APMP M.H. S5
Final Report
The Supplementary Comparison of Brinell Hardness

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Abstract

This report purposed the results of supplementary comparison of Brinell Hardness, APMP.M.H-S5 among three National Metrology Institutes (NIMT, NMIJ/AIST and KRISS). The comparison was carried out during April 2018 to July 2019 in order to determine the capability of the primary Brinell hardness standard, including standard conditions, of each participant, to confirm the accuracy of Brinell hardness scale HBW 10/500 and HBW 10/3000 measurement declared by each participant, which includes the effect of each participant's primary indenter and determine the degrees of equivalence of hardness scale measurement in the range 45HBW to 550HBW. The pilot institute was the National Institute of Metrology (Thailand), NIMT. There were 2 different types of artifacts for the comparison. The first set was the set of Brinell hardness comparison: hardness measurement. The second set is a set of diameter length comparison: diameter length measurement.

The measurement results of each participant were used to compute the degree of equivalence in Comparison Reference Value (CRV) and the uncertainty of this deviation at a 95% level of confidence. The E_n number was calculated to express the equivalence between the measurements of participant as well.

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1. Introduction

NIMT proposed a supplementary comparison of Brinell hardness measurement with the collaboration of Korea Research Institute of Standards and Science (KRISS) and National Metrology Institute of Japan (NMIJ). NIMT was nominated as the pilot laboratory of the comparison. This comparison is followed technical protocol APMP.M.H-S5[1].

A protocol of the comparison was prepared by the pilot institute and was distributed to participating institutes on October 2017 to gather the comments and opinions from them. All participants have accepted and approved the protocol. The participating institutes used the primary Brinell hardness machine as their standard. The artifacts of this comparison were 2 different sets of hardness blocks artifacts. The first set was the set of Brinell hardness comparison: hardness measurement. The second set is a set of diameter length comparison: diameter length measurement. Each set composed of 9 hardness levels: 45, 70 and 100 for HBW 10/500 and 180, 200, 300, 400, 500 and 550 HBW 10/3000. All artifacts were sent from one participant to the next according to a timetable in which the date of measurement had been agreed with the participating institutes.

The participants carried out the verification of their primary Brinell hardness machine according to ISO6506-3 [2] before preceding the measurement on artifact blocks. The measurement results determined from the participants were submitted to the pilot institute and were used for analyzing the degrees of equivalence in this report. The comparison results of the artifacts in set 1 was the priority of this comparison because it showed the deviations of Brinell hardness obtained from each national standard of the participants. Whereas the result of the artifacts in set 2 was presented for additional information to determine the performance of national microscope without the effect from Brinell hardness machine.

2. Artifact

In the supplementary comparison, the Brinell hardness measurement scale HBW 10/500 and HBW 10/3000 are used with the hardness level 45, 70 and 100 for HBW 10/500 and 180, 200, 300, 400, 500 and 550 HBW 10/3000. Details are presented in section 2 of technical protocol APMP.M.H-S5 [1]. The measurement location for each participant are presented in section 3 of technical protocol APMP.M.H-S5 [1].

3. Participating Institutes

There are three participants consisting of NIMT, NMIJ and KRISS as presented in section 4 of technical protocol APMP.M.H-S5 [1]. The list of participant and CMC declaration was given in Table 1 and Table 2, respectively.

Table 1. List of participants of the supplementary comparison.

NMIs	Address	Contact person
National Institute of Metrology (NIMT)	3/4–5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120	Montree PAKKRATOKE E-mail: montree@nimt.or.th Tel: +66 2 577 5100 ext. 2235
National Metrology Institute of Japan (NMIJ/AIST)	Tsukuba central 3, 1-1-1 Umezono, Tsukuba Ibaraki 305-8563, Japan	Koichiro Hattori E-mail: hattori-k@aist.go.jp Tel: +81 29 861 4048 FAX +81 29 861 4047
Korea Research Institute of Standards and Science (KRISS)	301-128, 267 Gajeong-ro, Yuseong-gu, Daejeon 34113, Republic of Korea	Nae Hyung Tak E-mail: nhtak@kriss.re.kr Tel : +82 42 868 5327 Mobile: +82 10 2114 0989

Table 2. List of comparison scale and CMC declaration

NMIs	Comparison scale	Claimed CMCs
National Institute of Metrology (NIMT)	HBW 10/500 and HBW 10/3000	± 1.2 % of HB for 25 to 100 HBW 10/500 ± 0.6 % of HB for 100 to 650 HBW 10/3000
Korea Research Institute of Standards and Science (KRISS)	HBW 10/500 and HBW 10/3000	1.4 % - 2.0 % of HB For scale HBW 10/500 and HBW 10/3000
National Metrology Institute of Japan (NMIJ/AIST)	HBW 10/500 and HBW 10/3000	$0.89+0.19/d-1.1\times10^{-3}H$ % d in mm and H is Brinell hardness of blocks (nominal). from 100 HBW to 600 HBW

4. Schedule

The comparison on artifacts started at pilot lab, NIMT, in Feb 2018. The original schedule was to transfer the artifacts from NIMT, NMIJ and KRISS respectively with about 4 weeks for measurement and about 2 weeks for transportation process as presented in section 5 of technical protocol APMP.M.H-S5 [1]. However, there was some delay during the measurement in KRISS due to a building construction. Table 3 showed the original schedule and actual time of measurement.

Table 3. Original schedule and actual time of measurement period.

Institute/ Country (or region)	Original schedule		Actual schedule	
	Time of measurement	Time of transportation (to next participant)	Time of measurement	Time of transportation (to next participant)
NIMT, Thailand	15 Apr to 15 May 2018	15 May to 30 May 2018	15 Apr to 15 May 2018	15 May to 30 May 2018
NMIJ/ AIST, Japan	15 Jul to 15 Aug 2018	15 Aug to 31 Aug 2018	13 July 2018 to 23 July 2018	11 Jul 2018 to 15 Jul 2018
KRISS, Rep. of Korea	15 Oct to 15 Nov 2018	15 Nov to 30 Nov 2018	15 Oct 2018 to 30 Nov 2018	1 Dec 2018 to 31 Dec 2018
NIMT, Thailand	1 Dec to 31 Dec 2018	-	19 Aug 2019 to 31 July 2019	-

5. Measurement of Artifacts

The primary Brinell hardness machines used for the comparison must be passed the verification according to ISO 6506-3 [2]. The participants measured the artifacts and evaluated the uncertainty according to “Measurement Procedure” and “Result Evaluation” described in section 6 and 7 of technical protocol APMP.M.H-S5 [1]. Each participant must give a characteristics description of their primary Brinell hardness machine, primary indenter, testing condition and environmental information. Also, laboratory must report the measurement results for each indentation and the uncertainty of measurement.

All measurement data and uncertainty for reference indentation and reference hardness block for all participants were presented in Table 4 and Table 5 to Table 8, respectively.

Table 4. The results of the measurement in HBW 10/500 and HBW 10/3000: For Block Artifact *(Reference Indentation)*

Scale	Nominal value	Measurement data of each participant (mm), X_i				Uncertainty (k =2) of each participant (mm), $U_{(x_i)}$				Uncertainty (k =2) of each participant (%), $U_{(x_i)}$			
		NIMT-BF	NMIJ	KRISS	NIMT-AF	NIMT-BF	NMIJ	KRISS	NIMT-AF	NIMT-BF	NMIJ	KRISS	NIMT-AF
HBW 10/500	45	3.8944	3.8918	3.8923	3.8915	0.0022	0.0046	0.0050	0.0021	0.06	0.12	0.13	0.05
	70	2.9398	2.9377	2.9376	2.9395	0.0021	0.0035	0.0048	0.0021	0.07	0.12	0.16	0.07
	100	2.6164	2.6175	2.6112	2.6172	0.0021	0.0031	0.0048	0.0021	0.08	0.12	0.18	0.08
HBW 10/3000	180	4.3880	4.3873	4.3930	4.3879	0.0021	0.0051	0.0049	0.0021	0.05	0.12	0.11	0.05
	200	4.2008	4.1999	4.2041	4.2007	0.0021	0.0049	0.0048	0.0021	0.05	0.12	0.11	0.05
	300	3.4979	3.4992	3.4989	3.4979	0.0021	0.0041	0.0038	0.0020	0.06	0.12	0.11	0.06
	400	3.0174	3.0187	3.0164	3.0176	0.0020	0.0036	0.0034	0.0020	0.07	0.12	0.11	0.07
	500	2.7812	2.7819	2.7796	2.7816	0.0020	0.0033	0.0033	0.0020	0.07	0.12	0.12	0.07
	550	2.5755	2.5752	2.5711	2.5755	0.0021	0.0030	0.0033	0.0020	0.08	0.12	0.13	0.08

Table 5. The results of the measurement in HBW 10/500 and HBW 10/3000: For Block Artifact *(Reference Hardness block)*

Scale	Nominal value	Measurement data of each participant (HB)				Uncertainty (k =2) of each participant (HB)				Uncertainty (k =2) of each participant (%)			
		NIMT-BF	NMIJ	KRISS	NIMT-AF	NIMT-BF	NMIJ	KRISS	NIMT-AF	NIMT-BF	NMIJ	KRISS	NIMT-AF
HBW 10/500	45	41.45	-	41.24	41.33	0.50	-	0.94	0.50	1.2	-	2.3	1.2
	70	70.96	-	70.4	70.60	0.85	-	1.7	0.85	1.2	-	2.4	1.2
	100	91.0	90.77	91.3	91.2	1.1	0.90	2.0	1.1	1.2	0.99	2.2	1.2
HBW 10/3000	180	187.5	186.0	187.0	187.6	1.1	1.4	2.6	1.1	0.60	0.75	1.4	0.60
	200	206.9	208.4	208.6	208.1	1.8	1.5	2.9	1.2	0.89	0.72	1.4	0.60
	300	308.8	308.9	309.4	309.1	1.9	1.9	4.3	1.9	0.60	0.62	1.4	0.60
	400	407.2	408.2	410.0	408.1	2.4	2.1	5.7	2.4	0.60	0.51	1.4	0.60
	500	496.4	496.9	498.8	496.8	3.0	2.1	7.0	3.0	0.60	0.42	1.4	0.60
	550	573.0	573.5	576.3	573.8	3.4	2.0	8.1	3.4	0.60	0.35	1.4	0.60

Table 6. The results of the measurement in HBW 10/500: For Block Artifact (Reference Hardness block

Nominal value	**45 HBW10/500**		**70 HBW10/500**		**100 HBW10/500**	
Lab$_i$	x_i **HBW10/500**	$u(x_i)$ **HBW10/500**	x_i **HBW10/500**	$u(x_i)$ **HBW10/500**	x_i **HBW10/500**	$u(x_i)$ **HBW10/500**
NIMT-Before	41.45	0.50	70.96	0.85	91.0	1.1
NMIJ	-	-	-	-	90.77	0.90
KRISS	41.24	0.94	70.4	1.7	91.3	2.0
NIMT-After	41.33	0.50	70.60	0.85	91.2	1.1

Table 7. The results of the measurement in HBW 10/3000: For Block Artifact (Reference Hardness block (cont.)

Nominal value	**180 HBW10/3000**		**200 HBW10/3000**		**300 HBW10/3000**	
Lab$_i$	x_i **HBW10/3000**	$u(x_i)$ **HBW10/3000**	x_i **HBW10/3000**	$u(x_i)$ **HBW10/3000**	x_i **HBW10/3000**	$u(x_i)$ **HBW10/3000**
NIMT-Before	187.5	1.1	206.9	1.8	308.8	1.9
NMIJ	186.0	1.4	208.4	1.5	308.9	1.9
KRISS	187.0	2.6	208.6	2.9	309.4	4.3
NIMT-After	187.6	1.1	208.1	1.2	309.1	1.9

Table 8. The results of the measurement in HBW 10/3000: For Block Artifact (Reference Hardness block (cont.)

Nominal value	**400 HBW10/3000**		**500 HBW10/3000**		**550 HBW10/3000**	
Lab$_i$	x_i **HBW10/3000**	$u(x_i)$ **HBW10/3000**	x_i **HBW10/3000**	$u(x_i)$ **HBW10/3000**	x_i **HBW10/3000**	$u(x_i)$ **HBW10/3000**
NIMT-Before	407.2	2.4	496.4	3.0	573.0	3.4
NMIJ	408.2	2.1	496.9	2.1	573.5	2.0
KRISS	410.0	5.7	498.8	7.0	576.3	8.1
NIMT-After	408.1	2.4	496.8	3.0	573.8	3.4

6. Analyzing Method of Comparison Results

The measurement results are used to compute the degree of equivalence in Comparison Reference Value (CRV) and E_n number. The calculation is described in section 9 of the Technical protocol of the supplementary comparison of Brinell hardness APMP.M.H-S5 [1], [3] and [4].

The calculation is shown in following formulas:

- Calculation of Comparison Reference Value (CRV)

Pilot laboratory determined CRV by calculating the weighted mean of measurements of all participants (x_{crv}).

$$x_{crv} = \frac{\frac{x_1}{U^2(x_1)} + \frac{x_2}{U^2(x_2)} + \cdots + \frac{x_n}{U^2(x_n)}}{\frac{1}{U^2(x_1)} + \frac{1}{U^2(x_2)} + \cdots + \frac{1}{U^2(x_n)}}$$

- The uncertainty of the CRV was calculated by following expression:

$$\frac{1}{U^2(crv)} = \frac{1}{U^2(x_1)} + \frac{1}{U^2(x_2)} + \cdots + \frac{1}{U^2(x_n)}$$

Where:
x_i = The measured value of participating institute (= 1, 2, …, n)
$U(x_i)$= The expanded uncertainty of x_i

- Its deviation from CRV

$$d_i = x_i - x_{crv}$$

- $U(d_i)$was given by

$$U(d_i) = \sqrt{U^2(x_i) - U^2(x_{crv})}$$

- Evaluation of Coefficient E_n
  The degree of equivalence between the measurements of participating institutes was expressed by coefficient E_n as well.

$$E_n = \frac{x_i - x_{crv}}{U(d_i)}$$

7. Comparison Results

In case of the evaluation of the reference indentation, comparison reference value (X_{CRV}) was calculated by the average of measurements of all participants. The E_n number was not calculated for reference indentation since they show only the consistent of the diagonal measurement between NMI.

