty, U [HBW] (k=2)											2,90	

Uncertainty report for 450HBW10/3000

450 HBW 10/3000

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	2942,0	N		Normal	2,942	N	0,2	HBW/N	5,88 E-01	A
2	Length measuring device	Length measuring device	2,867	mm		Normal	1,0 E-03	mm	3,24 E+02	HBW/mm	3,24 E-01	A
3		Repeatability of readings		mm		Normal	1,18 E-03	mm	3,24 E+02	HBW/mm	3,82 E-01	B
4	Indenter geometry	Diameter of the ball	10,0	mm	3,0 E-03	Rectangle	2,1 E-04	mm	1,89	HBW/mm	3,97 E-04	A
5	Testing cycle	Force application time	8	sec	0,5	Rectangle	0,3	sec	1,6 E-01	HBW/sec	4,9 E-02	B
6		Test force duration	15	sec	0,5	Rectangle	0,2	sec	-8,0 E-02	HBW/sec	1,6 E-02	B
combined standard uncertainty, u [HBW]											1,36	
expanded combined standard uncertainty, U [HBW] (k=2)											2,72	

End –VNIIFTRI–

Results and uncertainty report –NMIJ– **NMIJ 1/11**

Measurement results

Results for Reference and False indentations

Measurement result of measuremet of the length of Reference indents

reference Block	Hardness (HBW)	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Temp (ºC)
250	1.0/30	0.38180	0.38160	0.38166	0.38146	0.38146	0.38145	0.38157	0.38145	0.38157	22.8
	2.5/187.5	0.94370	0.94354	0.94344	0.94330	0.94338	0.94320	0.94343	0.94329	0.94343	21.6
	5/750	1.91417	1.91438	1.91431	1.91321	1.91301	1.91315	1.91371	1.91312	1.91371	21.5
350	1.0/30	0.32101	0.32117	0.32118	0.32044	0.32024	0.32000	0.32067	0.32023	0.32067	21.7
	2.5/187.5	0.80701	0.80721	0.80671	0.80661	0.80698	0.80690	0.80690	0.80683	0.80690	21.4
	5/750	1.60320	1.60258	1.60335	1.60198	1.60247	1.60238	1.60266	1.60228	1.60266	21.3
	10/3000	3.20289	3.20370	3.20305	3.20524	3.20574	3.20521	3.20372	3.20540	3.20431	21.2
450	1.0/30	0.28861	0.28796	0.28811	0.28790	0.28874	0.28864	0.28833	0.28843	0.28833	22.4
	2.5/187.5	0.71757	0.71794	0.71786	0.71895	0.71795	0.71877	0.71817	0.71856	0.71817	21.3
	5/750	1.43592	1.43477	1.43493	1.43544	1.43377	1.43445	1.43521	1.43455	1.43488	21.1
	10/3000	2.86219	2.86301	2.86182	2.86095	2.86333	2.86312	2.86240	2.86247	2.86240	21.2

Measurement result of measuremet of the length of "False Indentation"

Nominal Diameter	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Temp (ºC)
1.5	1.49941	1.49942	1.49927	1.49808	1.49834	1.49793	1.4994	1.4981	1.4987	20.8
0.8	0.79964	0.79983	0.79944	0.79912	0.79912	0.79936	0.7996	0.7992	0.7994	20.8
0.4	0.39933	0.39943	0.39977	0.39947	0.39947	0.39931	0.3995	0.3994	0.3995	20.8
0.24	0.24016	0.24032	0.24048	0.23968	0.24013	0.24013	0.2403	0.2400	0.2402	20.8

Results for 250HBW1/30, 250HBW2.5/187.5 and 250HBW5/750

NMIJ 2/11

Specimen
250 HBW

Block ID.	93241

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
c6	1.0/30	1	0.38194	0.38188	0.38204	0.38215	0.38201	0.38232	0.38200	0.38216	0.38206	251.76	22.8
f2		2	0.38084	0.38115	0.38146	0.38079	0.38075	0.38113	0.38115	0.38089	0.38102	253.19	
f5		3	0.38095	0.38147	0.38110	0.38063	0.38058	0.38077	0.38117	0.38066	0.38092	253.33	
g8		4	0.38094	0.38077	0.38079	0.38079	0.38058	0.38088	0.38083	0.38075	0.38079	253.50	
i5		5	0.38012	0.38012	0.38010	0.37978	0.38009	0.37977	0.38011	0.37988	0.38000	254.61	

Block ID.	93243

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
c6	2.5/187.5	1	0.94924	0.94927	0.94910	0.94910	0.94908	0.94843	0.94920	0.94887	0.94904	255.14	21.6
f2		2	0.94338	0.94330	0.94327	0.94310	0.94279	0.94309	0.94332	0.94299	0.94316	258.46	
f5		3	0.94236	0.94203	0.94230	0.94310	0.94358	0.94308	0.94223	0.94325	0.94274	258.70	
g8		4	0.94418	0.94426	0.94368	0.94405	0.94413	0.94410	0.94404	0.94409	0.94407	257.94	
i5		5	0.93982	0.93947	0.94002	0.93980	0.94020	0.93988	0.93977	0.93996	0.93987	260.35	

Block ID.	93242

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
c6	5/750	1	1.92590	1.92629	1.92623	1.92541	1.92476	1.92498	1.92614	1.92505	1.92560	247.61	21.5
f2		2	1.91959	1.92040	1.91974	1.92072	1.92017	1.92101	1.91991	1.92063	1.92027	249.04	
f5		3	1.91549	1.91504	1.91573	1.91605	1.91581	1.91554	1.91542	1.91580	1.91561	250.30	
g8		4	1.90880	1.90820	1.90862	1.90733	1.90796	1.90830	1.90854	1.90786	1.90820	252.33	
i5		5	1.90749	1.90749	1.90733	1.90663	1.90597	1.90612	1.90744	1.90624	1.90684	252.71	

Results for 350HBW1/30, 350HBW2.5/187.5, 350HBW5/750 and 350HBW10/3000

NMIJ 3/11

Specimen
350 HBW

Block ID.	94041

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
c6	1.0/30	1	0.32201	0.32198	0.32184	0.32217	0.322	0.32175	0.32194	0.32197	0.32196	358.68	21.7
f2		2	0.32064	0.32135	0.321	0.32052	0.32024	0.32038	0.32100	0.32038	0.32069	361.61	
f5		3	0.32135	0.32149	0.32169	0.3222	0.32182	0.32187	0.32151	0.32196	0.32174	359.19	
g8		4	0.32117	0.32087	0.32098	0.32117	0.32064	0.32133	0.32101	0.32105	0.32103	360.83	
i5		5	0.31964	0.31932	0.31935	0.3195	0.31917	0.31914	0.31944	0.31927	0.31935	364.73	

Block ID.	94043

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
c6	2.5/187.5	1	0.80832	0.80845	0.80848	0.809	0.80877	0.80892	0.80842	0.80890	0.80866	355.26	21.4
f2		2	0.80711	0.80652	0.8073	0.80667	0.80614	0.80713	0.80698	0.80665	0.80681	356.94	
f5		3	0.80473	0.80508	0.80473	0.80565	0.80615	0.80561	0.80485	0.80580	0.80533	358.29	
g8		4	0.80582	0.80467	0.80523	0.80543	0.80561	0.80571	0.80524	0.80558	0.80541	358.21	
i5		5	0.80346	0.8036	0.80362	0.80402	0.80448	0.80373	0.80356	0.80408	0.80382	359.67	

Block ID.	94042

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
c6	5/750	1	1.60774	1.60794	1.60735	1.60723	1.60685	1.60774	1.60768	1.60727	1.60748	359.75	21.3
f2		2	1.60531	1.60594	1.60569	1.60622	1.60585	1.60607	1.60565	1.60605	1.60585	360.50	
f5		3	1.60488	1.60453	1.60448	1.60453	1.60511	1.60422	1.60463	1.60462	1.60463	361.06	
g8		4	1.60033	1.6003	1.59984	1.60138	1.60065	1.601	1.60016	1.60101	1.60058	362.94	
i5		5	1.59913	1.59867	1.59864	1.59905	1.59816	1.59848	1.59881	1.59856	1.59869	363.83	

Block ID.	94037

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
a3	10/3000	1	3.21986	3.21981	3.21959	3.21784	3.21768	3.21752	3.21975	3.21768	3.21872	358.88	21.2
b6		2	3.21416	3.21414	3.21447	3.21534	3.21534	3.2158	3.21426	3.21549	3.21488	359.77	
c1		3	3.2097	3.20974	3.2098	3.20826	3.20802	3.20865	3.20975	3.20831	3.20903	361.11	
c4		4	3.21077	3.21032	3.21047	3.21029	3.2114	3.21121	3.21052	3.21097	3.21074	360.72	
e4		5	3.1992	3.19855	3.1988	3.19835	3.19858	3.19822	3.19885	3.19838	3.19862	363.54	