In case of the evaluation of the reference hardness block, comparison reference value (X_{CRV}) and E_n number were calculated as described in section 6

The comparison results, comparison reference value (X_{CRV}), the deviation value of each NMIs from CRV (d_i) as well as their uncertainty of their deviation ($U_{(di)}$) and E_n number were calculated and shown in Table 9 and Table 10, respectively. The overall comparison graphs were shown in Figure 1 to Figure 2. The comparison graphs based on the hardness scales were shown in Figure 3 to Figure 11.

The measurement results of the pilot lab composed of two different times measurement, measured before and measured after. The result that was used for calculate a degree of equivalent was the result from the measured after.

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Table 9. The deviation from comparison reference value in HBW 10/500 and HBW 10/3000: For Block Artifact

(Reference Indentation)

Scale	Nominal value	X_{CRV}, (mm)	Deviation from reference value (% of d), d_i		
			NIMT	NMIJ	KRISS
HBW 10/500	45	3.8918	-0.010	-0.002	0.012
	70	2.9382	0.043	-0.020	-0.023
	100	2.6153	0.072	0.085	-0.158
HBW 10/3000	180	4.3894	-0.034	-0.048	0.082
	200	4.2015	-0.021	-0.039	0.060
	300	3.4987	-0.021	0.016	0.005
	400	3.0175	0.001	0.038	-0.039
	500	2.7811	0.021	0.031	-0.052
	550	2.5739	0.061	0.048	-0.109

Table 10. The deviation from comparison reference value and E_n number in HBW 10/500 and HBW 10/3000: For Block Artifact (Reference Hardness Block)

Scale	Nominal value	X_{CRV} (HBW)	Deviation from reference value (% of HB), d_i			$U(X_{CRV})$ (%)	Uncertainty of Deviation (k =2) (% of HB), d_i			E_n numbers		
			NIMT	NMIJ	KRISS		NIMT	NMIJ	KRISS	NIMT	NMIJ	KRISS
HBW 10/500	45	41.3	0.05	-	-0.2	1.1	0.56	-	2.0	0.08	-	-0.08
	70	70.6	0.05	-	-0.2	1.1	0.54	-	2.1	0.10	-	-0.10
	100	90.97	0.22	-0.22	0.3	0.72	0.96	0.68	2.0	0.23	-0.32	0.16
HBW 10/3000	180	186.97	0.33	-0.52	0.0	0.44	0.40	0.61	1.3	0.81	-0.85	0.03
	200	208.23	-0.08	0.08	0.2	0.44	0.41	0.57	1.3	-0.20	0.13	0.13
	300	309.03	0.02	-0.05	0.1	0.41	0.44	0.46	1.3	0.05	-0.10	0.10
	400	408.33	-0.05	-0.02	0.4	0.38	0.47	0.35	1.3	-0.10	-0.06	0.30
	500	497.00	-0.03	-0.02	0.4	0.34	0.50	0.26	1.4	-0.06	-0.07	0.27
	550	573.73	0.01	-0.03	0.5	0.29	0.52	0.19	1.4	0.03	-0.18	0.33

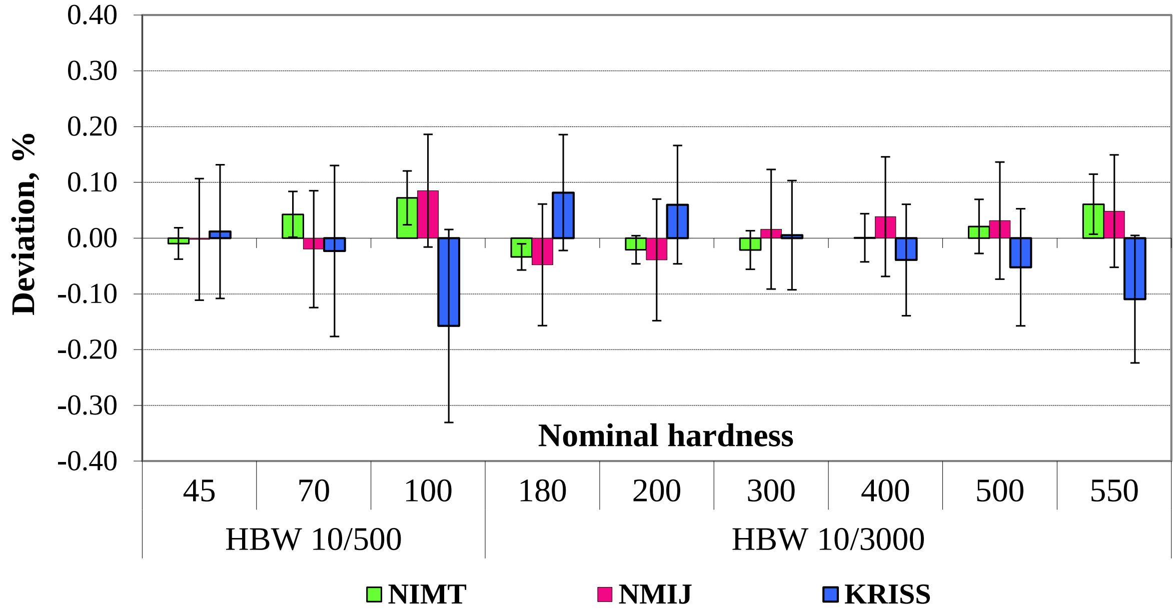

Figure 1. The overview of the deviation from the comparison reference value of Block artifact (Reference Indentation) for HBW 10/500 and HBW 10/3000

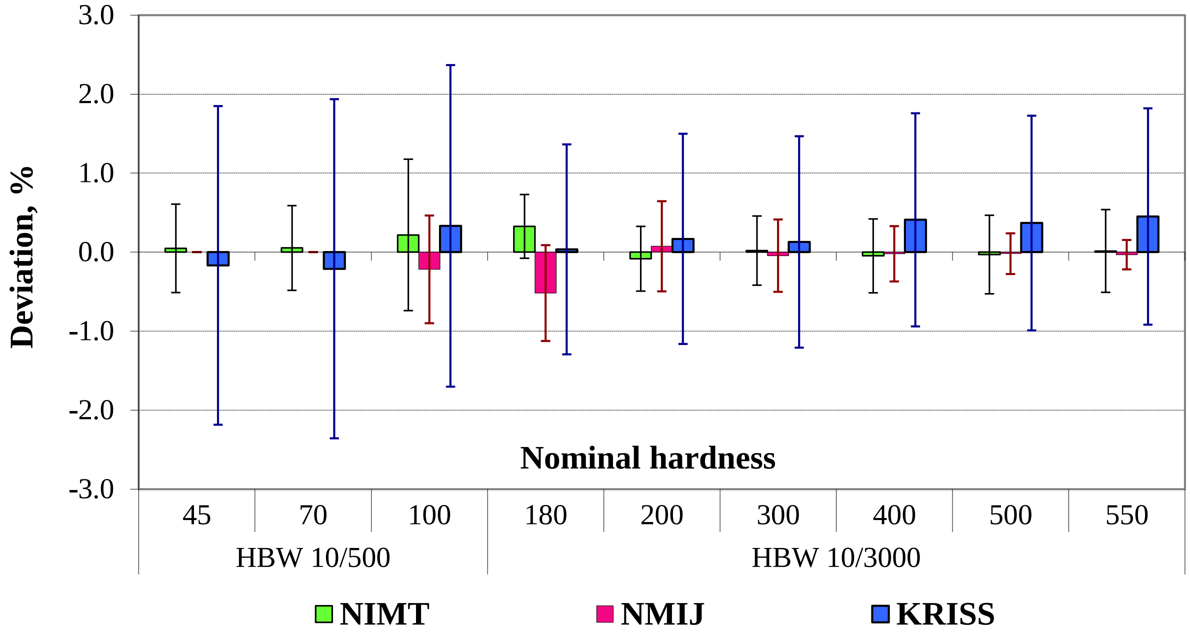

Figure 2. The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for HBW 10/500 and HBW 10/3000

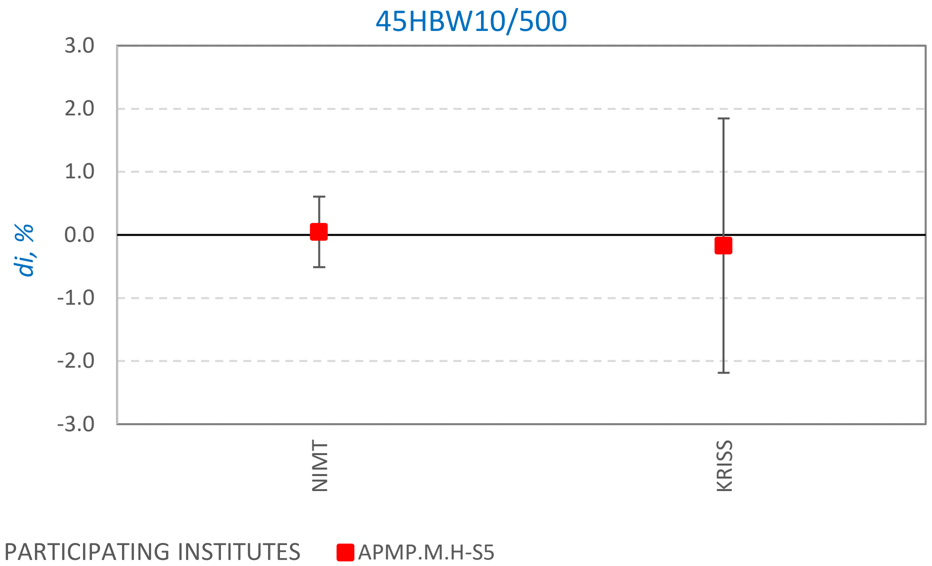

Figure 3. The deviation from the comparison reference value of Block artifact (Reference hardness block) for 45HBW 10/500

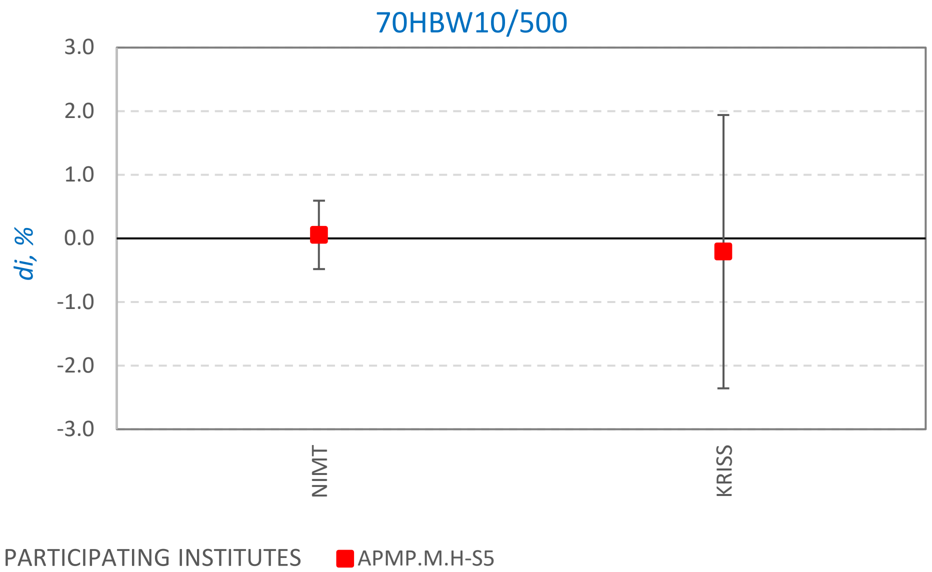

Figure 4. The deviation from the comparison reference value of Block artifact (Reference hardness block) for 70HBW 10/500

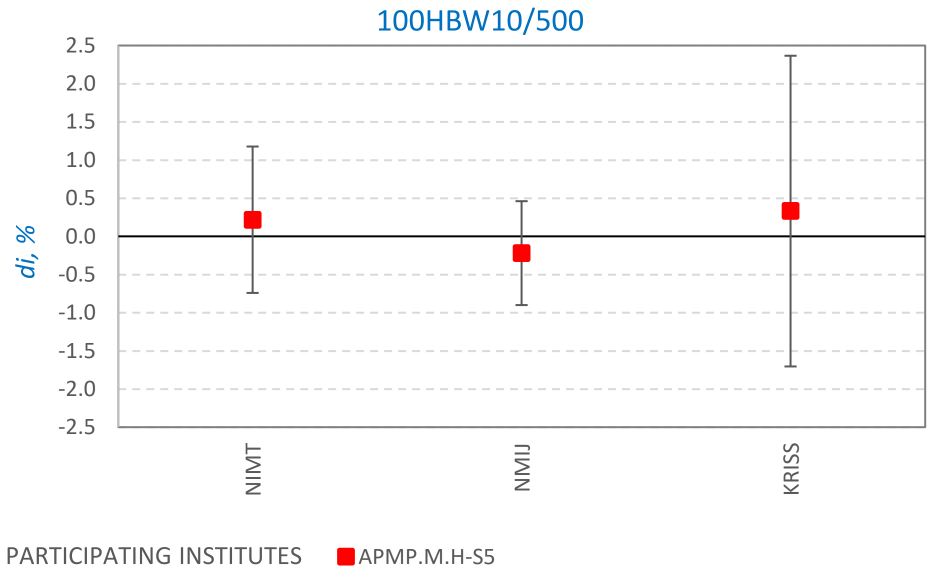

Figure 5. The deviation from the comparison reference value of Block artifact (Reference hardness block) for 100HBW 10/500

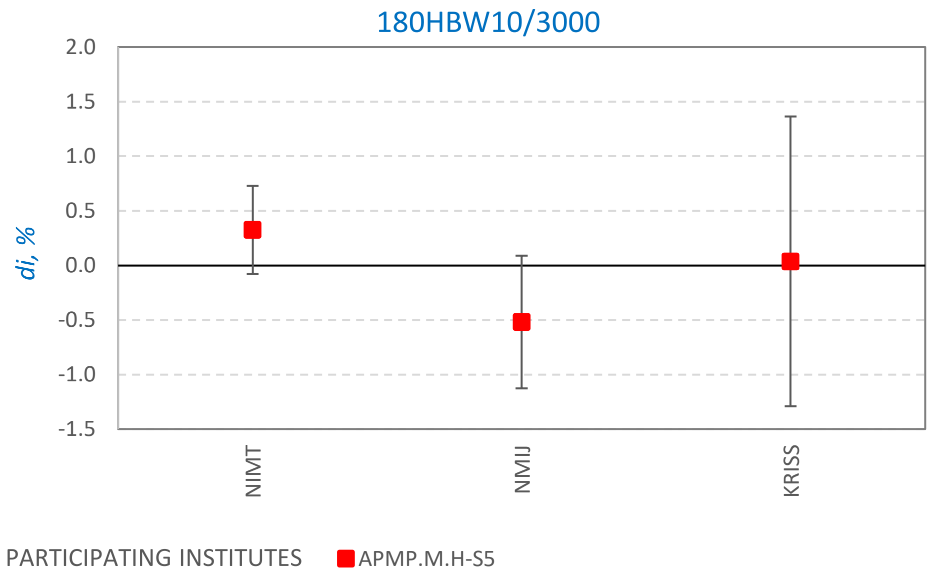

Figure 6. The deviation from the comparison reference value of Block artifact (Reference hardness block) for 180HBW 10/3000

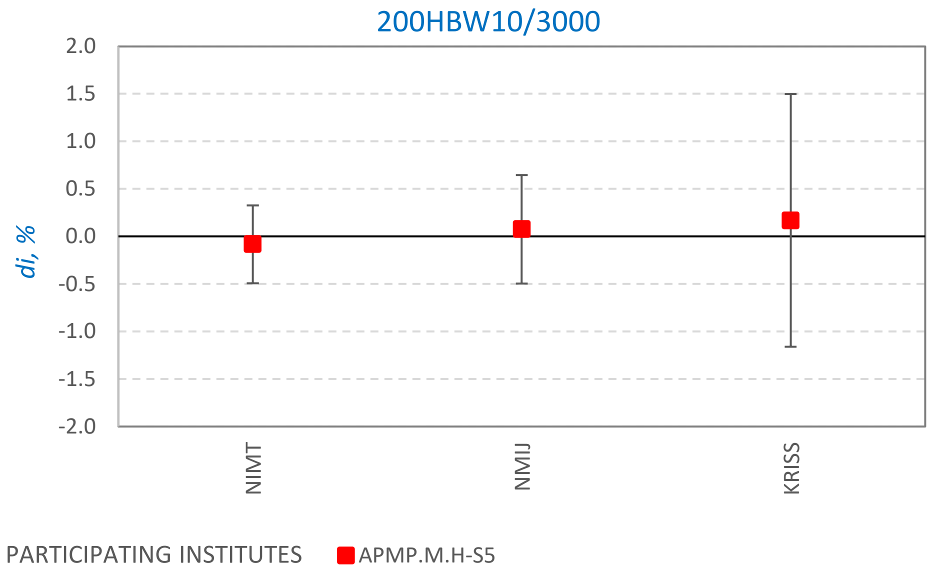

Figure 7. The deviation from the comparison reference value of Block artifact (Reference hardness block) for 200HBW 10/3000

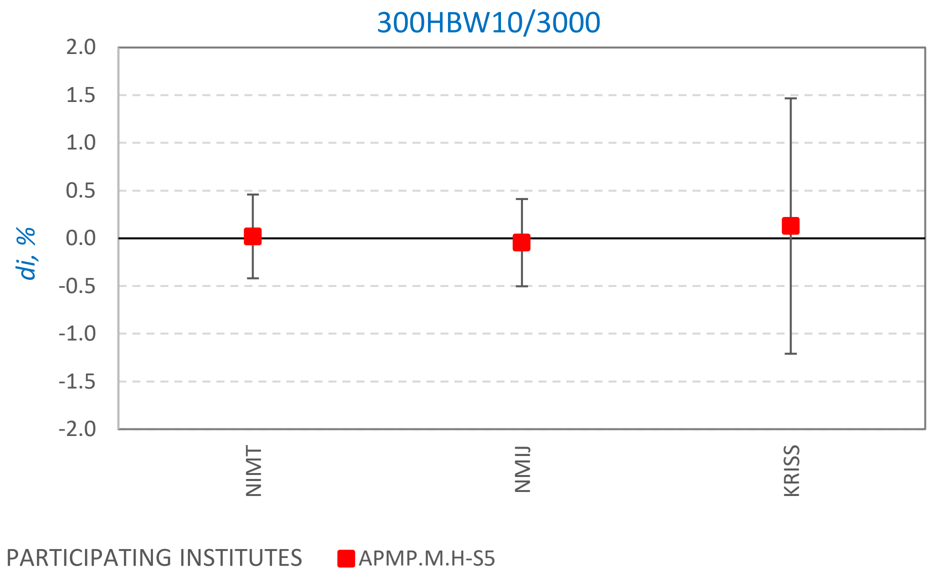

Figure 8. The deviation from the comparison reference value of Block artifact (Reference hardness block) for 300HBW 10/3000

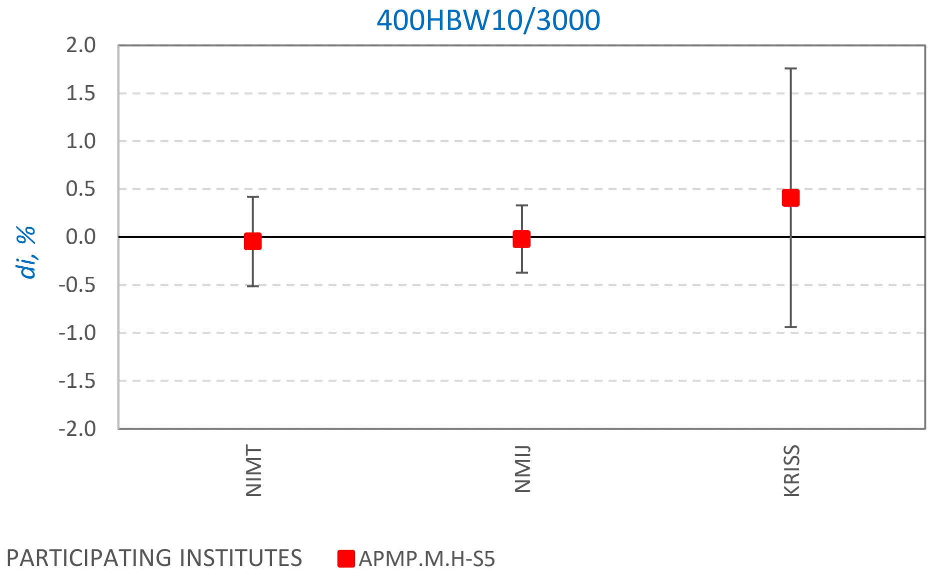

Figure 9. The deviation from the comparison reference value of Block artifact (Reference hardness block) for 400HBW 10/3000

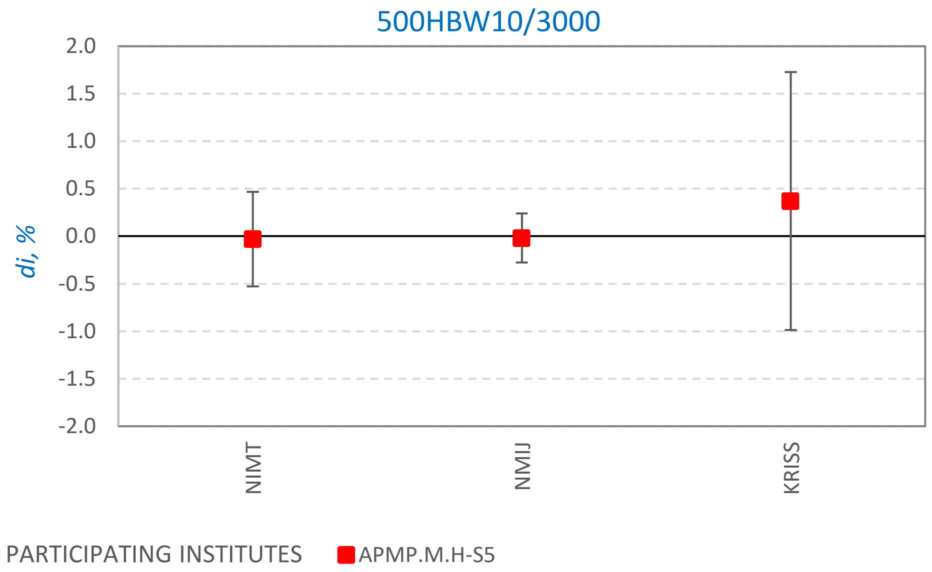

Figure 10. The deviation from the comparison reference value of Block artifact (Reference hardness block) for 500HBW 10/3000

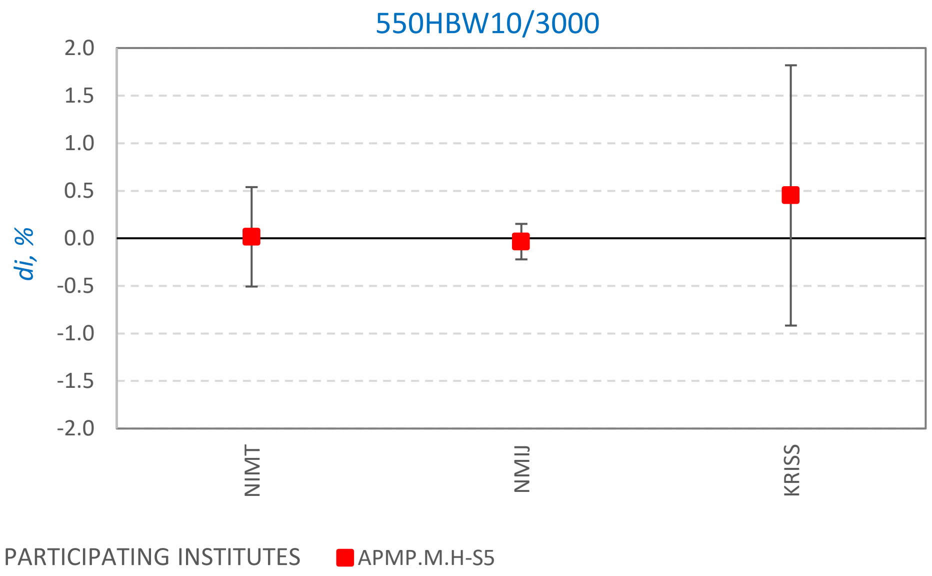

Figure 11. The deviation from the comparison reference value of Block artifact (Reference hardness block) for 550HBW 10/3000

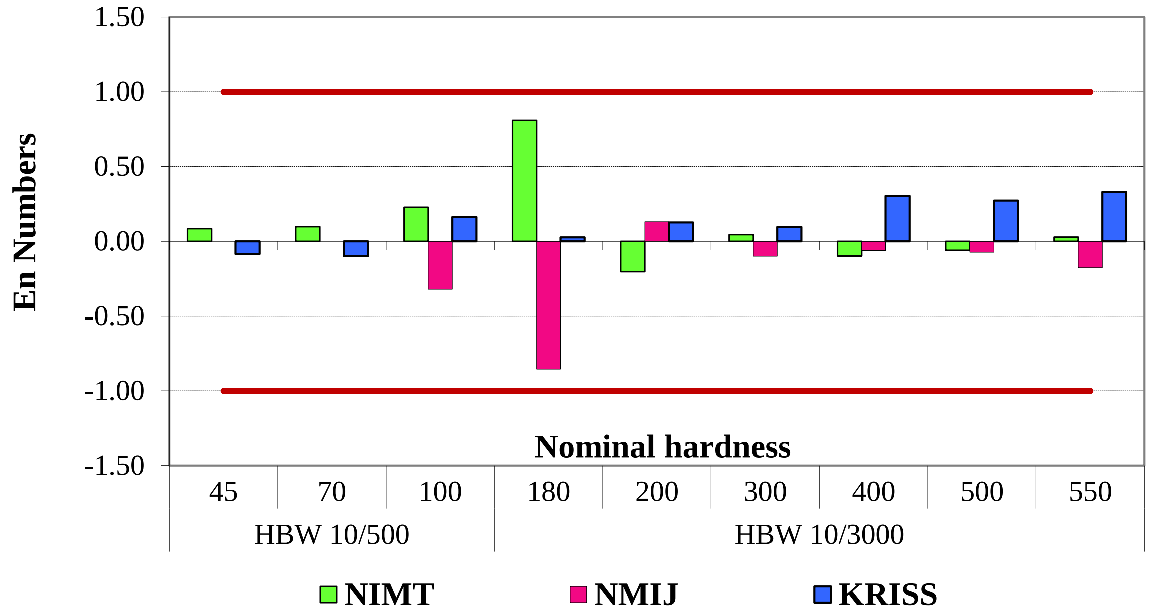

Figure 12. E_n numbers of APMP M.H-S5 supplementary comparison on Brinell hardness scale HBW10/500 and HBW 10/3000

Regarding to the pilot lab results of measured before and measured after, the deviation between each other of reference indentation measurement are agreed within ± 0.05 % of *d* (Table 11 and Figure 13) which is smaller than the overview of the deviation from all participant which are agreed within ±0.20 % of *d*

Table 11. Deviation of pilot measurement results (diameter of reference indentation), measured before and measured after circulation of block artifacts, for HBW 10/500 and HBW 10/3000.