Results for 450HBW1/30, 450HBW2.5/187.5, 450HBW5/750 and 450HBW10/3000

NMIJ 4/11

Specimen
450 HBW

Block ID.	95008

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
C6	1.0/30	1	0.28861	0.28877	0.28866	0.28885	0.28819	0.28809	0.28868	0.28838	0.28853	449.08	22.4
f2		2	0.28762	0.28777	0.28806	0.28808	0.28809	0.28839	0.28782	0.28819	0.28800	450.76	
f5		3	0.28908	0.28898	0.28854	0.28836	0.28809	0.28842	0.28887	0.28829	0.28858	448.92	
g8		4	0.28664	0.28691	0.2869	0.28724	0.28726	0.28756	0.28682	0.28735	0.28709	453.70	
i5		5	0.28882	0.28793	0.28911	0.2879	0.28807	0.28822	0.28862	0.28806	0.28834	449.67	

Block ID.	95011

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
c6	2.5/187.5	1	0.71846	0.71898	0.7183	0.71865	0.71852	0.71921	0.71858	0.71879	0.71869	452.45	21.3
f2		2	0.71825	0.71759	0.71806	0.71845	0.71776	0.71797	0.71797	0.71806	0.71801	453.31	
f5		3	0.71822	0.7181	0.71798	0.71825	0.71757	0.71805	0.71810	0.71796	0.71803	453.30	
g8		4	0.7171	0.71798	0.71778	0.71819	0.71747	0.71777	0.71762	0.71781	0.71772	453.70	
i5		5	0.71775	0.71744	0.71809	0.71688	0.71762	0.71743	0.71776	0.71731	0.71754	453.93	

Block ID.	95010

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
c6	5/750	1	1.43504	1.43577	1.43577	1.43584	1.4358	1.43613	1.43553	1.43592	1.43573	453.51	21.1
f2		2	1.43343	1.43214	1.43254	1.43361	1.43359	1.43374	1.43270	1.43365	1.43318	455.16	
f5		3	1.43484	1.43395	1.43345	1.4351	1.43478	1.43514	1.43408	1.43501	1.43454	454.27	
g8		4	1.4321	1.43293	1.43224	1.43361	1.43394	1.4341	1.43242	1.43388	1.43315	455.17	
i5		5	1.43125	1.43121	1.43094	1.43322	1.43211	1.43261	1.43113	1.43265	1.43189	456.00	

Block ID.	95004

Test identifiler	hardness scale	No. of test	dh1 (mm)	dh2 (mm)	dh3 (mm)	dv1 (mm)	dv2 (mm)	dv3 (mm)	dh mean (mm)	dv mean (mm)	d (mm)	Hardness (HBW)	Temp (ºC)
a3	30/3000	1	2.86512	2.86538	2.86553	2.86097	2.86083	2.8616	2.86534	2.86113	2.86324	456.17	21.2
b6		2	2.86182	2.86181	2.86194	2.86395	2.86506	2.86336	2.86186	2.86412	2.86299	456.25	
c1		3	2.86744	2.86685	2.86664	2.86631	2.86604	2.86533	2.86698	2.86589	2.86644	455.13	
c4		4	2.86586	2.86685	2.86672	2.86585	2.86585	2.86675	2.86648	2.86615	2.86631	455.17	
e4		5	2.86248	2.86267	2.86366	2.8621	2.86184	2.86227	2.86294	2.86207	2.86250	456.41	

Uncertainty report –NMIJ– **NMIJ 5/11**

Brief description of the measurement system

Name of Institute
NMIJ

Test Details

Instrument

Instrument type	Identifier
lever amplified dead weight	Akashi SHT-5/ NO. 20002

Measuring device

Device type	Identifier
Mitutoyo MF with interferometer stage	Mitutoyo M Plan Apo x100 N.A.0.55

Uncertainty of the instruments

Hardness scale	uF (N)	uL (mm)	Dia. of Indenter (mm)
1.0/30	7.58E-02	2.67E-04	2.89E-04
2.5/187.5	6.04E-01	2.67E-04	2.89E-04
5.0/750	9.98E-01	2.67E-04	2.89E-04
10/3000	1.93E+00	2.67E-04	2.89E-04

Comment

Summary of uncertainty tables

Summary: measurement uncertainty [HBW]

Hardness levels	Hardness scales	std. uncertainty without nonumiformity of blocks	uncertanity of non-unifomity of blocks	combined std. uncertainty	exp. Uncertainty
250HBW	1/30	1.106	0.457	1.197	2.393
	2.5/187.5	0.599	0.849	1.039	2.078
	5/750	0.376	0.968	1.039	2.077
350HBW	1/30	1.561	1.070	1.893	3.786
	2.5/187.5	0.906	0.743	1.172	2.344
	5/750	0.525	0.764	0.927	1.854
	10/3000	0.655	0.786	1.023	2.047
450HBW	1/30	2.043	0.881	2.225	4.450
	2.5/187.5	1.454	0.253	1.476	2.953
	5/750	0.673	0.427	0.797	1.595
	10/3000	0.836	0.279	0.882	1.763

Uncertainty report for 250HBW1/30

NMIJ 6/11

250HBW1/30

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H),	type
	division	subdivision										
1	Force	-	294.2	N	-	Normal	7.575E-02	N	8.50E-01	HBW/N	6.44E-02	A
2	Length measuring device	Length measuring device	0.383	mm	-	Normal	2.675E-04	mm	-1.36E+03	HBW/mm	3.63E-01	A
3		Repeatability of readings	0	mm	-	Normal	7.668E-04	mm	-1.36E+03	HBW/mm	1.04E+00	B
4	Indenter geometry	Diameter of the ball	1	mm	1.00E-03	Rectangle	2.887E-04	mm	2.07E+01	HBW/mm	5.97E-03	A
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	2.887E-01	sec	1.19E-01	HBW/sec	3.44E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	2.887E-01	sec	-1.19E-01	HBW/sec	3.44E-02	B
7	Uniformity of Blocks	-	253.3	HBW	-	Normal	4.570E-01	HBW	1.00E+00	-	4.57E-01	A
combined standard uncertainty, u [HBW]											1.197	
expanded combined standard uncertainty, U [HBW] (k=2)											2.39	

Uncertainty report for 250HBW2.5/187.5

250HBW2.5/187.5

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H),	type
	division	subdivision										
1	Force	-	1839	N	-	Normal	6.036E-01	N	1.36E-01	HBW/N	8.20E-02	A
2	Length measuring device	Length measuring device	0.959	mm	-	Normal	2.675E-04	mm	-5.43E+02	HBW/mm	1.45E-01	A
3		Repeatability of readings	0	mm	-	Normal	1.054E-03	mm	-5.43E+02	HBW/mm	5.73E-01	B
4	Indenter geometry	Diameter of the ball	2.5	mm	1.00E-04	Rectangle	2.887E-05	mm	8.28E+00	HBW/mm	2.39E-04	A
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	2.887E-01	sec	1.19E-01	HBW/sec	3.44E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	2.887E-01	sec	-1.19E-01	HBW/sec	3.44E-02	B
7	Uniformity of Blocks	-	258.1	HBW	-	Normal	8.490E-01	HBW	1.00E+00	-	8.49E-01	A
combined standard uncertainty, u [HBW]											1.039	
expanded combined standard uncertainty, U [HBW] (k=2)											2.08	

Uncertainty report for 250HBW5/750

NMIJ 7/11

250HBW5/750

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H),	type
	division	subdivision										
1	Force	-	7355	N	-	Normal	9.975E-01	N	3.40E-02	HBW/N	3.39E-02	A
2	Length measuring device	Length measuring device	1.917	mm	-	Normal	2.675E-04	mm	-2.72E+02	HBW/mm	7.27E-02	A
3		Repeatability of readings	0	mm	-	Normal	1.342E-03	mm	-2.72E+02	HBW/mm	3.64E-01	B
4	Indenter geometry	Diameter of the ball	5	mm	1.00E-03	Rectangle	2.887E-04	mm	4.14E+00	HBW/mm	1.19E-03	A
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	2.887E-01	sec	1.19E-01	HBW/sec	3.44E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	2.887E-01	sec	-1.19E-01	HBW/sec	3.44E-02	B
7	Uniformity of Blocks	-	250.4	HBW	-	Normal	9.680E-01	HBW	1.00E+00	-	9.68E-01	A
combined standard uncertainty, u [HBW]											1.039	
expanded combined standard uncertainty, U [HBW] (k=2)											2.08	