Scale	Nominal value	$X_{CRV,}$ (mm)	Deviation from X_{CRV}, d_i %	
			NIMT-BF	NIMT-AF
HBW 10/500	45	3.8928	0.039	-0.035
	70	2.9396	0.006	-0.005
	100	2.6168	-0.016	0.016
HBW 10/3000	180	4.3880	0.000	0.000
	200	4.2007	0.002	-0.002
	300	3.4979	0.000	0.000
	400	3.0175	-0.003	0.003
	500	2.7814	-0.007	0.007
	550	2.5755	-0.001	0.001

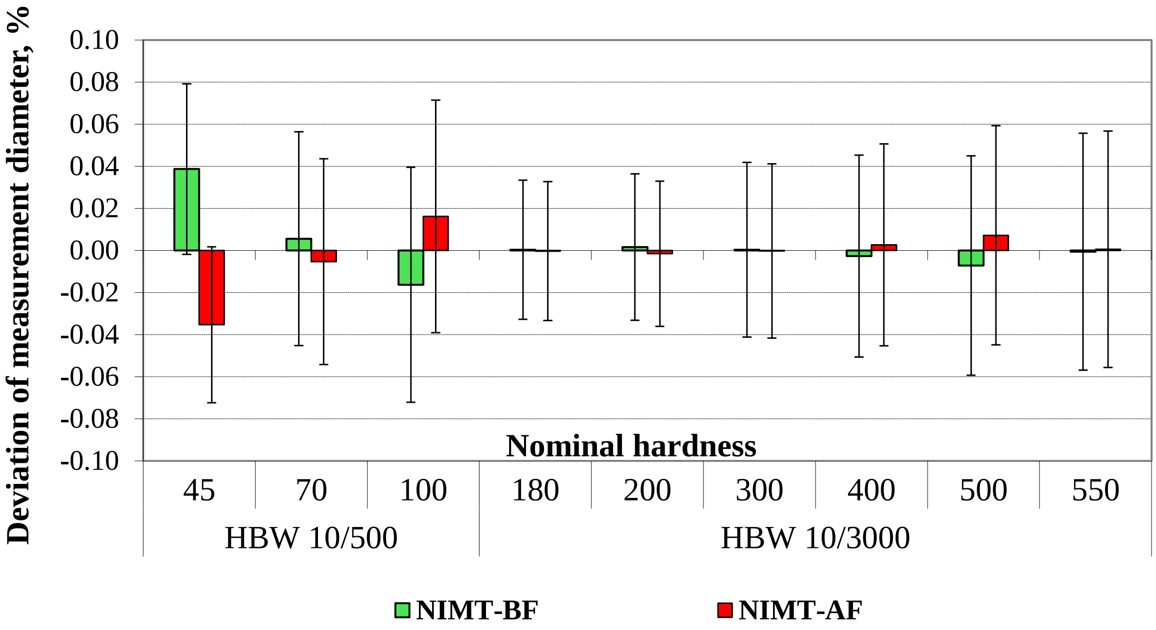

Figure 13. Deviation of pilot measurement results (reference indentation), measured before and measured after circulation of block artifacts, for HBW 10/500 and HBW 10/3000.

Moreover, the measurement results, measured before and measured after of reference hardness block artifact are agreed within ±0.4 % of Brinell hardness and $|E_n|$ number is less than 1, which is satisfactory. The results are presented in Table 12 and Figure 14 to Figure 15.

Table 12. Deviation of pilot measurement results and the E_n numbers (Reference Hardness block), measured before and measured after circulation of block artifact, for HBW10/500 and HBW 10/3000.

Scale	Nominal value	X_{CRV} (HBW)	Deviation from X_{CRV}, d_i %		$U(X_{CRV})$ (%)	Uncertainty of Deviation (k=2), $U(d_i)$%		E_n numbers	
			NIMT-BF	NIMT-AF		NIMT-BF	NIMT-AF	NIMT-BF	NIMT-AF
HBW 10/500	45	41.39	0.14	-0.14	0.85	0.85	0.85	0.17	-0.17
	70	70.78	0.25	-0.25	0.85	0.85	0.85	0.30	-0.30
	100	91.10	-0.07	0.07	0.85	0.85	0.85	-0.08	0.08
HBW 10/3000	180	187.57	-0.01	0.01	0.42	0.42	0.42	-0.02	0.02
	200	207.70	-0.37	0.17	0.50	0.74	0.34	-0.50	0.51
	300	308.95	-0.04	0.04	0.42	0.42	0.42	-0.10	0.10
	400	407.66	-0.12	0.12	0.42	0.42	0.42	-0.28	0.28
	500	496.60	-0.05	0.05	0.42	0.42	0.42	-0.12	0.12
	550	573.39	-0.07	0.07	0.42	0.42	0.42	-0.17	0.17

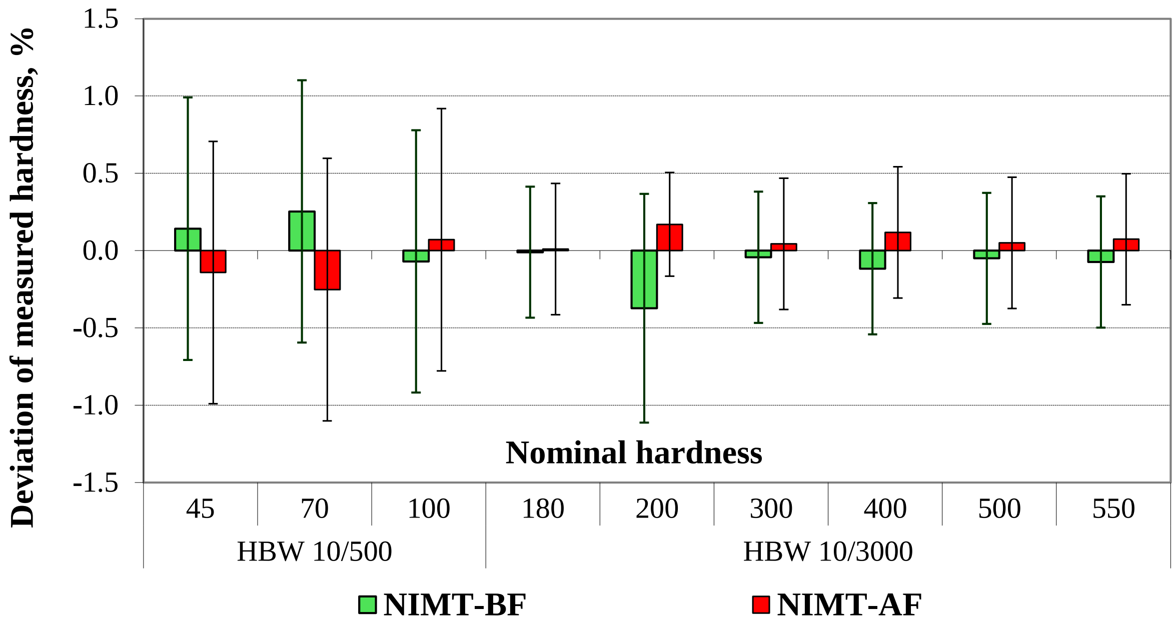

Figure 14. Deviation of pilot measurement results (reference hardness block), measured before and measured after circulation of block artifacts, for HBW 10/500 and HBW 10/3000.

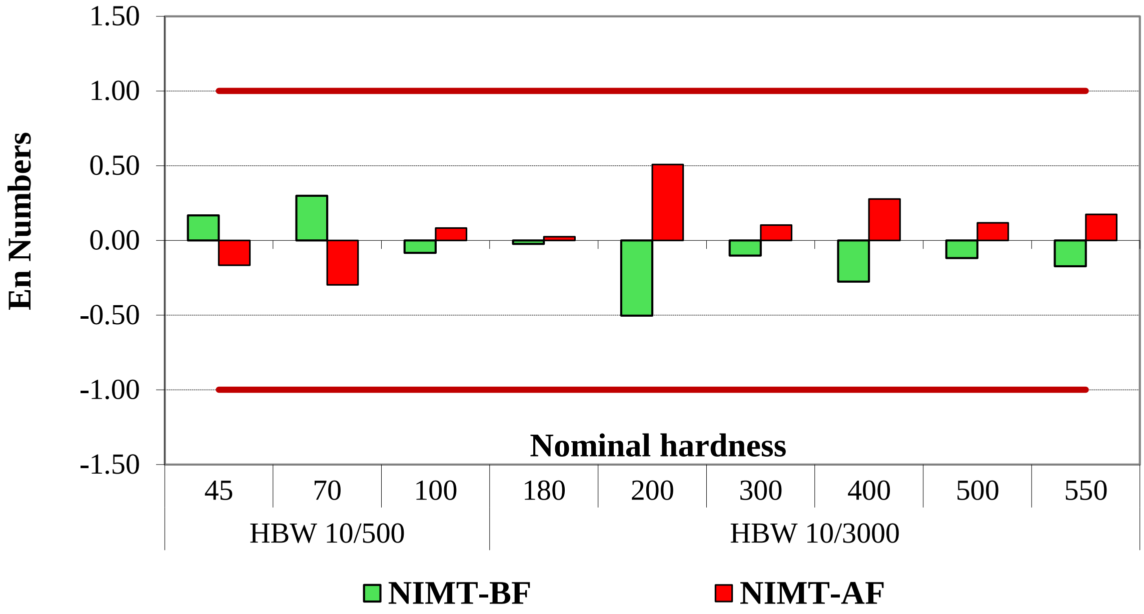

Figure 15. E_n number of the pilot laboratory results measured before and measured after of block artifact (Reference Hardness Block) for HBW 10/500 and HBW 10/3000

8. Conclusion

The APMP.M.H-S5 comparison can be supposed as a successful metrological exercise. In case of reference hardness block, the deviation from comparison reference value and E_n number of all participants is presented in Table 13. The overall comparison result in term of E_n number is presented in Figure 12.

Table 13. The deviation from comparison reference value and E_n numbers for Brinell hardness scale HBW 10/500 and HBW 10/3000

Hardness scale	The deviation from comparison reference value (% of HB)	E_n number
HBW10/500	-0.21 to 0.33	-0.32 to 0.23
HBW 10/3000	-0.08 to 0.45	-0.85 to 0.81

The supplementary comparison of Brinell hardness for scale HBW 10/500 and HBW 10/3000 of all participant gave the $|E_n| \leq 1$, which is totally acceptable.

9. References

[1] Technical protocol of the Supplementary Comparison of Brinell Hardness (APMP.M.H-S5)

[2] ISO 6506-3: Metallic materials-Brinell hardness test-Part 3: Calibration of reference blocks

[3] GUM: Guide to the Expression of "Uncertainty in Measurement"; edition 1993, corrected and reprinted 1995, International Organization for Standardization, Geneva, Switzerland

[4] M. G. Cox Metrologia 2002, The evaluation of key comparison data, 2002, 39, 589-595

Appendix A Description of the instrument

**National Metrology Institute of Japan,
National Institute of Advanced Industrial Science and Technology (NMIJ/AIST)**

General Information of Standardized Hardness Machine	
Model of standardized hardness machine	SHT-5
Serial number of standardized hardness machine	20002
Manufacturer of standardized hardness machine	Akashi Co.
Uncertainty of standardized hardness machine	**Result ± Uncertainty**
for HBW10 / 500 & HBW 10 / 3000	-
Calibration and Measurement Capabilities (CMCs)	**CMCs**
for HBW10 / 500 & HBW 10 / 3000	$(0.89 + 0.19/d - 1.1\text{x}10^{-3}H)$ %
	d : indentation diameter [mm], H : Brinell hardness [HBW]

General Information of Indentation Diameter Measuring System	
Model of indentation diameter measuring system	MF-U2010B
Serial number of indentation diameter measuring system	200010803
Manufacturer of indentation diameter measuring system	Mitutoyo
Uncertainty	**Result ± Uncertainty**
Stage for 50x N.A. 0.55, measuring length 0 to 5 mm	±0.4 μm
Optical resolutions	0.7 μm (N.A. 0.42) 0.6 μm (N.A. 0.55)

Force	Result ± Uncertainty
Test Force F 4,903N (HBW10/500)	±0.1 %
Test Force F 29,420N (HBW10/3000)	±0.1 %
Testing conditions	**Result ± Uncertainty**
Approach velocity of the indenter	less than 1 mm/s (no uncertainty)
Application of test force t_{0-1} (7 s)	±1 s
Test force duration time t_1 (14 s)	±1 s
Indenter geometry	**Result ± Uncertainty**
Diameter of the ball (10 mm)	±3 μm

Environment of comparison measurement	
Measurement place	AIST Central 3, hardenss lab.
Measurement date	July 13 to July 23, 2018
Environment (temperature/humidity)	22.0 °C ±1 °C / 40 %

Korea Research Institute of Standards and Science (KRISS)

General Information of Standardized Hardness Machine	
Model of standardized hardness machine	SHT-5
Serial number of standardized hardness machine	30003
Manufacturer of standardized hardness machine	Akashi Japan
Uncertainty of standardized hardness machine	**Result ± Uncertainty**
for HBW10/500	1.8%
for HBW10/3000	(1.2~1.3)%
Calibration and Measurement Capabilities (CMCs)	**CMCs**
for HBW10/500	2.0%
for HBW10/3000	1.4%

General Information of Indentation Diameter Measuring System	
Model of indentation diameter measuring system	WHM
Serial number of indentation diameter measuring system	54660
Manufacturer of indentation diameter measuring system	LEITZ
Uncertainty	**Result ± Uncertainty**
With Lens X40, measuring length 0 to 4.5 mm	0.002 6 mm
With Lens X60 , measuring length 0 to 3.5 mm	0.002 0mm

Force	**Result ± Uncertainty**
Test Force F 4,903N (HBW10/500)	4902.27 N ± 0.033%
Test Force F 29,420N (HBW10/3000)	29425.00 N ± 0.014%
Testing conditions	**Result ± Uncertainty**
Approach velocity of the indenter	(0.20 ± 0.02) mm/s
Application of test force t_{0-1}	(5 ± 0.2) s
Test force duration time t_1	(13 ± 0.2) s
Indenter geometry	**Result ± Uncertainty**
Diameter of the ball	(10.000 ± 0.002) mm

Environment of comparison measurement	
Measurement place	KRISS hardness lab.
Measurement date	15 Oct. 2018
Environment (temperature/humidity)	23 °C/ 45 %

National Institute of Metrology (Thailand)

General Information of Standardized Hardness Machine	
Model of standardized hardness machine	Z-10, Z50
Serial number of standardized hardness machine	DO721408/2014, DO721406/2014
Manufacturer of standardized hardness machine	Zwick/Roell
Uncertainty of standardized hardness machine	**Result ± Uncertainty**
for HBW10 / 500	-
for HBW10 / 3000	-
Calibration and Measurement Capabilities (CMCs)	**CMCs**
for HBW10 / 500	1.2 % of HB
for HBW10 / 3000	0.6 % of HB

General Information of Indentation Diameter Measuring System	
Model of indentation diameter measuring system	MFA-1720
Serial number of indentation diameter measuring system	210104
Manufacturer of indentation diameter measuring system	Mitutoyo Corporation
Uncertainty	**Result ± Uncertainty**
Stage for20x N.A. 0.42, measuring length 0.2 to 0.9 mm	±0.5 μm
Stage for20x N.A. 0.42, measuring length 1 to 2 mm	±1.0 μm
Stage for20x N.A. 0.42, measuring length 3 to 7 mm	±2.0 μm
Optical resolutions	0.72 μm (20X lens, N.A. 0.42)

Force	**Result ± Uncertainty**
Test Force F 4,903N (HBW10/500)	±0.1 %
Test Force F 29,420N (HBW10/3000)	±0.1 %
Testing conditions	**Result ± Uncertainty**
Approach velocity of the indenter	less than 1 mm/s (no uncertainty)
Application of test force t_{0-1} (7 s)	±1 s
Test force duration time t_1 (14 s)	±1 s
Indenter geometry	**Result ± Uncertainty**
Diameter of the ball (10 mm)	±3 μm

Environment of comparison measurement	
Measurement place	NIMT, hardenss lab.
Measurement date	January 29, 2018 to February 3, 2018
Environment (temperature/humidity)	22.0 ± 2 °C / 50 ± 5 %RH

Appendix B Uncertainty budgets of the participants

Uncertainty Budget of NMIJ

Short description:
The following tables show the full uncertainty budget of NMIJ Brinell hardenss measurement for the participated hardenss levels and scales.
The estimated unceratinty indicating the one of best measurement capability (BMC) of Brinel harndess measurement in NMIJ.
The conventional measurement capabilities (CMCs) also shown in the last line of each tables.

100 HBW 10 / 500

	source of uncertainty		estimated value	unit	Limit value $\pm a$	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, c_i	unit	uncertainty contribution $u_i(H)$	type
	division	subdivision										
1	Force	-	4903.3	N	4.9E+00	Rectangle	1.42E+00	N	2.04E-02	HBW/N	2.89E-02	B
2	Length measuring device	Length measuring device	2.503	mm	2.0E-04	Rectangle	1.15E-04	mm	-8.12E+01	HBW/mm	9.38E-03	B
3		Repeat-ability of readings	0	mm	3.1E-03	Rectangle	1.81E-03	mm	-8.12E+01	HBW/mm	1.47E-01	B
4	Indenter geometry	Diameter of the ball	10	mm	3.0E-03	Rectangle	1.73E-03	mm	3.29E-01	HBW/mm	5.69E-04	B
5	Testing cycle	Force application time	7	s	1	Rectangle	5.77E-01	s	8.66E-02	HBW/s	5.00E-02	B
6		Test force duration	14	s	1	Rectangle	5.77E-01	s	-1.41E-01	HBW/s	8.13E-02	B
7	Uniformity of Blocks	-	100	HBW	5.0E-01	Rectangle	1.29E-01	HBW	1.00E+00	-	1.29E-01	B
standard uncertainty, u [HBW]											0.2	
expanded uncertainty, U [HBW] (k=2)											0.4	
expanded uncertainty, U [HBW] (k=2) in CMC											**0.9**	**HBW**
relative expanded uncertainty, U/H [%] (k=2) in CMC											**0.9**	**%**

180 HBW 10 / 3000

	source of uncertainty		estimated value	unit	Limit value $\pm a$	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, c_i	unit	uncertainty contribution $u_i(H)$	type
	division	subdivision										
1	Force	-	29420	N	2.9E+01	Rectangle	8.49E+00	N	6.12E-03	HBW/N	5.20E-02	B
2	Length measuring device	Length measuring device	4.483	mm	2.0E-04	Rectangle	1.15E-04	mm	-8.51E+01	HBW/mm	9.82E-03	B
3		Repeat-ability of readings	0	mm	1.0E-02	Rectangle	5.80E-03	mm	-8.51E+01	HBW/mm	4.94E-01	B
4	Indenter geometry	Diameter of the ball	10	mm	3.0E-03	Rectangle	1.73E-03	mm	2.14E+00	HBW/mm	3.70E-03	B
5	Testing cycle	Force application time	7	s	1	Rectangle	5.77E-01	s	1.04E-01	HBW/s	6.00E-02	B
6		Test force duration	14	s	1	Rectangle	5.77E-01	s	-1.29E-01	HBW/s	7.46E-02	B
7	Uniformity of Blocks	-	180	HBW	9.0E-01	Rectangle	2.32E-01	HBW	1.00E+00	-	2.32E-01	B
standard uncertainty, u [HBW]											0.6	
expanded uncertainty, U [HBW] (k=2)											1.1	
expanded uncertainty, U [HBW] (k=2) in CMC											**1.4**	**HBW**
relative expanded uncertainty, U/H [%] (k=2) in CMC											**0.74**	**%**

NMIJ 2/ 3

200 HBW 10 / 3000

	source of uncertainty		estimated value	unit	Limit value $\pm a$	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, c_i	unit	uncertainty contribution $u_i(H)$	type
	division	subdivision										
1	Force	-	29420	N	2.9E+01	Rectangle	8.49E+00	N	6.80E-03	HBW/N	5.77E-02	B
2	Length measuring device	Length measuring device	4.265	mm	2.0E-04	Rectangle	1.15E-04	mm	-9.87E+01	HBW/mm	1.14E-02	B
3		Repeat-ability of readings	0	mm	9.1E-03	Rectangle	5.25E-03	mm	-9.87E+01	HBW/mm	5.18E-01	B
4	Indenter geometry	Diameter of the ball	10	mm	3.0E-03	Rectangle	1.73E-03	mm	2.11E+00	HBW/mm	3.66E-03	B
5	Testing cycle	Force application time	7	s	1	Rectangle	5.77E-01	s	1.08E-01	HBW/s	6.25E-02	B
6		Test force duration	14	s	1	Rectangle	5.77E-01	s	-1.26E-01	HBW/s	7.29E-02	B
7	Uniformity of Blocks	-	200	HBW	1.0E+00	Rectangle	2.58E-01	HBW	1.00E+00	-	2.58E-01	B
standard uncertainty, u [HBW]											0.6	
expanded uncertainty, U [HBW] (k=2)											1.2	
expanded uncertainty, U [HBW] (k=2) in CMC											**1.5**	**HBW**
relative expanded uncertainty, U/H [%] (k=2) in CMC											**0.72**	**%**

300 HBW 10 / 3000

	source of uncertainty		estimated value	unit	Limit value $\pm a$	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, c_i	unit	uncertainty contribution $u_i(H)$	type
	division	subdivision										
1	Force	-	29420	N	2.9E+01	Rectangle	8.49E+00	N	1.02E-02	HBW/N	8.66E-02	B
2	Length measuring device	Length measuring device	3.511	mm	2.0E-04	Rectangle	1.15E-04	mm	-1.77E+02	HBW/mm	2.04E-02	B
3		Repeat-ability of readings	0	mm	6.2E-03	Rectangle	3.56E-03	mm	-1.77E+02	HBW/mm	6.29E-01	B
4	Indenter geometry	Diameter of the ball	10	mm	3.0E-03	Rectangle	1.73E-03	mm	2.04E+00	HBW/mm	3.53E-03	B
5	Testing cycle	Force application time	7	s	1	Rectangle	5.77E-01	s	1.30E-01	HBW/s	7.51E-02	B
6		Test force duration	14	s	1	Rectangle	5.77E-01	s	-1.12E-01	HBW/s	6.45E-02	B
7	Uniformity of Blocks	-	300	HBW	1.5E+00	Rectangle	3.87E-01	HBW	1.00E+00	-	3.87E-01	B
standard uncertainty, u [HBW]											0.8	
expanded uncertainty, U [HBW] (k=2)											1.5	
expanded uncertainty, U [HBW] (k=2) in CMC											**1.9**	**HBW**
relative expanded uncertainty, U/H [%] (k=2) in CMC											**0.62**	**%**

400 HBW 10 / 3000

	source of uncertainty		estimated value	unit	Limit value $\pm a$	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, c_i	unit	uncertainty contribution $u_i(H)$	type
	division	subdivision										
1	Force	-	29420	N	2.9E+01	Rectangle	8.49E+00	N	1.36E-02	HBW/N	1.15E-01	B
2	Length measuring device	Length measuring device	3.053	mm	2.0E-04	Rectangle	1.15E-04	mm	-2.69E+02	HBW/mm	3.10E-02	B
3		Repeat-ability of readings	0	mm	4.7E-03	Rectangle	2.69E-03	mm	-2.69E+02	HBW/mm	7.23E-01	B
4	Indenter geometry	Diameter of the ball	10	mm	3.0E-03	Rectangle	1.73E-03	mm	2.01E+00	HBW/mm	3.47E-03	B
5	Testing cycle	Force application time	7	s	1	Rectangle	5.77E-01	s	1.52E-01	HBW/s	8.76E-02	B
6		Test force duration	14	s	1	Rectangle	5.77E-01	s	-9.72E-02	HBW/s	5.61E-02	B
7	Uniformity of Blocks	-	400	HBW	1.0E+00	Rectangle	2.58E-01	HBW	1.00E+00	-	2.58E-01	B
standard uncertainty, u [HBW]											0.8	
expanded uncertainty, U [HBW] (k=2)											1.6	
expanded uncertainty, U [HBW] (k=2) in CMC											**2.1**	**HBW**
relative expanded uncertainty, U/H [%] (k=2) in CMC											**0.52**	**%**

500 HBW 10 / 3000

	source of uncertainty		estimated value	unit	Limit value ± a	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, c_i	unit	uncertainty contribution $u_i(H)$	type
	division	subdivision										
1	Force	-	29420	N	2.9E+01	Rectangle	8.49E+00	N	1.70E-02	HBW/N	1.44E-01	B
2	Length measuring device	Length measuring device	2.737	mm	2.0E-04	Rectangle	1.15E-04	mm	-3.73E+02	HBW/mm	4.30E-02	B
3		Repeat-ability of readings	0	mm	3.7E-03	Rectangle	2.16E-03	mm	-3.73E+02	HBW/mm	8.06E-01	B
4	Indenter geometry	Diameter of the ball	10	mm	3.0E-03	Rectangle	1.73E-03	mm	1.99E+00	HBW/mm	3.44E-03	B
5	Testing cycle	Force application time	7	s	1	Rectangle	5.77E-01	s	1.74E-01	HBW/s	1.00E-01	B
6		Test force duration	14	s	1	Rectangle	5.77E-01	s	-8.27E-02	HBW/s	4.77E-02	B
7	Uniformity of Blocks	-	500	HBW	1.3E+00	Rectangle	3.23E-01	HBW	1.00E+00	-	3.23E-01	B
standard uncertainty, u [HBW]											0.9	
expanded uncertainty, U [HBW] (k=2)											1.8	
expanded uncertainty, U [HBW] (k=2) in CMC											**2.1**	**HBW**
relative expanded uncertainty, U/H [%] (k=2) in CMC											**0.41**	**%**

550 HBW 10 / 3000

	source of uncertainty		estimated value	unit	Limit value ± a	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, c_i	unit	uncertainty contribution $u_i(H)$	type
	division	subdivision										
1	Force	-	29420	N	2.9E+01	Rectangle	8.49E+00	N	1.87E-02	HBW/N	1.59E-01	B
2	Length measuring device	Length measuring device	2.612	mm	2.0E-04	Rectangle	1.15E-04	mm	-4.29E+02	HBW/mm	4.95E-02	B
3		Repeat-ability of readings	0	mm	3.4E-03	Rectangle	1.97E-03	mm	-4.29E+02	HBW/mm	8.44E-01	B
4	Indenter geometry	Diameter of the ball	10	mm	3.0E-03	Rectangle	1.73E-03	mm	1.98E+00	HBW/mm	3.43E-03	B
5	Testing cycle	Force application time	7	s	1	Rectangle	5.77E-01	s	1.84E-01	HBW/s	1.06E-01	B
6		Test force duration	14	s	1	Rectangle	5.77E-01	s	-7.54E-02	HBW/s	4.35E-02	B
7	Uniformity of Blocks	-	550	HBW	1.4E+00	Rectangle	3.55E-01	HBW	1.00E+00	-	3.55E-01	B
standard uncertainty, u [HBW]											0.9	
expanded uncertainty, U [HBW] (k=2)											1.9	
expanded uncertainty, U [HBW] (k=2) in CMC											**2.0**	**HBW**
relative expanded uncertainty, U/H [%] (k=2) in CMC											**0.36**	**%**

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Report Form 4.1:Uncertainty Budget of *Block Artifact*

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Brinell Scale : HBW10/500

Uncertainty budget of hardness block 45 HBW10/500 S/N : 1/45: AZ40322B

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/500	0.39	Normal	1	0.39
Resolution of machine, H_{res}	HBW10/500	0.010	Rectangular	-22.30	0.22
Repeatability of measurement, H_{rep}	HBW10/500	0.0063	Normal	-22.30	0.14
Measured hardness, H_{mh}	HBW10/500	41.24	Combined uncertainty, u_c		0.47
			Expanded uncertainty, Ue k=2		0.94

Uncertainty budget of hardness block 70 HBW10/500 S/N : 1/70 : AZ75324B

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/500	0.67	Normal	1.0	0.67
Resolution of machine, H_{res}	HBW10/500	0.010	Rectangular	-47.5	0.48
Repeatability of measurement, H_{rep}	HBW10/500	0.0043	Normal	-47.5	0.20
Measured hardness, H_{mh}	HBW10/500	70.42	Combined uncertainty, u_c		0.85
			Expanded uncertainty, Ue k=2		1.69

Uncertainty budget of hardness block 100 HBW10/500 S/N : 1/100 : AZ100408G

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Normal Rectangular Normal	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/500	0.86	Normal	1.0	0.86
Resolution of machine, H_{res}	HBW10/500	0.005	Rectangular	-76.0	0.38
Repeatability of measurement, H_{rep}	HBW10/500	0.0039	Normal	-76.0	0.30
Measured hardness, H_{mh}	HBW10/500	91.27	Combined uncertainty, u_c		0.99
			Expanded uncertainty, Ue k=2		1.97