Uncertainty report for 350HBW1/30

350HBW1/30

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H),	type
	division	subdivision										
1	Force	-	294.2	N	-	Normal	7.575E-02	N	1.19E+00	HBW/N	9.01E-02	A
2	Length measuring device	Length measuring device	0.326	mm	-	Normal	2.675E-04	mm	-2.21E+03	HBW/mm	5.91E-01	A
3		Repeatability of readings	0	mm	-	Normal	6.517E-04	mm	-2.21E+03	HBW/mm	1.44E+00	B
4	Indenter geometry	Diameter of the ball	1	mm	1.00E-03	Rectangle	2.887E-04	mm	2.02E+01	HBW/mm	5.83E-03	A
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	2.887E-01	sec	1.93E-01	HBW/sec	5.58E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	2.887E-01	sec	-1.61E-01	HBW/sec	4.65E-02	B
7	Uniformity of Blocks	-	361.0	HBW	-	Normal	1.070E+00	HBW	1.00E+00	-	1.07E+00	A
combined standard uncertainty, u [HBW]											1.893	
expanded combined standard uncertainty, U [HBW] (k=2)											3.79	

Uncertainty report for 350HBW2.5/187.5

NMIJ 8/11

350HBW2.5/187.5

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H),	type
	division	subdivision										
1	Force	-	1839	N	-	Normal	6.036E-01	N	1.90E-01	HBW/N	1.15E-01	A
2	Length measuring device	Length measuring device	0.815	mm	-	Normal	2.675E-04	mm	-8.84E+02	HBW/mm	2.36E-01	A
3		Repeatability of readings	0	mm	-	Normal	9.777E-04	mm	-8.84E+02	HBW/mm	8.64E-01	B
4	Indenter geometry	Diameter of the ball	2.5	mm	1.00E-03	Rectangle	2.887E-04	mm	8.08E+00	HBW/mm	2.33E-03	A
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	2.887E-01	sec	1.93E-01	HBW/sec	5.58E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	2.887E-01	sec	-1.61E-01	HBW/sec	4.65E-02	B
7	Uniformity of Blocks	-	357.7	HBW	-	Normal	7.430E-01	HBW	1.00E+00	-	7.43E-01	A
combined standard uncertainty, u [HBW]											1.172	
expanded combined standard uncertainty, U [HBW] (k=2)											2.34	

Uncertainty report for 350HBW5/750

350HBW5/750

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H),	type
	division	subdivision										
1	Force	-	7355	N	-	Normal	9.975E-01	N	4.76E-02	HBW/N	4.75E-02	A
2	Length measuring device	Length measuring device	1.629	mm	-	Normal	2.675E-04	mm	-4.42E+02	HBW/mm	1.18E-01	A
3		Repeatability of readings	0	mm	-	Normal	1.141E-03	mm	-4.42E+02	HBW/mm	5.04E-01	B
4	Indenter geometry	Diameter of the ball	5	mm	1.00E-03	Rectangle	2.887E-04	mm	4.04E+00	HBW/mm	1.17E-03	A
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	2.887E-01	sec	1.93E-01	HBW/sec	5.58E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	2.887E-01	sec	-1.61E-01	HBW/sec	4.65E-02	B
7	Uniformity of Blocks	-	361.6	HBW	-	Normal	7.640E-01	HBW	1.00E+00	-	7.64E-01	A
combined standard uncertainty, u [HBW]											0.927	
expanded combined standard uncertainty, U [HBW] (k=2)											1.85	

Uncertainty report for 350HBW10/3000

NMIJ 9/11

350HBW10/3000

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H),	type
	division	subdivision										
1	Force	-	29420	N	-	Normal	1.925E+00	N	1.19E-02	HBW/N	2.29E-02	A
2	Length measuring device	Length measuring device	3.259	mm	-	Normal	2.675E-04	mm	-2.21E+02	HBW/mm	5.91E-02	A
3		Repeatability of readings	0	mm	-	Normal	2.933E-03	mm	-2.21E+02	HBW/mm	6.48E-01	B
4	Indenter geometry	Diameter of the ball	10	mm	1.00E-03	Rectangle	2.887E-04	mm	2.02E+00	HBW/mm	5.83E-04	A
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	2.887E-01	sec	1.93E-01	HBW/sec	5.58E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	2.887E-01	sec	-1.61E-01	HBW/sec	4.65E-02	B
7	Uniformity of Blocks	-	360.8	HBW	-	Normal	7.860E-01	HBW	1.00E+00	-	7.86E-01	A
combined standard uncertainty, u [HBW]											1.023	
expanded combined standard uncertainty, U [HBW] (k=2)											2.05	

Uncertainty report for 450HBW1/30

450HBW1/30

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H),	type
	division	subdivision										
1	Force	-	294.2	N	-	Normal	7.575E-02	N	1.53E+00	HBW/N	1.16E-01	A
2	Length measuring device	Length measuring device	0.288	mm	-	Normal	2.675E-04	mm	-3.19E+03	HBW/mm	8.54E-01	A
3		Repeatability of readings	0	mm	-	Normal	5.800E-04	mm	-3.19E+03	HBW/mm	1.85E+00	B
4	Indenter geometry	Diameter of the ball	1	mm	1.00E-03	Rectangle	2.887E-04	mm	2.00E+01	HBW/mm	5.76E-03	A
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	2.887E-01	sec	2.07E-01	HBW/sec	5.98E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	2.887E-01	sec	-1.61E-01	HBW/sec	4.65E-02	B
7	Uniformity of Blocks	-	450.4	HBW	-	Normal	8.810E-01	HBW	1.00E+00	-	8.81E-01	A
combined standard uncertainty, u [HBW]											2.225	
expanded combined standard uncertainty, U [HBW] (k=2)											4.45	

Uncertainty report for 450HBW2.5/187.5

NMIJ 10/11

450HBW2.5/187.5

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H),	type
	division	subdivision										
1	Force	-	1839	N	-	Normal	6.036E-01	N	2.45E-01	HBW/N	1.48E-01	A
2	Length measuring device	Length measuring device	0.721	mm	-	Normal	2.675E-04	mm	-1.28E+03	HBW/mm	3.41E-01	A
3		Repeatability of readings	0	mm	-	Normal	1.1E-03	mm	-1.28E+03	HBW/mm	1.40E+00	B
4	Indenter geometry	Diameter of the ball	2.5	mm	1.00E-03	Rectangle	2.887E-04	mm	7.98E+00	HBW/mm	2.30E-03	A
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	2.887E-01	sec	2.07E-01	HBW/sec	5.98E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	2.887E-01	sec	-1.61E-01	HBW/sec	4.65E-02	B
7	Uniformity of Blocks	-	453.3	HBW	-	Normal	2.530E-01	HBW	1.00E+00	-	2.53E-01	A
combined standard uncertainty, u [HBW]											1.476	
expanded combined standard uncertainty, U [HBW] (k=2)											2.95	

Uncertainty report for 450HBW5/750

450HBW5/750

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H),	type
	division	subdivision										
1	Force	-	7355	N	-	Normal	9.975E-01	N	6.12E-02	HBW/N	6.10E-02	A
2	Length measuring device	Length measuring device	1.441	mm	-	Normal	2.675E-04	mm	-6.38E+02	HBW/mm	1.71E-01	A
3		Repeatability of readings	0	mm	-	Normal	1.009E-03	mm	-6.38E+02	HBW/mm	6.44E-01	B
4	Indenter geometry	Diameter of the ball	5	mm	1.00E-03	Rectangle	2.887E-04	mm	3.99E+00	HBW/mm	1.15E-03	A
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	2.887E-01	sec	2.07E-01	HBW/sec	5.98E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	2.887E-01	sec	-1.61E-01	HBW/sec	4.65E-02	B
7	Uniformity of Blocks	-	454.8	HBW	-	Normal	4.270E-01	HBW	1.00E+00	-	4.27E-01	A
combined standard uncertainty, u [HBW]											0.797	
expanded combined standard uncertainty, U [HBW] (k=2)											1.59	

Uncertainty report for 450HBW10/3000

NMIJ 11/11

450HBW10/3000

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, ci	unit	uncertainty contribution, u(H),	type
	division	subdivision										
1	Force	-	29420	N	-	Normal	1.925E+00	N	1.53E-02	HBW/N	2.94E-02	A
2	Length measuring device	Length measuring device	2.883	mm	-	Normal	2.675E-04	mm	-3.19E+02	HBW/mm	8.54E-02	A
3		Repeatability of readings	0	mm		Normal	2.595E-03	mm	-3.19E+02	HBW/mm	8.28E-01	B
4	Indenter geometry	Diameter of the ball	10	mm	1.00E-03	Rectangle	2.887E-04	mm	2.00E+00	HBW/mm	5.76E-04	A
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	2.887E-01	sec	2.07E-01	HBW/sec	5.98E-02	B
6		Test force dulation	15	sec	0.5	Rectangle	2.887E-01	sec	-1.61E-01	HBW/sec	4.65E-02	B
7	Uniformity of Blocks	-	455.8	HBW	-	Normal	2.790E-01	HBW	1.00E+00	-	2.79E-01	A
combined standard uncertainty, u [HBW]											0.882	
expanded combined standard uncertainty, U [HBW] (k=2)											1.76	

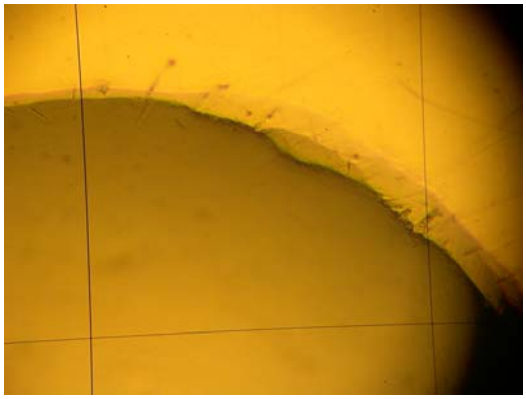
End –NMIJ–

Appendix B: Comments from participant

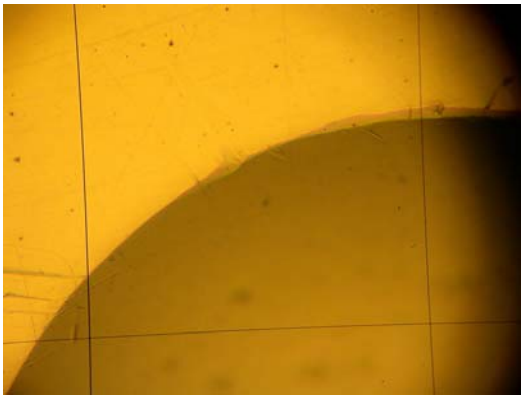
PTB comment of May 20, 2004, which is attached to measurement report

1) The 3 reference indents ID 93243, 93242 and 94043 do not have an ideal shape. ID 93243 is deformed over half the circumference. ID 93242 is not round, and ID 94043 is scratched and deformed. We have added photos of the mentioned indents.

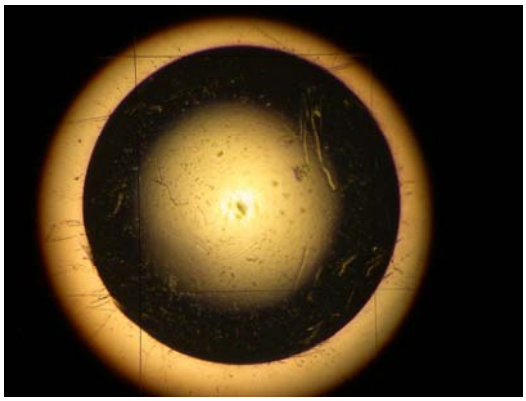
Attached figures:



250HBW2.5/187.5(ID: 93243)



250HBW2.5/187.5(ID: 93243)



350HBW2.5/187.5(ID: 94043)

2) In one field of our test indents we have already found an indent. Therefore we have made in this field ours as the second indent.

3) The inhomogeneity of the hardness distribution of the blocks in some cases is rather large. This can be seen from the hardness variation over the 5 indents on one block.

Appendix C. Diameter measurement of the Brinell hardness

C.1 Aim of the analysis:

For harmonization of the Brinell hardness values, we analyzed the result of the comparison and result obtained from the supplementary items. We predicted that the diameter measurement was the most significant uncertainty source in the Brinell hardness measurement.

C.2 The result from the comparisons:

From the analysis of the Reference Value(RV) using the each uncertainty, the measured hardness of blocks has significant deviation. Firstly, we indicate the result of analysis of variance of the measured hardness in the following tables.

Table C-1: Variance of Analysis for 250HBW hardness level

For 250HBW1/30

Source	Variation	DoF	Variance	ratio of Var.	
Between NM	392.671	6	65.445	38.182	**
In NMI	47.993	28	1.714		
Sum	440.664	34			

For 250HBW2.5/187.5

Source	Variation	DoF	Variance	ratio of Var.	
Between NM	716.321	6	119.387	36.147	**
In NMI	92.479	28	3.303		
Sum	808.800	34			

For 250HBW5/750

Source	Variation	DoF	Variance	ratio of Var.	
Between NM	404.975	6	67.496	33.836	**
In NMI	55.854	28	1.995		
Sum	460.829	34			

Table C-2: Variance of Analysis for 350HBW hardness level

For 350HBW1/30

Source	Variation	DoF	Variance	ratio of Var.	
Between NM	286.899	6	47.816	10.080	**
In NMI	132.819	28	4.744		
Sum	419.718	34			

For 350HBW2.5/187.5

Source	Variation	DoF	Variance	ratio of Var.	
Between NM	506.482	6	84.414	37.259	**
In NMI	63.436	28	2.266		
Sum	569.918	34			

For 350HBW5/750

Source	Variation	DoF	Variance	ratio of Var.	
Between NM	333.179	6	55.530	42.430	**
In NMI	36.645	28	1.309		
Sum	369.824	34			

For 350HBW10/3000

Source	Variation	DoF	Variance	ratio of Var.	
Between NM	145.163	6	24.194	6.332	**
In NMI	106.978	28	3.821		
Sum	252.141	34			

Table C-3: Variance of Analysis for 450HBW hardness level

For 450HBW1/30

Source	Variation	DoF	Variance	ratio of Var.	
Between NMII	225.098	5	45.020	10.587	**
In NMI	102.058	24	4.252		
Sum	327.156	29			

For 450HBW2.5/187.5

Source	Variation	DoF	Variance	ratio of Var.	
Between NMII	307.891	6	51.315	41.753	**
In NMI	34.412	28	1.229		
Sum	342.304	34			

For 450HBW5/750

Source	Variation	DoF	Variance	ratio of Var.	
Between NMII	157.901	6	26.317	23.900	**
In NMI	30.831	28	1.101		
Sum	188.732	34			

For 450HBW10/3000

Source	Variation	DoF	Variance	ratio of Var.	
Between NMII	14.852	6	2.475	4.152	**
In NMI	16.691	28	0.596		
Sum	31.542	34			

**: significant (level of confidence, 99%)

In the tables, variance of “Between NMI” indicates the variance between the mean hardness of each participant, in other word deviation of the Brinell hardness values. “In NMI” indicates the variance of five indentations of the measurement of each participant. It is consider

that the non-uniformity of the block. The ratio of variance shows that there are hardness deviation between participants can not be explained by non-uniformity of blocks at the level of confidence 99%.

C.3 Results from the supplementary Items of the comparison:

We introduced to the diameter measurement of reference indentation and artificial indentation to separate the 3D diameter measurement and 2D measurements, respectively. The former corresponds to the actual diameter measurement and the latter corresponds to the length calibration of the apparatus used to the diameter measurement. We predict to the diameter measurement is the most significant uncertainty sources in the Brinell hardness measurement.

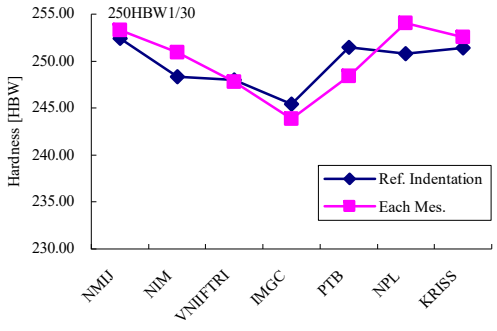
C.4 Results of reference indentations and result of the comparison:

The following analysis, the reported diameter is converted into Brinell hardness. Each measurement is the reported hardness of blocks including the indentation process. We indicate it by using “each measurement” in the followings.