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Report Form 4.2:Uncertainty Budget of *Block Artifact*

Brinell Scale : HBW10/3000

Uncertainty budget of hardness block 180 HBW10/3000 S/N : 1/180: B91576

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/3000	1.22	Normal	1.0	1.22
Resolution of machine, H_{res}	HBW10/3000	0.0013	Rectangular	-86.4	0.11
Repeatability of measurement, H_{rep}	HBW10/3000	0.0029	Normal	-86.4	0.25
Measured hardness, H_{mh}	HBW10/3000	187.04	Combined uncertainty, u_c		1.25
			Expanded uncertainty, Ue k=2		2.50

Uncertainty budget of hardness block 200 HBW10/3000 S/N : 1/200: A92785

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/3000	1.35	Normal	1.0	1.35
Resolution of machine, H_{res}	HBW10/3000	0.0013	Rectangular	-104.8	0.14
Repeatability of measurement, H_{rep}	HBW10/3000	0.0030	Normal	-104.8	0.31
Measured hardness, H_{mh}	HBW10/3000	208.58	Combined uncertainty, u_c		1.39
			Expanded uncertainty, Ue k=2		2.78

Uncertainty budget of hardness block 300 HBW10/3000 S/N : 1/300: B94160

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/3000	2.01	Normal	1.0	2.01
Resolution of machine, H_{res}	HBW10/3000	0.0010	Rectangular	-184.8	0.18
Repeatability of measurement, H_{rep}	HBW10/3000	0.0035	Normal	-184.8	0.65
Measured hardness, H_{mh}	HBW10/3000	309.43	Combined uncertainty, u_c		2.12
			Expanded uncertainty, Ue k=2		4.24

Uncertainty budget of hardness block 400 HBW10/3000 S/N : 1/400: 94679

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/3000	2.46	Normal	1.0	2.46
Resolution of machine, H_{res}	HBW10/3000	0.0010	Rectangular	-278.4	0.28
Repeatability of measurement, H_{rep}	HBW10/3000	0.0020	Normal	-278.4	0.54
Measured hardness, H_{mh}	HBW10/3000	410.01	Combined uncertainty, u_c		2.53
			Expanded uncertainty, Ue k=2		5.07

Uncertainty budget of hardness block 500 HBW10/3000 S/N : 1/500: 95741

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/3000	2.99	Normal	1.0	2.99
Resolution of machine, H_{res}	HBW10/3000	0.0010	Rectangular	-371.2	0.37
Repeatability of measurement, H_{rep}	HBW10/3000	0.0008	Normal	-371.2	0.31
Measured hardness, H_{mh}	HBW10/3000	498.84	Combined uncertainty, u_c		3.03
			Expanded uncertainty, Ue k=2		6.06

Uncertainty budget of hardness block 550 HBW10/3000 S/N : 1/550: E2222

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/3000	3.46	Normal	1.0	3.46
Resolution of machine, H_{res}	HBW10/3000	0.0010	Rectangular	-459.1	0.46
Repeatability of measurement, H_{rep}	HBW10/3000	0.0027	Normal	-459.1	1.23
Measured hardness, H_{mh}	HBW10/3000	576.33	Combined uncertainty, u_c		3.70
			Expanded uncertainty, Ue k=2		7.40

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Report Form 4.1:Uncertainty Budget of *Block Artifact*

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Brinell Scale : HBW10/500

Uncertainty budget of hardness block 45 HBW10/500 S/N : 1/45: AZ40322B

Quantity Xi	Estimate xi		Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	41.33	HBW10/500	0.103	Normal	1.0	0.1
Resolution of machine, H_{res}	0	HBW10/500	0.0002	Rectangular	-22.4	0.0
Repeatability of measurement, H_{rep}	0	HBW10/500	0.14	Normal	1.0	0.1
Measured hardness, H_{mh}	41.33	HBW10/500		Combined uncertainty, u_c		0.17
				Expanded uncertainty, Ue		0.50

Uncertainty budget of hardness block 70 HBW10/500 S/N : 1/70 : AZ75324B

Quantity Xi	Estimate xi		Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	70.60	HBW10/500	0.177	Normal	1.0	0.2
Resolution of machine, H_{res}	0	HBW10/500	0.0002	Rectangular	-48.7	0.0
Repeatability of measurement, H_{rep}	0	HBW10/500	0.24	Normal	1.0	0.2
Measured hardness, H_{mh}	70.60	HBW10/500		Combined uncertainty, u_c		0.30
				Expanded uncertainty, Ue		0.85

Uncertainty budget of hardness block 100 HBW10/500 S/N : 1/100 : AZ100408G

Quantity Xi	Estimate xi		Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, $H_{hm\ (excluing\ non-unifm)}$	91.17	HBW10/500	0.228	Normal	1.0	0.2
Resolution of machine, H_{re}	0	HBW10/500	0.0002	Rectangular	-70.9	0.0
Repeatability of measurement, $H_{rep\ (non-u}$	0	HBW10/500	0.07	Normal	1.0	0.1
Measured hardness, H_{mh}	91.17	HBW10/500		Combined uncertainty, u_c		0.24
				Expanded uncertainty, Ue		1.09

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Report Form 4.1:Uncertainty Budget of *Block Artifact*

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Brinell Scale : HBW10/3000

Uncertainty budget of hardness block 180 HBW10/3000 S/N : 1/180: B91576

Quantity Xi	Estimate xi		Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, $H_{hm\ (excluing\ non\text{-}unifm)}$	187.58	HBW10/3000	0.469	Normal	1.0	0.47
Resolution of machine, H_{re}	0	HBW10/500	0.0002	Rectangular	-90.2	-0.02
Repeatability of measurement, $H_{rep\ (non\text{-}u}$	0	HBW10/500	0.11	Normal	1.0	0.11
Measured hardness, H_{mh}	187.58	HBW10/500		Combined uncertainty, u_c		0.48
				Expanded uncertainty, Ue		1.13

Uncertainty budget of hardness block 200 HBW10/3000 S/N : 1/200: A92785

Quantity Xi	Estimate xi		Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, $H_{hm\ (excluing\ non\text{-}unifm)}$	208.1	HBW10/3000	0.520	norm.	1.00	0.52
Resolution of machine, H_{re}	0	HBW10/500	0.0002	rect.	-104.4	-0.02
Repeatability of measurement, $H_{rep\ (non\text{-}u}$	0	HBW10/500	0.34	norm.	1.00	0.34
Measured hardness, H_{mh}	208.1	HBW10/500		Combined uncertainty, u_c		0.62
				Expanded uncertainty, Ue		1.25

Uncertainty budget of hardness block 300 HBW10/3000 S/N : 1/300: B94160

Quantity Xi	Estimate xi		Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, $H_{hm\ (excluing\ non\text{-}unifm)}$	309.1	HBW10/3000	0.773	norm.	1.00	0.77
Resolution of machine, H_{re}	0	HBW10/500	0.0002	rect.	-184.5	-0.04
Repeatability of measurement, $H_{rep\ (non\text{-}u}$	0	HBW10/500	0.33	norm.	1.00	0.33
Measured hardness, H_{mh}	309.1	HBW10/500		Combined uncertainty, u_c		0.84
				Expanded uncertainty, Ue		1.85

Uncertainty budget of hardness block 400 HBW10/3000 S/N : 1/400: 94679

Quantity Xi	Estimate xi		Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, $H_{hm\ (excluing\ non\text{-}unifm)}$	408.1	HBW10/3000	1.020	norm.	1.00	1.0
Resolution of machine, H_{re}	0	HBW10/500	0.0002	rect.	-276.6	-0.1
Repeatability of measurement, $H_{rep\ (non\text{-}u}$	0	HBW10/500	0.32	norm.	1.00	0.3
Measured hardness, H_{mh}	408.1	HBW10/500		Combined uncertainty, u_c		1.07
				Expanded uncertainty, Ue		2.45

Uncertainty budget of hardness block 500 HBW10/3000 S/N : 1/500: 95741

Quantity Xi	Estimate xi		Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, $H_{hm\ (excluing\ non\text{-}unifm)}$	496.8	HBW10/3000	1.242	norm.	1.00	1.2
Resolution of machine, H_{re}	0	HBW10/500	0.0002	rect.	-369.1	-0.1
Repeatability of measurement, $H_{rep\ (non\text{-}u}$	0	HBW10/500	0.19	norm.	1.00	0.2
Measured hardness, H_{mh}	496.8	HBW10/500		Combined uncertainty, u_c		1.26
				Expanded uncertainty, Ue		2.98

Uncertainty budget of hardness block 550 HBW10/3000 S/N : 1/550: E2222

Quantity Xi	Estimate xi		Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, $H_{hm\ (excluing\ non\text{-}unifm)}$	573.8	HBW10/3000	1.435	norm.	1.00	1.4
Resolution of machine, H_{re}	0	HBW10/500	0.0002	rect.	-456.3	-0.1
Repeatability of measurement, $H_{rep\ (non\text{-}u}$	0	HBW10/500	0.29	norm.	1.00	0.3
Measured hardness, H_{mh}	573.8	HBW10/500		Combined uncertainty, u_c		1.47
				Expanded uncertainty, Ue		3.44

Appendix C Technical protocol of supplementary comparison of Brinell hardness (APMP.M.H-S5)

สถาบันมาตรวิทยาแห่งชาติ
National Institute of Metrology (Thailand)

Technical Protocol of The Supplementary Comparison of Brinell Hardness

APMP.M.H-S5

2018
Piloted by NIMT

Content

Technical Protocol of
The Supplementary Comparison of Brinell Hardness
(APMP.M.H-S5)

1. Introduction

NIMT proposed a supplementary comparison of Brinell hardness measurement with the collaboration of Korea Research Institute of Standard and Science (KRISS) and National Metrology Institute of Japan (NMIJ). NIMT was nominated as the pilot laboratory of the comparison.

2. Measurand and artifact

In the supplementary comparison, the Brinell hardness measurement scale HBW10/500 and HBW10/3000 are used with the hardness level 45, 70 and 100 for HBW10/500 and 180, 200, 300, 400, 500 and 550 HBW10/3000. The circular shape reference hardness blocks as artifacts are manufactured by Asahi Giken Co., Ltd. Japan for hardness level 180, 200, 300, 400, 500 and 550 HBW10/3000, with dimensions of the blocks are 115 mm in diameter and 18 mm in thickness. Meanwhile, the square reference hardness blocks are manufactured by Euro products limited , England for hardness level 45, 70, 100 HBW10/500 have the dimensions of the blocks are 150× 125 × 16 mm.

It is well known that Brinell measurements are significantly affected by the diameter measurement especially the difference of number of aperture of objective lens [1, 2]. Therefore, in order to reflect the degree of equivalent of the hardness measurement and classify the effect of indentation diameter measurement, the comparison measurement are provided by 2 different set artifacts.

The first set is the set of Brinell hardness comparison: hardness measurement and indentation diameter measurement for participants. The hardness scale and artifact ID are presented in Table 1.

The second set is a set of indentation diameter measurement comparison for participants. The reference indentations prepared by pilot laboratory are presented in Table 1.

Scale	Hardness level	Artifact ID : S/N	
		Hardness measurement Set 1st	Reference indentation measurement Set 2nd
10/500	45	1/45: AZ40322B	2/45: AZ40308B
	70	1/70 : AZ75324B	2/70: AZ75341B
	100	1/100 : AZ100409G	2/100: AZ100408G
10/3000	180	1/180: B91576	2/180 : B91577
	200	1/200: A92785	2/200 : A92782
	300	1/300: B94160	2/300 : B94161
	400	1/400: 94679	2/400 : 94698
	500	1/500: 95741	2/500 : 95739
	550	1/550: E2222	2/550 : 90146

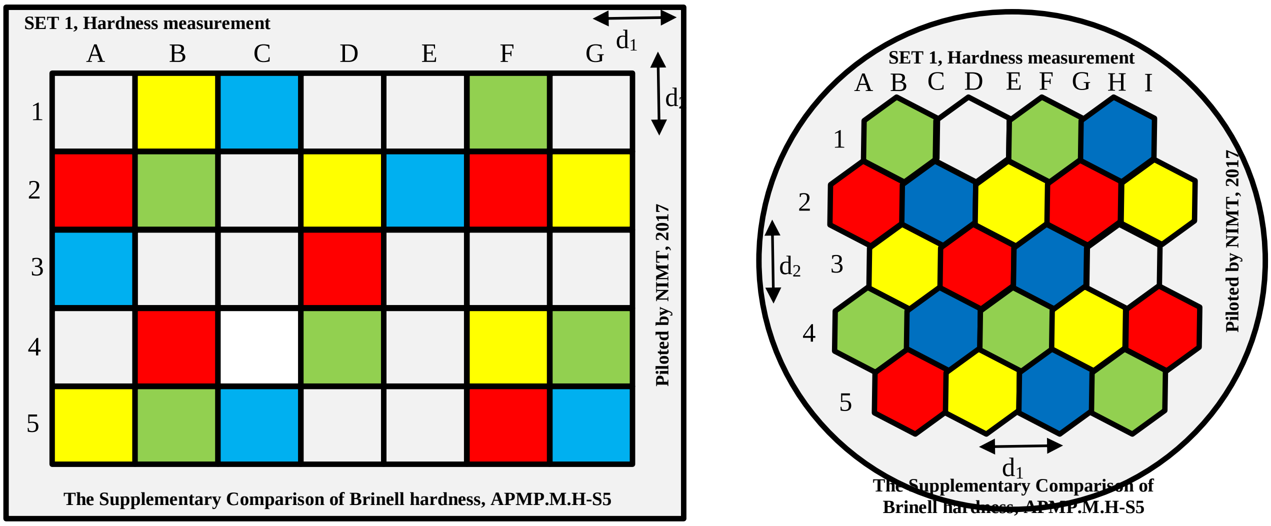
Table 1: The artifact ID: S/N of the block artifacts.