Table C-4: Comparison result of reference indentation measurement with each hardness measurement

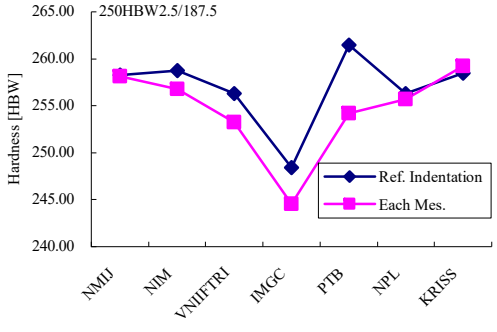
For 250HBW1/30

Participants	Ref. Indent	Each Meas.
NMIJ	252.43	253.28
NIM	248.35	250.91
VNIIFTRI	247.99	247.83
INRIM	245.45	243.89
PTB	251.49	248.44
NPL	250.77	254.03
KRISS	251.38	252.54
Stdev.	2.50	3.62
Correlation	0.80	



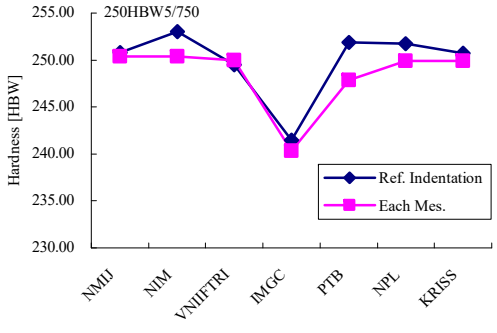
For 250HBW2.5/187.5

Participants	Ref. Indent	Each Meas.
NMIJ	258.31	258.12
NIM	258.74	256.80
VNIIFTRI	256.28	253.26
INRIM	248.40	244.54
PTB	261.46	254.18
NPL	256.32	255.71
KRISS	258.45	259.24
Stdev.	4.11	4.89
Correlation	0.83	



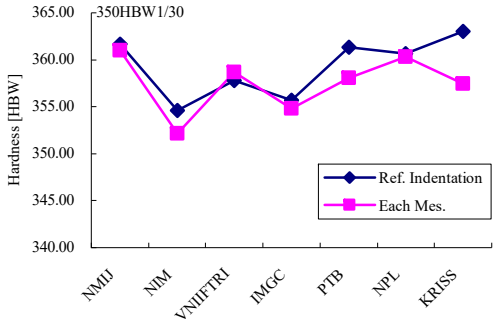
For 250HBW5/750

Participants	Ref. Indent	Each Meas.
NMIJ	250.82	250.40
NIM	253.03	250.38
VNIIFTRI	249.52	249.99
INRIM	241.45	240.30
PTB	251.88	247.87
NPL	251.76	249.93
KRISS	250.74	249.91
Stdev.	3.88	3.67
Correlation	0.92	



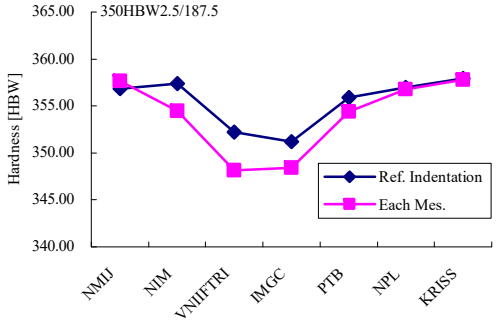
For 350HBW1/30

Participants	Ref. Indent	Each Meas.
NMIJ	361.65	361.01
NIM	354.61	352.18
VNIIFTRI	357.83	358.69
INRIM	355.69	354.82
PTB	361.35	358.06
NPL	360.68	360.31
KRISS	363.02	357.47
Stdev.	3.23	3.09
Correlation	0.77	



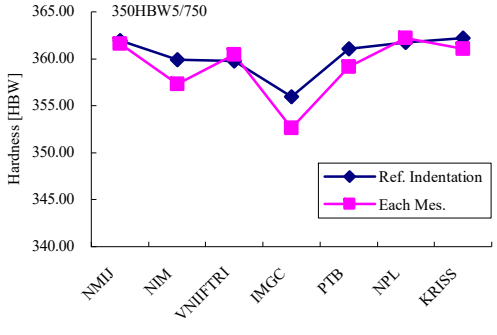
For 350HBW2.5/187.5

Participants	Ref. Indent	Each Meas.
NMIJ	356.85	357.68
NIM	357.37	354.45
VNIIFTRI	352.26	348.16
INRIM	351.18	348.41
PTB	355.87	354.37
NPL	356.99	356.81
KRISS	357.90	357.77
Stdev.	2.67	4.11
Correlation	0.95	



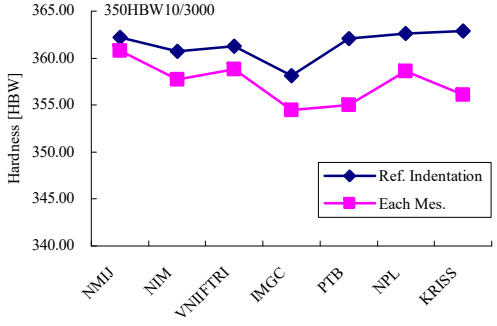
For 350HBW5/750

Participants	Ref. Indent	Each Meas.
NMIJ	361.97	361.62
NIM	359.89	357.32
VNIIFTRI	359.74	360.44
INRIM	355.97	352.63
PTB	361.03	359.17
NPL	361.75	362.22
KRISS	362.24	361.04
Stdev.	2.18	3.33
Correlation	0.93	



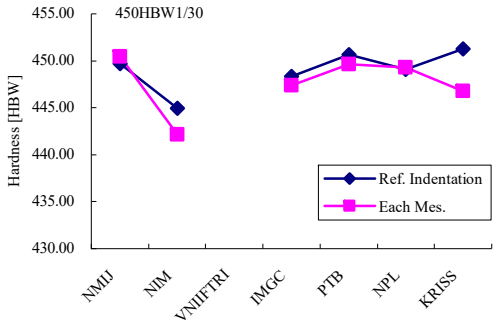
For 350HBW10/3000 (The values Each Meas. of NPL and KRISS are corrected by using deviation between KCRVs).

Participants	Ref. Indent	Each Meas.
NMIJ	362.21	360.80
NIM	360.74	357.71
VNIIFTRI	361.28	358.78
INRIM	358.15	354.44
PTB	362.09	355.03
NPL*	362.62	358.62
KRISS*	362.92	356.10
NMIJ2*	362.21	358.70
Stdev.	1.53	2.16
Correlation	0.46	



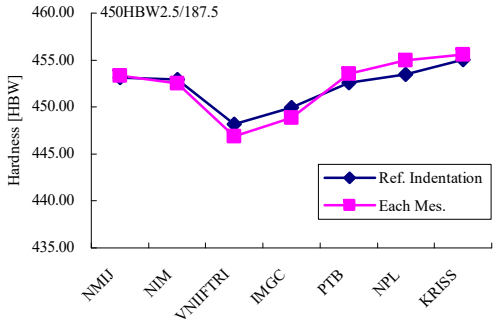
For 450HBW1/30

Participants	Ref. Indent	Each Meas.
NMIJ	449.72	450.42
NIM	444.95	442.19
VNIIFTRI	-	-
INRIM	448.36	447.41
PTB	450.66	449.65
NPL	449.07	449.29
KRISS	451.30	446.81
Stdev.	2.25	3.00
Correlation	0.76	



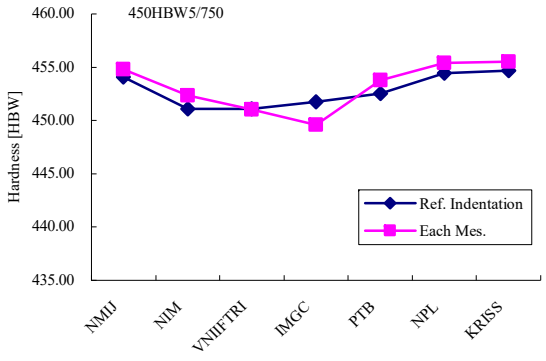
For 450HBW2.5/187.5

Participants	Ref. Indent	Each Meas.
NMIJ	453.11	453.34
NIM	452.90	452.56
VNIIFTRI	448.21	446.88
INRIM	449.98	448.88
PTB	452.57	453.55
NPL	453.48	454.97
KRISS	455.06	455.57
Stdev.	2.31	3.20
Correlation	0.98	



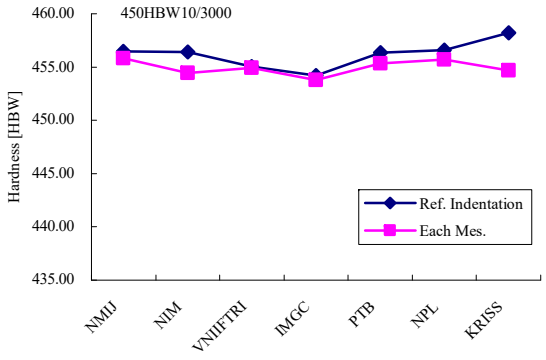
For 450HBW5/750

Participants	Ref. Indent	Each Meas.
NMIJ	454.06	454.82
NIM	451.08	452.33
VNIIFTRI	451.08	451.01
INRIM	451.75	449.62
PTB	452.53	453.80
NPL	454.42	455.38
KRISS	454.68	455.54
Stdev.	1.57	2.29
Corr.	0.87	



For 450HBW10/3000 (The values Each Meas. of NPL and KRISS are corrected by using deviation between KCRVs).

Participants	Ref. Indent	Each Meas.
NMIJ	456.44	455.83
NIM	456.41	454.42
VNIIFTRI	455.06	454.94
INRIM	454.18	453.77
PTB	456.34	455.33
NPL*	456.61	455.71
KRISS*	458.21	454.65
NMIJ2*	456.44	455.10
Stdev.	1.18	0.68
Correlation	0.41	



We found that the similar tendency between the result of reference indentation and each measured hardness. The coefficient of correlation indicates about 0.8 for the HBW1/30, 0.9~0.98 for the HBW2.5/187.5 and HBW5/750. For the HBW10/3000, the coefficient indicates the slightly low, about 0.4 as shown in the fig. C-1 (fig. 6-3 in the main text). For the result of hardness scale HBW10/3000, the values are corrected using difference between KCRVs, therefore the ambiguity of the result may be enlarged.

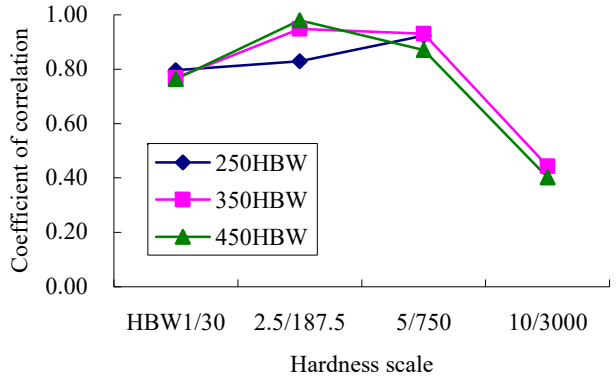


Fig. C-1: Coefficient of correlation between the results of reference indentation and the hardness measurement carried out each participant.

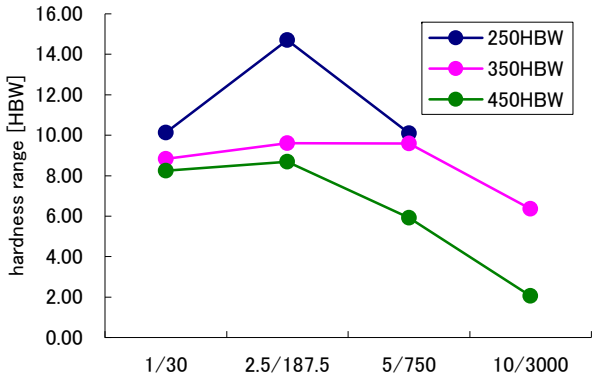


Fig. C-2: Difference among NMI's reported hardness

In the fig. C-2, the hardness range (max. – min.) among NMIs was plotted. The range is about 10 HBW. The range is decreasing with increasing of test force and also decreasing with increasing of the hardness level.

C.5 Result of Artificial Indentation:

In this comparison, the diameter measurement of the artificial indentation is also compared. The artificial indentation is useful to investigate the difference of calibration and edge detection conditions among NMIs. The 0.24, 0.4, 0.8 and 1.5 mm in diameter are corresponding to the indentation diameter of 650 HBW 1/30, 230 HBW 1/30, 360 HBW 2.5/187.5 and 415 HBW 5/750, respectively. This range is narrower than that of used in the comparison from 0.28 to 3.2 mm. However that gives us useful information regarding the diameter measurement of the 2D artifact. Figure C-3 shows the result of the measurements. The black line shows the nominal diameter of the artifact.

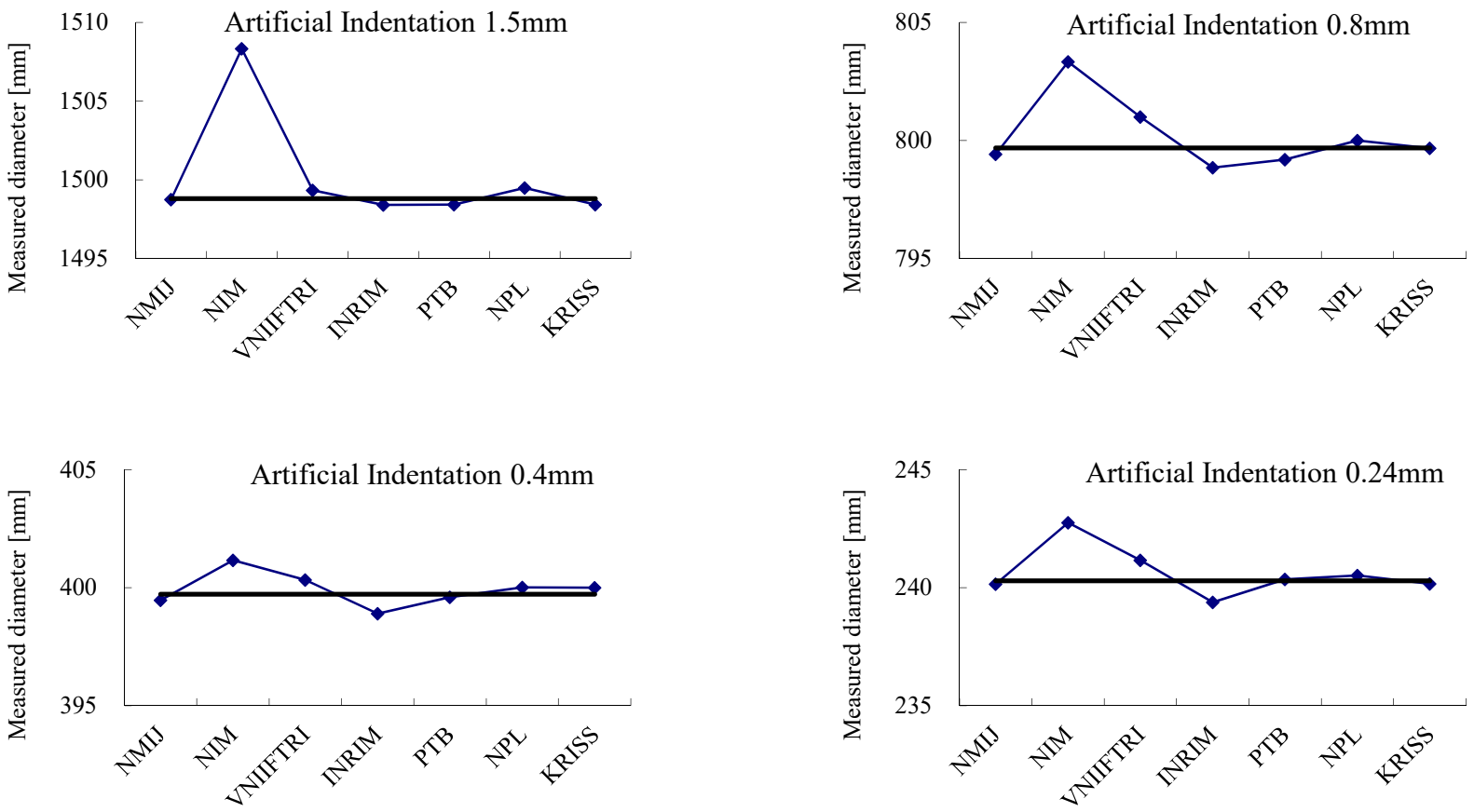


Fig. C-3: Result of diameter measurement of artificial indentation.

From the result of diameter measurement of “Artificial indentation”, the result of NIM for the 1.5mm and the 800mm looks slightly

deviated from other results. The measured diameter deference is about 2 μm between institutes. The 2 μm difference in diameter gives the Brinell hardness change: 3~6HBW for 1/30, 1~3HBW for 2.5/187.5, 0.6~1.2HBW for 5/750 and 0.4~0.6 HBW for 10/3000 hardness scale, respectively. Those values are too small to explain the difference observed by the actual indentation measurement.

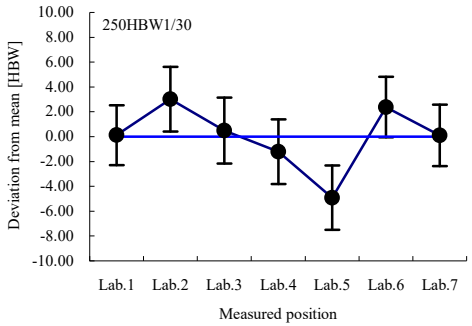
C.6 Result of the diameter measurement of indentations by the NMIJ:

The above results indicate the significant difference exist in the diameter measurement in Brinell indentation diameter measurement. That difference may be reduced if the measurement was carried out by single laboratory. NMIJ measured the diameter of all remained indentation on the circulated block. The objective lens with N.A. =0.55 and Köhler illumination through objective lens is used. Identification of the indentation was carried out according to the measurement position designated in protocol. Because of the some indentations have significant change in shape, the result from that indentations are eliminated. The result is shown in the figs., C-4~C-5. We treat the result by the arithmetic mean of the participant. Because of some indentations are carried out incorrect position, this grouping includes some of ambiguity.