3. Measurement Location

The measurement surface of artifacts are engraved with a square segment and hexagonal segment for set of Asahi Giken Co., Ltd and Euro products limited, respectively. Each segment is used for single indentation and each artifact block intent to have sufficient area for comparison of all 3 NMIs and each NMI measured 5 indentations according to ISO6506-1 [3], ASTM E10 [4] and JIS Z2243 [5]. In order to avoid the dense indentation which cause the significant increase in hardness by the number of indentation, 1 block artifact is used for only 1 scales.

The indentation segments are estimated at 20 segments based on the number of 5 indentation/scale/participant × 1 scales × 5 measurement set for 3 participants. To ensure the indentation segment not less than the requirement, the reference block is divided to 20 segments with each segment of 6 mm x 6 mm as shown in Figure 1. The location of each segment is designate with X and Y coordinate. The position in X-direction (column) is defined by the letter and it is identified as indentation diameter length measurement d_2 direction. Meanwhile, the position in Y-direction (row) is defined by the numbers and it is ide44ntified as the indentation diameter length measurement d_1 direction.

The locations of indentation of each participant are given in coordinates (the combination of a number and a letter) as presented in Table 2. Pilot laboratory prepares the plastic sheet indicating the indentation position of each participant to prevent the incorrect indentation. The exact location of indentation for each participant are given once each participant confirmed the Brinell scale for comparison.



(a) (b)

Figure 1: Indentation position for each segment in X and Y coordination (a) Hardness level below 180HBW (b) Hardness level at 180-550HBW

Hardness	Position	NIMT before	NMIJ/AIST	KRISS	NIMT after
45HBW10/500 70HBW10/500 100HBW10/500	1st	3D	4D	2D	2E
	2nd	2A	2B	1B	1C
	3rd	2F	1F	2G	5G
	4th	5F	4G	4F	5C
	5th	4B	5B	5A	3A
180HBW10/3000 200HBW10/3000 300HBW10/3000 400HBW10/3000 500HBW10/3000 550HBW10/3000	1st	3D	4E	4G	3F
	2nd	2A	1B	2E	2C
	3rd	2G	1F	2I	1H
	4th	4I	5H	5D	5F
	5th	5B	4A	3B	4C

Table 2: The location of indentation in coordinates for each participant.

The positions of reference indentation are shown in the second set; indentation diameter measurement comparison is arranged at the center of the block. The position and location of reference indentation are presented in Figure 2.

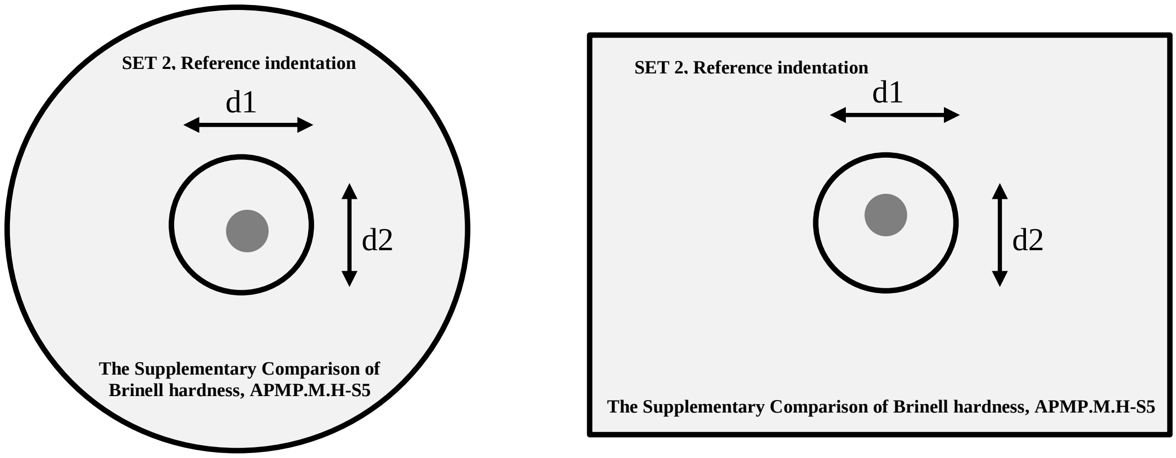


Figure 2: The position of a reference indentation.

4. Participants and CMCs.

The participant and the responsible person for the supplementary comparison are presented in Table Table 3.

NMIs	Address	Contact person
National Institute of Metrology (NIMT)	3/4–5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120	Montree PAKKRATOKE E-mail: montree@nimt.or.th Tel: +66 2 577 5100 ext. 2235
National Metrology Institute of Japan (NMIJ/AIST)	Tsukuba central 3, 1-1-1 Umezono, Tsukuba Ibaraki 305-8563, Japan	Koichiro Hattori E-mail: hattori-k@aist.go.jp Tel: +81 29 861 4048 FAX +81 29 861 4047
Korea Research Institute of Standard and Science (KRISS)	301-128, 267 Gajeong-ro, Yuseong-gu, Daejeon 34113, Republic of Korea	Nae Hyung Tak E-mail: nhtak@kriss.re.kr Tel : +82 42 868 5327 Mobile: +82 10 2114 0989

Table 3 : List of participants of the supplementary comparison.

Also, the comparison scale for each NMI and CMCs declaration for the supplementary comparison are presented in Table 4.

NMIs	Comparison scale	Claimed CMCs
National Institute of Metrology (NIMT)	HBW10/500 and HBW10/3000	± 1.2 % of HB for 25 to 100 HBW10/500 ± 0.6 % of HB for 100 to 650 HBW10/3000
Korea Research Institute of Standard and Science (KRISS)	HBW10/500 and HBW10/3000	1.4%-2.0% of HB For scale 10/500HBW and HBW 10/3000
National Metrology Institute of Japan (NMIJ/AIST)	HBW10/500 and HBW10/3000	$0.89+0.19/d-1.1\times10^{-3}H$ % d in mm and H is Brinell hardness of blocks (nominal). from 100 HBW to 600 HBW

Table 4 : List of comparison scale and CMC declaration

5. Transportation and time schedule

The set of artifacts are sent from one participant to the next participant according to a timetable in which the date of the measurement has been agreed with the participating NMI's as the timetable in Table 5. Each participant is responsible for shipping cost, customs and related administrative fees to next participant.

Institute/Country/ (or region)	Time of measurement	Time of transportation (to next participant)
NIMT, Thailand	15 Apr to 15 May 2018	15 May to 30 May 2018
NMIJ/ AIST, Japan	15 Jul to 15 Aug 2018	15 Aug to 31 Aug 2018
KRISS, Rep. of Korea	15 Oct to 15 Nov 2018	15 Nov to 30 Nov 2018
NIMT, Thailand	1 Dec to 31 Dec 2018	-

Table 5: Timetable of the measurement and artifact delivery period.

A set of artifacts, indentation position sheet, gloves, dust brush, dust blower and check list are packed inside aluminum case as shown in Figure 3. Each participant needs to investigate the completion of the artifacts based on the checklist before and after sending the artifacts. If there is anything lost or damaged, it shall be reported to email to the pilot laboratory as soon as possible.

Check list of the key comparison of Brinell hardness (APMP.M.H-S5)

Set 1 : A Set of Brinell Hardness Comparison

Hardness Level	S/N	NIMT Check by...............		NMIJ Check by...............		KRISS Check by...............	
		Before	After	Before	After	Before	After
45	1/45: AZ40322B						
70	1/70 : AZ75324B						
100	1/100 : AZ100409G						
180	1/180: B91576						
200	1/200: A92785						
300	1/300: B94160						
400	1/400: 94679						
500	1/500: 95741						
550	1/550: L2222						
Positioning Sheet	-						

Set 2: A Set of Reference Indentation Measurement Length Comparison

Hardness Level	S/N	NIMT Check by...............		NMIJ Check by...............		KRISS Check by...............	
		Before	After	Before	After	Before	After
45	2/45: AZ40308B						
70	2/70: AZ75341B						
100	2/100: AZ100408G						
180	2/180 : B91577						
200	2/200 : A92782						
300	2/300 : B94161						
400	2/400 : 94698						
500	2/500 : 95739						
550	2/550 : 90146						
Positioning Sheet	-						

Figure 3: Packaging for artifacts and check list for each participant.

6. Measurement Procedure

6.1 The standardized hardness machine shall be verified according to National or International document standard such as ISO 6506-2 [6], ISO 6506-3 [7], ASTM E10 [4] or JIS Z2243 [5]. The participants need to review and fill the information description of standardized hardness machine in Report Form 1.

6.2 Clean the indenter and anvil of the standardized hardness machine. It is recommended to avoid cleaning the artifacts since the heavy cleaning can cause the reference indentation damage especially at hardness level of 45-200 HB. These damage can cause the error in measurement for the next participant, or the subsequent examination in case of suspicion results. The participants need to handle and clean the artifacts with gloves and dust brush. Pilot laboratory is responsible to clean and physical investigate the artifacts before sending to the participants.

6.3 The procedure of the artifact measurement.

6.3.1 *Measure reference indentation*: each participant measures the indentation diameter length in d_1 and d_2 direction five times for one reference indentation. A set of indentation diameter length comparison is provided with 9 blocks based on the hardness level from 45HBW10/500 to 550HBW10/3000 as presented in Figure 2. Each block artifact consists of one reference indentation for each hardness scale. The position of each reference indentation is at the center of the block as shown in Figure 2. Each participant record the measurement results, average value, magnification lens and number of aperture of objective lens for each hardness level on each hardness scale in Report Form 2.

6.3.2 *Measure hardness*: each participant makes indentation on artifacts of a set of Brinell hardness comparison for the reserved segment for your participant based on the attached positioning sheet or the location of indentation as shown in Table 2. The participant can mark use a magic pen to mark the position on the artifact. Indentation should be made in the center of segments in order to keep enough distance between neighboring indents.

Measure the indentation diameter lengths of the indentation in d_1 and d_2 direction and Brinell hardness three time for each indentation. The indentation diameter length and Brinell hardness are measured with 5 different positions as follow the positioning sheet. Record the measurement results, average value, standard deviation and uncertainty in Report form 3.

Any deviations of the measurement procedure from the testing of ISO6506-3 [7] or the machine from the requirement of the standard (ASTM E10 [4], JIS Z 2243 [5]) must be reported.

7. Result Evaluation

Please estimate the uncertainty of measurement according to the GUM [8]. If you have already established your own method to estimate the uncertainty, you should use your method. At least the following influence quantities on the uncertainty should be considered:

- Uncertainty of the test force
- Uncertainty of the length measuring system
- Uncertainty of the diameter of the indenter

The draft of EA: "Guideline for the estimation of the uncertainty of measurement of Brinell and Vickers hardness scales [9]" or ISO 6506-3 [7] may be used. (An example of the uncertainty budget is available in annex E)

8. Data Report

8.1 Please give a characteristics description of your Brinell hardness machine, your standard indenter, testing condition and environmental information in Report Form 1.

8.2 Please fill your measurement and uncertainty results as follow;

- Indentation diameter length in d1 and d2 for each indentation for the set of indentation diameter length comparison (Set 2) in Report Form 2: Result and Uncertainty of the Measurement: For Reference Indentation.
- Hardness measurement for the set of Brinell hardness comparison (Set 1) in Report Form 3: Result and Uncertainty of the Measurement: For Hardness Measurement.

8.3 Please give the uncertainty budget of your measurement in Report Form 4: Uncertainty Budget of Block Artifact and Form 5: Uncertainty Budget of reference indentation measurement length.

9. Analyzing method of comparison results

The measurement results are used to compute the degree of equivalence in Comparison Reference Value (CRV) and En ratio. The calculation is shown in following formulas [10]:

- Calculation of Comparison Reference Value (CRV)

Pilot laboratory determined CRV by calculating the weighted mean of measurements of all participants, x_{crv}.

$$x_{crv} = \frac{\frac{x_1}{u^2(x_1)} + \frac{x_2}{u^2(x_2)} + \cdots + \frac{x_n}{u^2(x_n)}}{\frac{1}{u^2(x_1)} + \frac{1}{u^2(x_2)} + \cdots + \frac{1}{u^2(x_n)}}$$

- The uncertainty of the CRV was calculated by following expression:

$$\frac{1}{u^2(crv)} = \frac{1}{u^2(x_1)} + \frac{1}{u^2(x_2)} + \cdots + \frac{1}{u^2(x_n)}$$

Where:
x_i = The measured value of participating institute (=1,2,…,n)
$u(x_i)$= The standard uncertainty of x_i

- Its deviation from CRV, d_i

$$d_i = x_i - x_{crv}$$

- $u(d_i)$was given by

$$u^2(d_i) = u^2(x_i) - u^2(x_{crv})$$

- The uncertainty of this deviation at a 95% level of confidence

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

Where: k = 2

- Evaluation of Coefficient E_n
The degree of equivalence between the measurements of participating institutes was expressed by coefficient E_n as well.

$$E_n = \frac{x_i - x_{crv}}{U(d_i)}$$

Reference

[1] K. Herrmann and et al., HARDMEKO 2004, Hardness Measurements Theory and Application in Laboratories and Industries, 11-12 November, 2004, Washington, D.C.,USA, CCM Vickers supplementary comparison - State of the art and perspective.
[2] A. Germak and C. Origlial, HARDMEKO 2007, Recent Advancement of Theory and Practice in Hardness Measurement, 19-21 November, 2007, Tsukuba, Japan, Analysis and estimation of possible large systematic error in Brinell hardness measurement.
[3] ISO 6506-1: Metallic materials-Brinell hardness test-Part 1: Test method.
[4] ASTM E10-15: Standard test method for Brinell Hardness of Metallic Materials.
[5] JIS Z 2243: Method of Brinell hardness test.
[6] ISO 6506-2: Metallic materials-Brinell hardness test-Part 2: Verification and calibration of testing machines.
[7] ISO 6506-3: Metallic materials-Brinell hardness test-Part 3: Calibration of reference blocks.
[8] GUM: Guide to the Expression of "Uncertainty in Measurement"; edition 1993, corrected and reprinted 1995, International Organization for Standardization, Geneva, Switzerland
[9] Draft of EA working group Hardness: "Guideline to the determination of the uncertainty of the Brinell and the Vickers measuring method", 09/1999
[10] M. G. Cox Metrologia 2002, "The evaluation of key comparison data", 2002, 39, 589-595