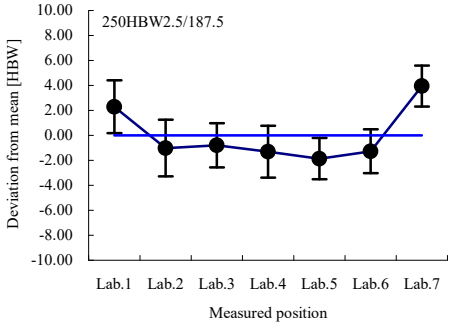
The length of error bars indicate the expanded uncertainty of measurement, which is given by the combination of the NMIJ diameter measurement uncertainty including the repeatability of the measurement and the uncertainty of the mean values of five (or less) indentations. The hardness levels for HBW10/3000, the hardness difference between blocks A and B are corrected by using difference of arithmetic mean values. We do not indicate the absolute values of the measurement, because the result also including the bias component of NMIJ.

From the result, we can found that difference between NMIs reduces for all hardness levels and scales when the measurement was carried out by the single laboratory.

(a)



(b)



(c)

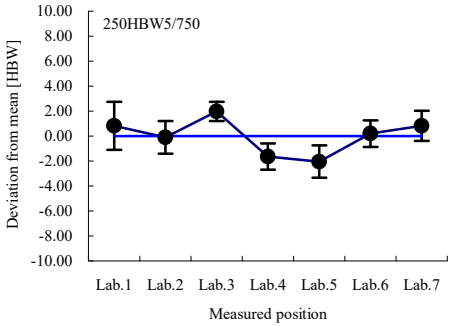


Fig. C-4: Brinell hardness of corresponding laboratories obtained by NMIJ measurements for 250HBW1/30(a), for 250HBW2.5/187.5 (b) and for 250HBW5/750(c).

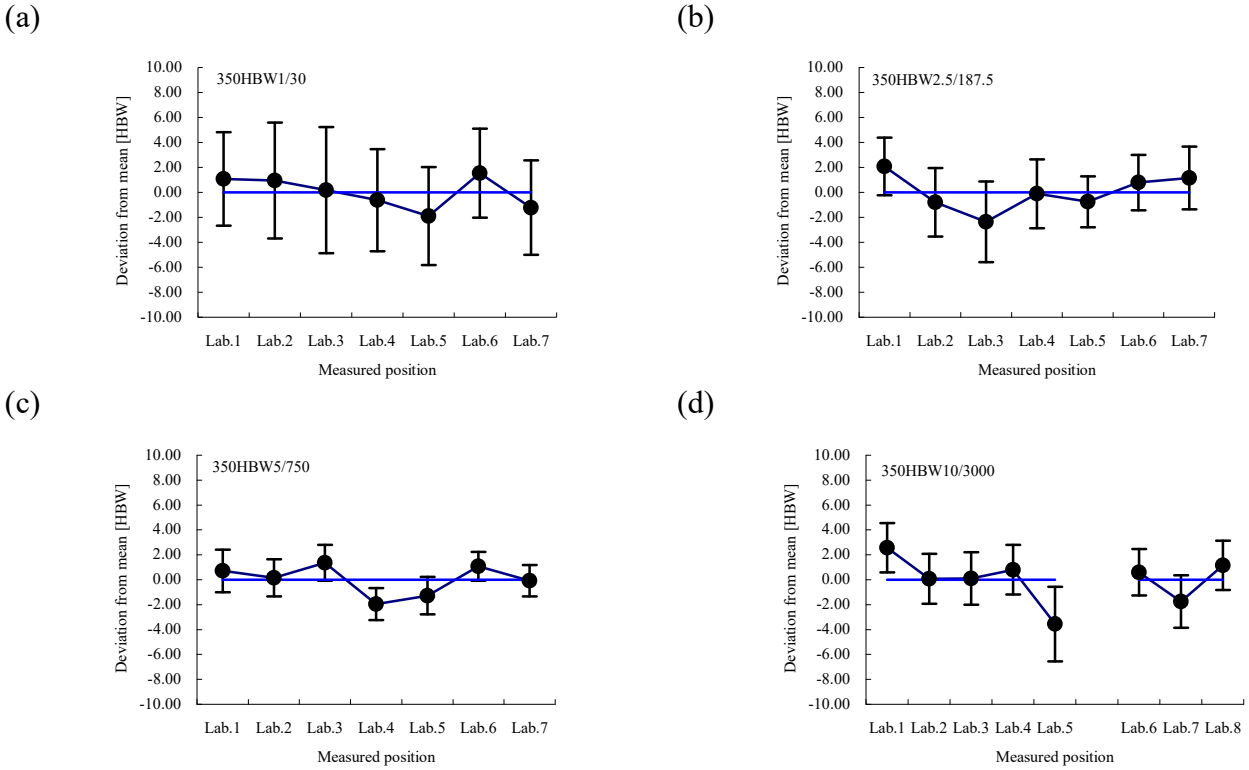
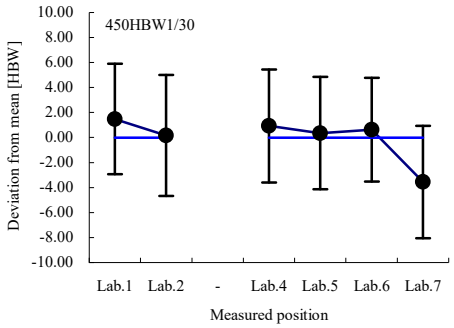
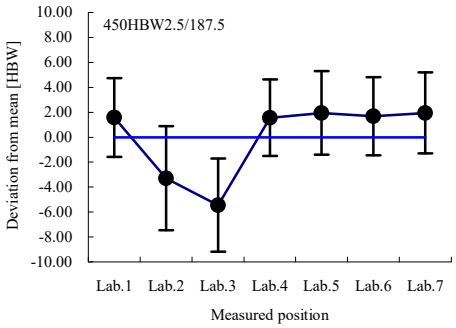


Fig. C-5: Brinell hardness of corresponding laboratories obtained by NMIJ measurements for 350HBW1/30(a), for 350HBW2.5/187.5 (b), for 350HBW5/750(c) and for 350HBW10/3000(d).

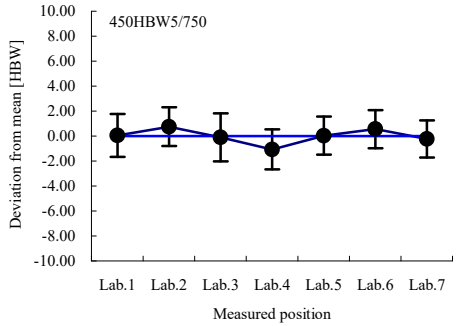
(a)



(b)



(c)



(d)

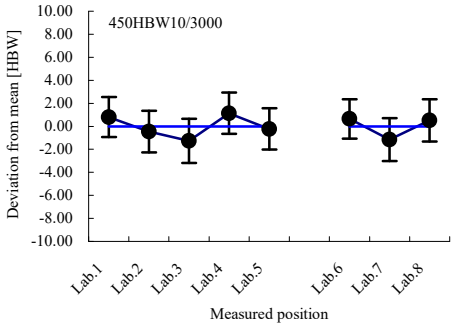


Fig. C-6: Brinell hardness of corresponding laboratories obtained by NMIJ measurements for 450HBW1/30(a), for 450HBW2.5/187.5 (b), for 450HBW5/750(c) and for 450HBW10/3000(d).

C.7 Summary of Appendix C: diameter measurement of Brinell hardness:

The results indicate that the some of difference exist in the diameter measurement of Brinell hardness between NMIs and that is not explained by the non-uniformity of blocks. From the result of the coefficient of correlation, that strongly suggested that the some bias in the diameter measurement affect the Brinell hardness measurement. The bias is quite large in the Brinell hardness measurement.

The calibration of diameter measurement devices is not significant from artificial indentation measurement. From the results of diameter measurement obtained by the single laboratory, that suggests the difference between NMIs will be reduced if the diameter measurement condition is fixed.

That result indicate that:

Further improvement is required to determine the diameter of the Brinell hardness indentation.

Some additional protocol should be required in the diameter measurement for the harmonization of the Brinell hardness.

Appendix D: Effect of optical system in Brinell indentation diameter measurement

Some dependence was found in a Brinell Diameter measurement. The effect of a numerical aperture (N.A.) of objective lens is investigated and reported by INRIM, Italy, and NMIJ, Japan.

The N.A. used in the comparison is shown in Table D-1. The typical cross sectional view of Brinell indentation at the edge obtained by HBW 5/750 is shown in fig. D-1.

Table D-1 Reported Numerical Aperture of Objectives

Participant	250HBW			350HBW				450HBW			
	1/30	2.5/187.5	5/750	1/30	2.5/187.5	5/750	10/3000	1/30	2.5/187.5	5/750	10/3000
NMIJ	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
NIM	-	0.25	0.1	-	0.25	0.1	0.1	-	0.25	0.1	0.1
VNIIFTRI	0.17	0.11	0.11	0.17	0.11	0.11	0.11	0.17	0.11	0.11	0.11
INRM	0.09	0.07	0.07	0.09	0.07	0.07	0.07	0.09	0.07	0.07	0.07
PTB	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
NPL	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
KRISS	0.65	0.65	0.65	0.65	0.65	0.65	0.25	0.65	0.65	0.65	0.25

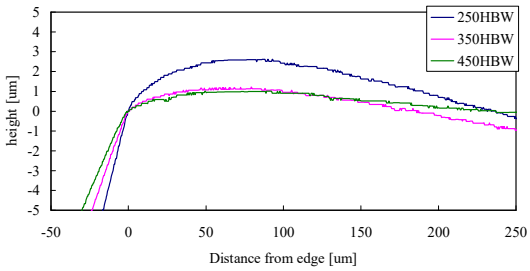


Fig. D-1 Typical Cross sectional view of Brinell indentation edge (HBW 5/750)

The outside of the edge, the “hill” can be observed as a pile-up due to material flow in the fig. D-1. The illumination through the objective lens is generally used in the Brinell indentation diameter measurement. In this case, the slope due to the pile-up reflects incident light to the outside direction and make the dark contrast. The light reflected is caught by the objective, however, is depending on the numerical aperture of the objective lens and also numerical aperture of the light incident and is causes apparent indentation edge outside of the real indentation edge.

INRIM’s report: the dependence of indentation diameter on objective’s N.A.

The measured results and some correction function was reported. The measured N.A. are 0.07, 0.09, 0.2, 0.4 and 0.5.

The difference of diameter for correction vs. Numerical Aperture was shown in the figure. The difference is normalized by using diameter at N.A.=0.5 as reference. The indicated difference gives directly correction value, so that, dimeter obtained at N.A. = 0.07 gives about 1.5 % large diameter than that obtained at N.A.=0.5.

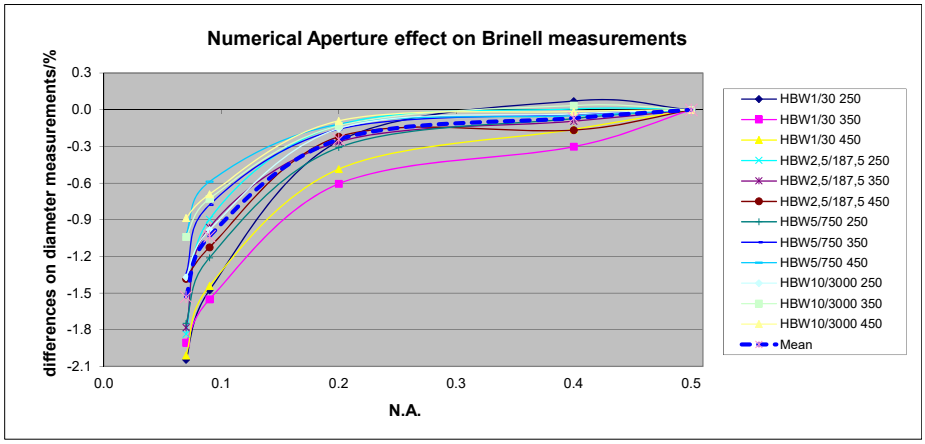


Fig. D-2 Difference on diameter measurement vs. N.A. reported by INRIM

The proposed correction function is given by,

$$d_{\text{correction}} = C_{NA3}NA^3 + C_{NA2}NA^2 + C_{NA}NA + C_H H + C_L L + C_B D + C \quad \text{(in \%)}. \text{ (D.1)}$$

Where the NA: numerical aperture of objective lens that used to diameter measurement of Brinell indent, H is the nominal hardness, L is the load in F [N]/9.80665, and D is the diameter of the indenter ball in mm, respectively.
The coefficients obtained by the Regression are below.

Table D-2 Coefficients of correction fuction (D.1)

NA3	NA2	NA	H	F	B	C
65.09104	-70.6407	24.76834	0.000494	-0.00025	0.124558	-3.35459

NMIJ's report:

NMIJ just reported the dependence of Brinell hardness on N.A.
The N.A. used in this report are 0.06, 0.14, 0.30, 0.40, 0.50 and 0.70. The measured hardness looks almost the same in N.A. greater or equal 0.4 in 250 HBW, this critical N.A. decreases with increasing hardness, critical N.A. = 0.3 at 350 HBW and between 0.2 or 0.3 at 450 HBW.

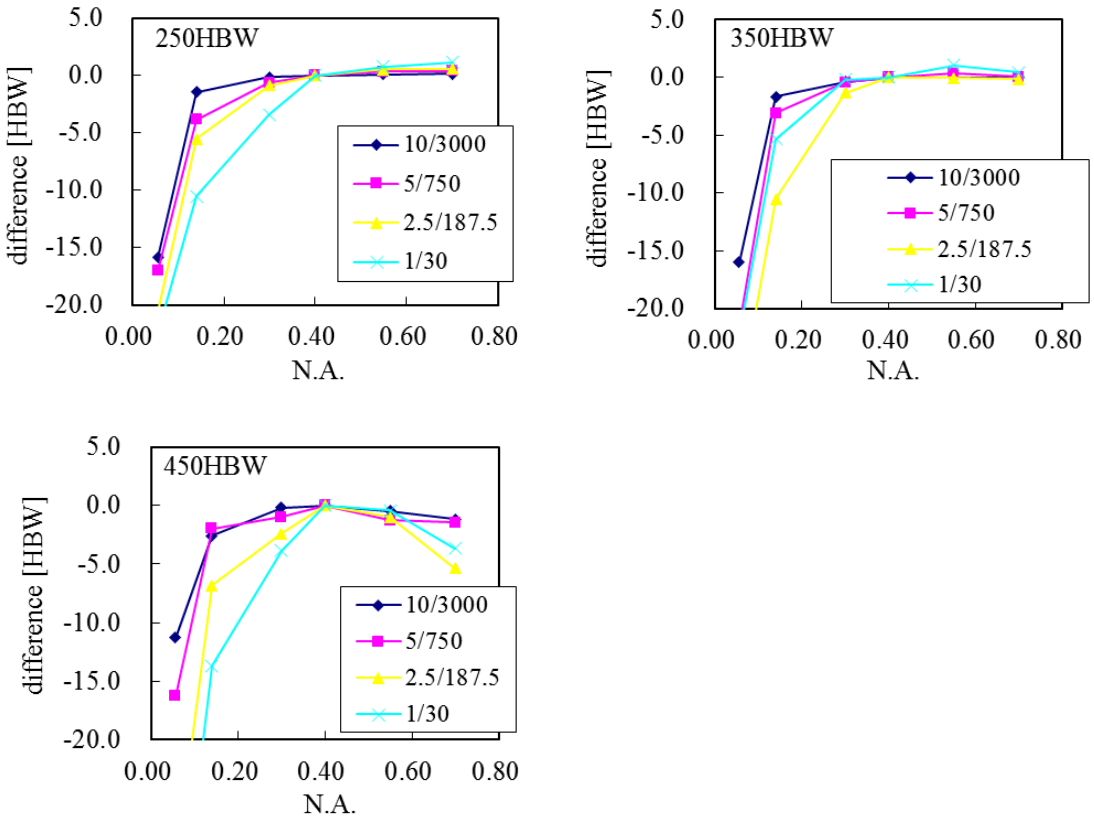


Fig. D-3 Hardness difference dependend on numerical aperture, reported by NMIJ.

It is important to note that:
One is the illumination. In the NMIJ's measurement, Köhler illumination was used. The light provided through the objective lens, the light illuminate the sample surface almost normal direction only. The results may differs if the different illumination system, such as Ring light source, that illuminate the sample from outside the objective lens.
The second is the surface finish of the block. The mirror finished surface was used as artifact and also this investigation. The rough surface, where the light is randomly reflected, may shows different dependence on Numerical Aperture.

Short Summary:
This N.A. dependence is very useful information, especially the users who measures the indentation diameter or indentation area using image analysis system. In such systems, the user tend to use a low numerical aperture lens to improve the contrast of the image.
These results give the large difference in diameter measurement, 1.7 % in diameter measurement gives about 0.065 mm for d=3.833 mm (250 HBW 10/3000) for example.