Appendix A: Measurement Report. (Example)

Measurement Report

OF

THE SUPPLEMENTARY COMPARISON OF BRINELL HARDNESS

APMP.M.H-S5

Laboratory :

Address :

Website:

Email:

Measurement date :

Measured by:	**Checked by:**
(Signature)	(Signature)
Typed Name	**Typed Name**

Appendix B: Description of Hardness machine. (Example)

Report Form 1: Description of Standardized Hardness Machine

General Information of Standardized Hardness Machine	
Model of standardized hardness machine	
Serial number of standardized hardness machine	
Manufacturer of standardized hardness machine	
Uncertainty of standardized hardness machine	**Result ± Uncertainty**
for HBW10/500	
for HBW10/3000	
Calibration and Measurement Capabilities (CMCs)	**CMCs**
for HBW10/500	
for HBW10/3000	

General Information of Indentation Diameter Measuring System	
Model of indentation diameter measuring system	
Serial number of indentation diameter measuring system	
Manufacturer of indentation diameter measuring system	
Uncertainty	**Result ± Uncertainty**
With Lens xx , measuring length xx to yy mm	
With Lens xx , measuring length xx to yy mm	

Force	**Result ± Uncertainty**
Test Force F 4,903N (HBW10/500)	
Test Force F 29,420N (HBW10/3000)	
Testing conditions	**Result ± Uncertainty**
Approach velocity of the indenter	
Application of test force t_{0-1}	
Test force duration time t_1	
Indenter geometry	**Result ± Uncertainty**
Diameter of the ball	

Environment of comparison measurement	
Measurement place	
Measurement date	
Environment (temperature/humidity)	

Appendix C: Measurement report form. (Example)

Report Form 2: Result and Uncertainty of the Measurement: ***For Reference Indentation***

A Set of Indentation Diameter Length Comparison

Brinell Scale : **HBW10/500**

Hardness Block Number (S/N)	Measured Value								
	2/45: AZ40308B			2/70: AZ75341B			2/100: AZ100408G		
Nominal Value (HBW10/500)	45			70			100		
Magnification of objective lens / NA									
Diameter	d1, µm	d2, µm	d, µm	d1, µm	d2, µm	d, µm	d1, µm	d2, µm	d, µm
No 1									
No 2									
No 3									
No 4									
No 5									
Average Value									
S.D.									
Expanded uncertainty (k=2)									

Brinell Scale : **HBW10/3000**

Hardness Block Number (S/N)	Measured Value											
	2/180 : B91577			2/200 : A92782			2/300 : B94161			2/400 : 94698		
Nominal Value (HBW10/3000)	180			200			300			400		
Magnification of objective lens / NA												
Diameter	d1, µm	d2, µm	d, µm	d1, µm	d2, µm	d, µm	d1, µm	d2, µm	d, µm	d1, µm	d2, µm	d, µm
No 1												
No 2												
No 3												
No 4												
No 5												
Average Value												
S.D.												
Expanded uncertainty (k=2)												

Hardness Block Number (S/N)	Measured Value					
	2/500 : 95739			2/550 : 90146		
Nominal Value (HBW10/3000)	500			550		
Magnification of objective lens / NA						
Diameter	d1, µm	d2, µm	d, µm	d1, µm	d2, µm	d, µm
No 1						
No 2						
No 3						
No 4						
No 5						
Average Value						
S.D.						
Expanded uncertainty (k=2)						

Report Form 3 : Result and Uncertainty of the Measurement: ***For Hardness Measurement***

A Set of Brinell Hardness Comparison

Brinell Scale : **HBW10/500**

Hardness Block Number (S/N)	Measured Value											
	1/45 : AZ40322B				1/70 : AZ75324B				1/100 : AZ100409G			
Nominal Value (HBW10/500)	45				70				100			
Magnification of objective lens / NA	10X											
Indentation diameter/HB	d1, µm	d2, µm	d, µm	HBW10/500	d1, µm	d2, µm	d, µm	HBW10/500	d1, µm	d2, µm	d, µm	HBW10/500
Indentation 1												
Indentation 2												
Indentation 3												
Indentation 4												
Indentation 5												
Average Value												
S.D.												
Expanded uncertainty (k=2)												

Brinell Scale : **HBW10/3000**

Hardness Block Number (S/N)	Measured Value															
	1/180: B91576				1/200: A92785				1/300: B94160				1/400: 94679			
Nominal Value (HBW10/3000)	180				200				300				400			
Magnification of objective lens / NA																
Indentation diameter/HB	d1, µm	d2, µm	d, µm	HBW10/3000	d1, µm	d2, µm	d, µm	HBW10/3000	d1, µm	d2, µm	d, µm	HBW10/3000	d1, µm	d2, µm	d, µm	HBW10/3000
Indentation 1																
Indentation 2																
Indentation 3																
Indentation 4																
Indentation 5																
Average Value																
S.D.																
Expanded uncertainty (k=2)																

Hardness Block Number (S/N)	Measured Value							
	1/500: 95741				1/550: B2222			
Nominal Value (HBW10/3000)	500				550			
Magnification of objective lens / NA								
Indentation diameter/HB	d1, µm	d2, µm	d, µm	HBW10/3000	d1, µm	d2, µm	d, µm	HBW10/3000
Indentation 1								
Indentation 2								
Indentation 3								
Indentation 4								
Indentation 5								
Average Value								
S.D.								
Expanded uncertainty (k=2)								

Appendix D: Uncertainty budget. (Example)

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Report Form 4.1:Uncertainty Budget of *Block Artifact*

Brinell Scale : HBW10/500

Uncertainty budget of hardness block 45 HBW10/500 S/N : 1/45: AZ40322B

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/500				
Resolution of machine, H_{res}	HBW10/500				
Repeatability of measurement, H_{rep}	HBW10/500				
Measured hardness, H_{mh}	HBW10/500		Combined uncertainty, u_c Expanded uncertainty, Ue		

Uncertainty budget of hardness block 70 HBW10/500 S/N : 1/70 : AZ75324B

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/500				
Resolution of machine, H_{res}	HBW10/500				
Repeatability of measurement, H_{rep}	HBW10/500				
Measured hardness, H_{mh}	HBW10/500		Combined uncertainty, u_c Expanded uncertainty, Ue		

Uncertainty budget of hardness block 100 HBW10/500 S/N : 1/100 : AZ100409G

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/500				
Resolution of machine, H_{res}	HBW10/500				
Repeatability of measurement, H_{rep}	HBW10/500				
Measured hardness, H_{mh}	HBW10/500		Combined uncertainty, u_c Expanded uncertainty, Ue		

Appendix D (cont.): Uncertainty budget. (Example)

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Report Form 4.2:Uncertainty Budget of ***Block Artifact***

Brinell Scale : HBW10/3000

Uncertainty budget of hardness block 180 HBW10/3000 S/N : 1/180: B91576

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/3000				
Resolution of machine, H_{res}	HBW10/3000				
Repeatability of measurement, H_{rep}	HBW10/3000				
Measured hardness, H_{mh}	HBW10/3000		Combined uncertainty, u_c Expanded uncertainty, Ue		

Uncertainty budget of hardness block 200 HBW10/3000 S/N : 1/200: A92785

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/3000				
Resolution of machine, H_{res}	HBW10/3000				
Repeatability of measurement, H_{rep}	HBW10/3000				
Measured hardness, H_{mh}	HBW10/3000		Combined uncertainty, u_c Expanded uncertainty, Ue		

Uncertainty budget of hardness block 300 HBW10/3000 S/N : 1/300: B94160

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/3000				
Resolution of machine, H_{res}	HBW10/3000				
Repeatability of measurement, H_{rep}	HBW10/3000				
Measured hardness, H_{mh}	HBW10/3000		Combined uncertainty, u_c Expanded uncertainty, Ue		

Uncertainty budget of hardness block 400 HBW10/3000 S/N : 1/400: 94679

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/3000				
Resolution of machine, H_{res}	HBW10/3000				
Repeatability of measurement, H_{rep}	HBW10/3000				
Measured hardness, H_{mh}	HBW10/3000		Expanded uncertainty, Ue Expanded uncertainty, Ue k=2		

Appendix D (cont.): Uncertainty budget. (Example)

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Uncertainty budget of hardness block 500 HBW10/3000 S/N : 1/500: 95741

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/3000				
Resolution of machine, H_{res}	HBW10/3000				
Repeatability of measurement, H_{rep}	HBW10/3000				
Measured hardness, H_{mh}	HBW10/3000		Combined uncertainty, u_c Expanded uncertainty, Ue		

Uncertainty budget of hardness block 550 HBW10/3000 S/N : 1/550: E2222

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Hardness machine, H_{hm}	HBW10/3000				
Resolution of machine, H_{res}	HBW10/3000				
Repeatability of measurement, H_{rep}	HBW10/3000				
Measured hardness, H_{mh}	HBW10/3000		Combined uncertainty, u_c Expanded uncertainty, Ue		

Appendix D (cont.): Uncertainty budget. (Example)

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Report Form 5.2:Uncertainty Budget of Reference Indentation Measurement Length

Brinell Scale : HBW10/500

Uncertainty budget of hardness block 45 HBW10/500 S/N : 2/45: AZ40308B

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Measuring system, M_{std}	mm				
Resolution of microscope, M_{res}	mm				
Repeatability of measurement, M_{rep}	mm				
Measured diameter, d_{mh}	mm		Combined uncertainty, u_c Expanded uncertainty, Uc		

Uncertainty budget of hardness block 70 HBW10/500 S/N : 2/70: AZ75341B

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Measuring system, M_{std}	mm				
Resolution of microscope, M_{res}	mm				
Repeatability of measurement, M_{rep}	mm				
Measured diameter, d_{mh}	mm		Combined uncertainty, u_c Expanded uncertainty, Ue		

Uncertainty budget of hardness block 100 HBW10/500 S/N : 2/100: AZ100408G

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Measuring system, M_{std}	mm				
Resolution of microscope, M_{res}	mm				
Repeatability of measurement, M_{rep}	mm				
Measured diameter, d_{mh}	mm		Combined uncertainty, u_c Expanded uncertainty, Ue		

Appendix D (cont.): Uncertainty budget. (Example)

Report Form 5.2:Uncertainty Budget of Reference Indentation Measurement Length

Brinell Scale : HBW10/3000

Uncertainty budget of hardness block 180 HBW10/3000 S/N : 2/180 : B91577

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Measuring system, M_{std}	mm				
Resolution of microscope, M_{res}	mm				
Repeatability of measurement, M_{rep}	mm				
Measured diameter, d_{mh}	mm		Combined uncertainty, u_c		
			Expanded uncertainty, Ue		

Uncertainty budget of hardness block 200 HBW10/3000 S/N : 2/200 : A92782

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Measuring system, M_{std}	mm				
Resolution of microscope, M_{res}	mm				
Repeatability of measurement, M_{rep}	mm				
Measured diameter, d_{mh}	mm		Combined uncertainty, u_c		
			Expanded uncertainty, Ue		

Uncertainty budget of hardness block 300 HBW10/3000 S/N : 2/300 : B94161

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Measuring system, M_{std}	mm				
Resolution of microscope, M_{res}	mm				
Repeatability of measurement, M_{rep}	mm				
Measured diameter, d_{mh}	mm		Combined uncertainty, u_c		
			Expanded uncertainty, Ue		

Uncertainty budget of hardness block 400 HBW10/3000 S/N : 2/400 : 94698

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Measuring system, M_{std}	mm				
Resolution of microscope, M_{res}	mm				
Repeatability of measurement, M_{rep}	mm				
Measured diameter, d_{mh}	mm		Expanded uncertainty, Ue		
			Expanded uncertainty, Ue k=2		

Appendix D (cont.): Uncertainty budget. (Example)

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Uncertainty budget of hardness block 500 HBW10/3000 S/N : 2/500 : 95739

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Measuring system, M_{std}	mm				
Resolution of microscope, M_{res}	mm				
Repeatability of measurement, M_{rep}	mm				
Measured diameter, d_{mh}	mm		Combined uncertainty, u_c Expanded uncertainty, Ue		

Uncertainty budget of hardness block 550 HBW10/3000 S/N : 2/550 : 90146

Quantity Xi	Estimate xi	Standard uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient (c_i)	Uncertainty Contribution $u(y_i)$
Measuring system, M_{std}	mm				
Resolution of microscope, M_{res}	mm				
Repeatability of measurement, M_{rep}	mm				
Measured diameter, d_{mh}	mm		Combined uncertainty, u_c Expanded uncertainty, Ue		

<u>Appendix E: The example of uncertainty budget</u> [9]
1. for reporting the uncertainty. An uncertainty budget estimated for 350HBW2.5/187.5.
2. Estimated value means the center value of the uncertainty estimation. For example raw 6 means the target test force duration is 15sec.
3. Make the budget for each hardness and test forces.

Estimated for 350HBW2.5/187.5

	source of uncertainty		estimated value	unit	Limit value	Distribution type	Standard uncertainty	unit	Sensitivity coefficient, c_i	unit	uncertainty contribution, u(H), HBW	type
	division	subdivision										
1	Force	-	1839	N	-	Normal	1.84	N	1.90E-01	HBW/N	3.50E-01	A
2	Length measuring device	Length measuring device	0.8	mm	-	Normal	8.20E-04	mm	-8.83E+02	HBW/mm	7.24E-01	A
3		Repeatability of readings	0	mm	-	Normal	5.00E-04	mm	-8.83E+02	HBW/mm	4.42E-01	B
4	Indenter geometry	Diameter of the ball	2.5	mm	5.00E-04	Rectangle	2.89E-04	mm	8.08	HBW/mm	2.33E-03	A
5	Testing cycle	Force application time	8	sec	0.5	Rectangle	0.289	sec	0.15	HBW/sec	4.33E-02	B
6		Test force duration	15	sec	0.5	Rectangle	0.289	sec	-0.12	HBW/sec	3.46E-02	B
...	….	….	….	….	….	….	….	….	….	….	….	….
combined standard uncertainty, u [HBW]											0.84	
expanded combined standard uncertainty, U [HBW] (k=2)											1.7	

Memo: