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Final Report
The Supplementary Comparison of Vickers Hardness

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Abstract

This report purposed the results of supplementary comparison of Vickers Hardness, APMP.M.H-S6 among five National Metrology Institutes (NIMT, NMIJ/AIST, KRISS, CMS/ITRI and SASO-NMCC). The comparison was carried out during November 2015 to January 2019 in order to determine the capability of the primary Vickers hardness standard, including standard conditions, of each participant, to confirm the accuracy of Vickers hardness scale HV5, HV10, HV20, HV30, HV50 and HV100 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 100HV to 900HV. The pilot institute was the National Institute of Metrology (Thailand), NIMT. There were 2 different types of artifacts for the comparison. The first and second set were the set of Vickers hardness comparison: hardness measurement. The third set is a set of diagonal length comparison: diagonal 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 parameter was calculated to express the equivalence between the measurements of participant as well.

Content

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1. Introduction

NIMT proposed a supplementary comparison of Vickers hardness measurement with the collaboration of Korea Research Institute of Standard and Science (KRISS) and National Metrology Institute of Japan (NMIJ). Then, during the meeting of 32nd Asia Pacific Metrology Programme (APMP), 2016 at Danang, Vietnam, Center for Measurement Standard, Industrial Technology Research Institute (ITRI), Taiwan, requested to participate in the supplementary comparison. During the comparison, Saudi Standard Metrology and Quality Org.-National Measurement Calibration Center (SASO-NMCC) also interested to participate in this comparison for HV100. NIMT was nominated as the pilot laboratory of the comparison.

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 Vickers hardness machine as their standard. The artifacts of this comparison were 3 sets of hardness blocks. The comparison measurement are provided by 3 different set artifacts. The first set and second set are the set of Vickers hardness comparison: hardness measurement and diagonal length measurement for participants. The first set is a set of scale HV5, HV20 and HV100 and the second set is a set of scale HV10, HV30 and HV50.
The third set is a set of diagonal length comparison: diagonal length measurement for participants. Each set composed of 9 hardness levels: 100 HV, 200 HV, 300 HV, 400 HV, 500 HV, 600 HV, 700 HV, 800 HV and 900 HV. 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 Vickers hardness machine according to ISO 6507-3 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 result of the artifacts in set 1 and 2 was the priority of this comparison because it showed the deviations of Vickers hardness obtained from each national standard of the participants. Whereas the result of the artifacts in set 3 was presented for additional information to determine the performance of national microscope without the effect from Vickers hardness machine.

The first objective of this comparison was to confirm the existing calibration and measurement capability (CMC) of each participant on the Vickers measurement. The second objective is to confirm the reported expanded uncertainty for the participants who intent to propose for new approached CMC

2. Participating Institutes

First, there were 4 participants consisting of NIMT, NMIJ, KRISS and ITRI as presented in Technical Protocol of the supplementary comparison of Vickers hardness [1]. However, during the comparison, SASO-NMCC has participated the comparison. The list of participant and CMC declaration was given in Table 1 and Table 2.

Table 1 List of participants

Participant	Address	Contact person
National Institute of Metrology (NIMT)	3/4–5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120	Tassanai Sanponpute Tel: +6625775100 ext. 2235 E-mail: Tassanai@nimt.or.th
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
Center for Measurement Standards/Industrial Technology Research Institute (CMS/ITRI)	Rm.207, 2F, Bldg. 8, No. 321, Sec. 2, Kuang Fu Rd., Hsinchu, Taiwan	Chung-Lin Wu E-mail: clwu@itri.org.tw
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
SASO-NMCC (Saudi Standard Metrology and Quality Org.-National Measurement Calibration Center)	Kingdom of Saudi Arabia–Riyadh-SASO-Al Mohammadiyyah-building No: 4	Sami A. Bin Jarbua E-mail: s.jarbua@saso.gov.sa

Table 2 List of CMC declaration

NMIs	Comparison scale	Existing CMCs
NIMT	HV5, HV10, HV20, HV30, HV50, HV100	± 0.4 + (165/d) % of HV for $100 \leq d \leq 200$ ± 0.24 + (195/d) % of HV for $d > 200$ d is diagonal length in μm
NMIJ	HV5, HV10, HV30	± 1.0 + (200/d) % of HV for $d < 200$ ± 2.0 % of HV for $d \geq 200$ d is diagonal length in μm
ITRI	HV5, HV10, HV20, HV30	± 3.0 % of HV
KRISS	HV10, HV30, HV50	± (0.9-2.5) % of HV
SASO	HV100	± (0.4-1.4) % of HV

3. Schedule

The comparison on artifacts started at pilot lab, NIMT, in Feb 2018. The original schedule was to transfer the artifacts from NIMT, NMIJ, ITRI, and KRISS respectively with about 4 weeks for measurement and about 2 weeks for transportation process as presented in Technical Protocol of the supplementary comparison of Vickers hardness [1].

However, there was some delay during the measurement in KRISS due to a building construction. Also, KRISS could not perform the HV100 measurement due to a technical problem. Therefore, there was the indentation left for other participants. SASO-NMCC requested to measure HV100 as a last participant in July 2019. Table 3 showed the original schedule and actual time of measurement

Table 3 Original schedule and actual time of measurement

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	1 Feb 2018 to 31 Mar 2018	15 May 2018 to 30 May 2018	1 Feb 2018 to 31 Mar 2018	10 May 2018 to 10 Jun 2018
NMIJ/ AIST, Japan	1 Jun 2018 to 30 Jun 2018	1 Jul 2018 to 15 Jul 2018	11 Jun 2018 to 11 Jul 2018	11 Jul 2018 to 15 Jul 2018
CMS/ITRI, Chinese Taipei	15 Jul 2018 to 15 Aug 2018	15 Aug 2018 to 31 Aug 2018	15 Jul 2018 to 22 Aug 2018	3 Sep 2018 to 5 Sep 2018
KRISS, Rep. of Korea	15 Oct 2018 to 15 Nov 2018	15 Nov 2018 to 30 Nov 2018	15 Oct 2018 to 30 Nov 2018	1 Dec 2018 to 31 Dec 2018
SASO-NMCC, Saudi Arabia	-	-	29 Jul 2019 to 31 Jul 2019	-

Three sets of artifact blocks (set1, set2 and set3) were contained in the aluminum box for transportation as shown in Figure 1. The indentation-positioning sheet of each participant and checklist of artifact were attached with the artifacts in the aluminum boxes as well.

Figure 1 Artifacts for Vickers hardness measurement

4. Artifacts

In the supplementary comparison, the Vickers hardness measurement scale HV5, HV10, HV20, HV30, HV50 and HV100 are used with the hardness level 100 HV, 200 HV, 300 HV, 400 HV, 500 HV, 600 HV, 700 HV, 800 HV and 900 HV. The reference hardness blocks as artifacts are manufactured by Asahi Giken Co., Ltd. Japan.
The dimensions of the blocks are 65 mm in diameter and 15 mm and 10 mm in thickness for the steel blocks and brass block, respectively.

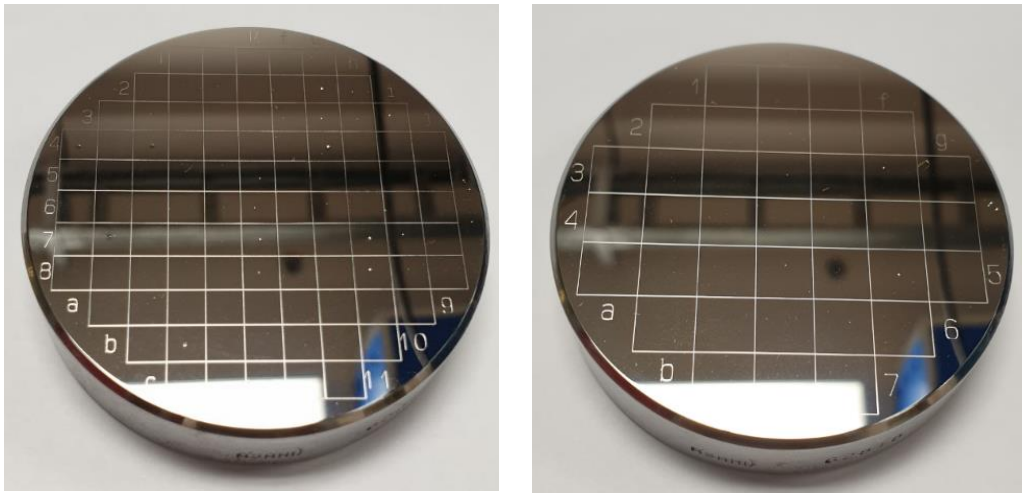
The first set and second set are the set of Vickers hardness comparison: hardness measurement and diagonal length measurement for participants. Due to the limitation of block area and the indented area for hardness scale 100 HV and 200 HV of hardness scale HV50 and HV100, it is difficult to measure the hardness for only 1 artifact block for all hardness scales. Therefore, it requires two set artifacts for each hardness level. The first set is a set of scale HV5, HV20 and HV100 and the second set is a set of scale HV10, HV30 and HV50. The hardness scale and artifact ID are presented in Table 4.

The third set is a set of diagonal length comparison: diagonal length measurement for participants. The reference indentations prepared by pilot laboratory are presented in Table 4.

Table 4 : The artifact ID : S/N of the block artifacts

Hardness level	Artifact ID : S/N		
	Hardness measurement, scale		Reference indentation measurement, scale
	Set 1 HV5,HV20 and HV100	Set 2 HV10,HV30 and HV50	Set 3 All scales
100	1/100.1 : A60114 1/100.2 : A60116	2/100.1 : A60117 2/100.2 : A60118 2/100.3 : A60115	3/100: A60113
200	1/200 : 62634	2/200: 62636	3/200: 62635
300	1/300 : A62447	2/300: A62449	3/300: A62448
400	1/400 : A63076	2/400: A63075	3/400 : A63074
500	1/500 : A64494	2/500: A64493	3/500 : A64492
600	1/600 : 63439	2/600: 63440	3/600 : 63438
700	1/700 : A66986	2/700: A66985	3/700 : A66984
800	1/800 : B67462	2/800: B67461	3/800 : B67463
900	1/900 : 62819	2/900: 62817	3/900 : 62818

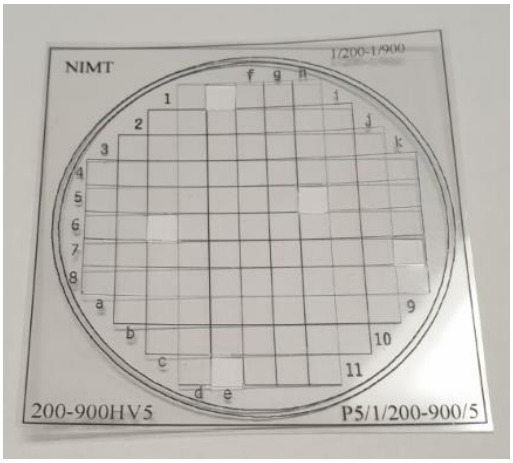
The surface of each artifact block was engraved with laser engraver machine. Set 1 and set 2 of artifacts are engraved with divided segments for indicating the indentation positions. Each segment is used for single indentation in the comparison. Set 3 of artifacts are engraved for indicating the position pattern of reference indentation for each HV. An example of artifacts on set1, 2 and 3 is shown in Figure 2.



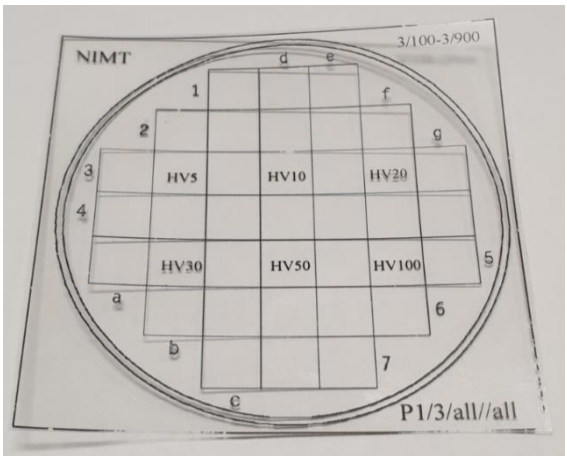
Set 1 and Set 2 Set 3

Figure 2 Set of artifacts (Set1 and 2: Set of Vickers hardness comparison, Set3: set of diagonal length comparison)

The plastic sheet indicating the indentation position of each participant will be enclosed with the artifact sets. It shall be placed on the artifact block in order to ensure the indentation position before making the indentation as shown in Figure 3.



Set 1 and Set 2



Set 3

Figure 3 Indentation positioning sheet for the artifacts

5. Measurement of Artifacts

The primary Vickers hardness machines used for the comparison must be passed the verification according to ISO 6507-3 [2, 3].

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 of the supplementary comparison of Vickers hardness APMP.M.H-S6.

Each participant must give a characteristics description of their primary Vickers hardness machine, your 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 **5** - Table **10** and Table **11** -Table **16**, respectively.

Please noted that in Table **11** - Table **16**, the expanded uncertainties of each participant in measurement report are based on the existing CMC as reported in Table 2.

However, each participant can report the expanded uncertainty smaller than the existing CMC, in case the participant would like to propose for new approached CMC. The results would be presented in later section.

Table 5 The results of the measurement in HV5: For Block Artifact (Reference Indentation)

Nominal value		Measurement data of each participant (μm), X*i*					Uncertainty *(k=2)* of each participant (μm), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV5	100	296.72	-	-	297.35	-	2.05	-	-	0.56	-	0.69	-	-	0.19	-
	200	206.59	205.1	-	206.28	-	2.05	1.1	-	0.53	-	0.99	0.53	-	0.26	-
	300	174.45	172.2	-	173.46	-	2.05	1.1	-	0.47	-	1.17	0.63	-	0.27	-
	400	149.57	147.7	-	149.27	-	2.06	1.1	-	0.48	-	1.38	0.74	-	0.32	-
	500	133.96	132.4	-	134.21	-	2.05	1.1	-	0.47	-	1.53	0.82	-	0.35	-
	600	121.47	119.9	-	121.21	-	2.05	1.1	-	0.47	-	1.69	0.91	-	0.39	-
	700	113.35	111.5	-	113.62	-	2.05	1.1	-	0.47	-	1.81	0.98	-	0.41	-
	800	105.53	104.1	-	106.54	-	2.05	1.1	-	0.47	-	1.94	1.05	-	0.44	-
	900	100.44	100.5	-	100.55	-	2.05	1.1	-	0.49	-	2.04	1.08	-	0.48	-

Table 6 The results of the measurement in HV10: For Block Artifact (Reference Indentation)

Nominal value		Measurement data of each participant (μm), X*i*					Uncertainty *(k=2)* of each participant (μm), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV10	100	421.15	-	421.67	420.33	-	2.05	-	0.72	0.77	-	0.49	-	0.17	0.18	-
	200	291.60	289.3	290.88	291.35	-	2.05	1.1	0.58	0.52	-	0.70	0.40	0.20	0.18	-
	300	246.32	243.3	245.57	245.22	-	2.05	1.1	0.58	0.50	-	0.83	0.45	0.24	0.20	-
	400	213.11	209.7	211.16	211.41	-	2.06	1.1	0.58	0.47	-	0.97	0.52	0.27	0.22	-
	500	190.93	188.3	189.06	190.13	-	2.05	1.1	0.58	0.50	-	1.07	0.58	0.31	0.26	-
	600	172.72	169.9	170.48	171.43	-	2.05	1.1	0.58	0.50	-	1.19	0.64	0.34	0.29	-
	700	160.78	158.4	159.23	160.37	-	2.05	1.1	0.58	0.50	-	1.27	0.69	0.36	0.31	-
	800	149.95	147.5	148.47	150.52	-	2.05	1.1	0.58	0.48	-	1.37	0.74	0.39	0.32	-
	900	142.69	140.8	140.90	142.04	-	2.05	1.1	0.58	0.50	-	1.44	0.77	0.41	0.35	-

Table 7 The results of the measurement in HV20: For Block Artifact (Reference Indentation)

Nominal value		Measurement data of each participant (μm), X*i*					Uncertainty *(k=2)* of each participant (μm), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV20	100	595.37	-	-	593.58	-	2.05	-	-	0.88	-	0.34	-	-	0.15	-
	200	412.48	-	-	411.80	-	2.05	-	-	0.52	-	0.50	-	-	0.13	-
	300	347.42	-	-	346.96	-	2.05	-	-	0.50	-	0.59	-	-	0.14	-
	400	299.80	-	-	298.85	-	2.05	-	-	0.47	-	0.68	-	-	0.16	-
	500	268.45	-	-	268.42	-	2.05	-	-	0.48	-	0.76	-	-	0.18	-
	600	242.30	-	-	242.33	-	2.05	-	-	0.50	-	0.85	-	-	0.21	-
	700	226.76	-	-	226.54	-	2.05	-	-	0.46	-	0.90	-	-	0.21	-
	800	211.64	-	-	212.94	-	2.05	-	-	0.52	-	0.97	-	-	0.25	-
	900	201.74	-	-	200.96	-	2.05	-	-	0.49	-	1.02	-	-	0.24	-

Table 8 The results of the measurement in HV30: For Block Artifact (Reference Indentation)

Nominal value		Measurement data of each participant (μm), X*i*					Uncertainty *(k=2)* of each participant (μm), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV30	100	728.41	-	728.11	726.87	-	2.05	-	0.76	0.54	-	0.28	-	0.10	0.07	-
	200	503.37	502.6	502.75	503.45	-	2.05	1.6	0.59	0.77	-	0.41	0.31	0.12	0.15	-
	300	425.02	423.7	424.82	424.58	-	2.05	1.1	0.59	0.62	-	0.48	0.27	0.14	0.15	-
	400	366.97	363.6	366.38	365.86	-	2.05	1.1	0.58	0.51	-	0.56	0.32	0.16	0.14	-
	500	328.48	326.5	328.03	328.54	-	2.05	1.1	0.58	0.54	-	0.62	0.35	0.18	0.16	-
	600	297.52	294.6	295.96	296.90	-	2.05	1.1	0.58	0.49	-	0.69	0.39	0.20	0.17	-
	700	277.01	275.4	276.20	277.85	-	2.05	1.1	0.58	0.48	-	0.74	0.42	0.21	0.17	-
	800	259.44	257.7	257.25	260.19	-	2.05	1.1	0.59	0.48	-	0.79	0.45	0.23	0.19	-
	900	246.78	245.4	245.91	245.89	-	2.05	1.1	0.58	0.54	-	0.83	0.44	0.24	0.22	-

Table 9 The results of the measurement in HV50: For Block Artifact (Reference Indentation)

Nominal value		Measurement data of each participant (μm), X*i*					Uncertainty *(k=2)* of each participant (μm), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV50	100	938.76	-	938.90	-	-	2.05	-	0.92	-	-	0.22	-	0.10	-	-
	200	650.67	-	652.33	-	-	2.05	-	0.58	-	-	0.31	-	0.09	-	-
	300	548.27	-	549.46	-	-	2.05	-	0.62	-	-	0.37	-	0.11	-	-
	400	472.51	-	471.89	-	-	2.05	-	0.60	-	-	0.43	-	0.13	-	-
	500	423.47	-	423.61	-	-	2.05	-	0.58	-	-	0.48	-	0.14	-	-
	600	383.46	-	383.08	-	-	2.05	-	0.61	-	-	0.53	-	0.16	-	-
	700	357.87	-	357.61	-	-	2.05	-	0.60	-	-	0.57	-	0.17	-	-
	800	334.59	-	335.54	-	-	2.05	-	0.58	-	-	0.61	-	0.17	-	-
	900	318.75	-	318.68	-	-	2.05	-	0.58	-	-	0.64	-	0.18	-	-

Table 10 The results of the measurement in HV100: For Block Artifact (Reference Indentation)

Nominal value		Measurement data of each participant (μm), X*i*					Uncertainty *(k=2)* of each participant (μm), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV100	100	1333.94	-	-	-	1334.39	2.05	-	-	-	0.45	0.15	-	-	-	0.03
	200	920.63	-	-	-	921.18	2.05	-	-	-	0.40	0.22	-	-	-	0.04
	300	779.50	-	-	-	778.17	2.05	-	-	-	0.43	0.26	-	-	-	0.06
	400	670.87	-	-	-	671.71	2.05	-	-	-	0.42	0.31	-	-	-	0.06
	500	602.90	-	-	-	602.23	2.05	-	-	-	0.44	0.34	-	-	-	0.07
	600	545.23	-	-	-	545.41	2.05	-	-	-	0.41	0.38	-	-	-	0.07
	700	509.47	-	-	-	508.38	2.05	-	-	-	0.44	0.40	-	-	-	0.09
	800	476.19	-	-	-	476.33	2.05	-	-	-	0.40	0.43	-	-	-	0.08
	900	455.55	-	-	-	454.89	2.05	-	-	-	0.40	0.45	-	-	-	0.09

Table 11 The results of the measurement in HV5: For Block Artifact (Reference Hardness Block)

Nominal value		Measurement data of each participant (HV), Xi					Uncertainty *(k=2)* of each participant (HV), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV5	100	106.05	-	-	104.72	-	0.99	-	-	3.40	-	0.93	-	-	3.25	-
	200	215.48	220.44	-	214.71	-	2.73	4.41	-	6.50	-	1.27	2.00	-	3.03	-
	300	294.85	300.68	-	295.96	-	4.21	6.43	-	9.00	-	1.43	2.14	-	3.04	-
	400	407.65	417.53	-	408.93	-	6.09	9.78	-	12.40	-	1.49	2.34	-	3.03	-
	500	510.21	520.35	-	508.24	-	8.35	13.00	-	15.40	-	1.64	2.50	-	3.03	-
	600	627.32	632.48	-	617.59	-	11.02	16.77	-	18.70	-	1.76	2.65	-	3.03	-
	700	720.09	728.77	-	712.59	-	13.64	20.21	-	21.50	-	1.89	2.77	-	3.02	-
	800	828.26	828.75	-	815.05	-	16.23	23.96	-	24.60	-	1.96	2.89	-	3.02	-
	900	910.96	891.73	-	909.32	-	18.54	26.41	-	27.50	-	2.04	2.96	-	3.02	-

Table 12 The results of the measurement in HV10: For Block Artifact (Reference Hardness Block)

Nominal value		Measurement data of each participant (HV), Xi					Uncertainty *(k=2)* of each participant (HV), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV10	100	104.51	-	103.64	103.85	-	0.80	-	2.38	3.20	-	0.76	-	2.30	3.08	-
	200	217.84	219.61	217.63	215.75	-	2.15	4.39	3.70	6.60	-	0.99	2.00	1.70	3.06	-
	300	306.05	309.05	305.23	305.42	-	3.17	6.18	4.88	9.30	-	1.03	2.00	1.60	3.04	-
	400	412.97	418.48	413.75	409.13	-	4.79	8.37	7.03	12.40	-	1.16	2.00	1.70	3.03	-
	500	512.67	516.87	514.13	509.72	-	6.71	10.63	7.71	15.40	-	1.31	2.06	1.50	3.02	-
	600	627.81	631.91	625.70	618.12	-	8.54	13.70	10.64	18.70	-	1.36	2.17	1.70	3.03	-
	700	724.76	726.11	720.39	716.93	-	10.38	16.35	9.37	21.60	-	1.43	2.25	1.30	3.01	-
	800	827.73	827.19	830.00	817.43	-	12.44	19.32	9.34	24.60	-	1.50	2.34	1.13	3.01	-
	900	912.27	905.22	912.17	908.01	-	14.64	21.70	11.84	27.50	-	1.61	2.40	1.30	3.03	-

Table 13 The results of the measurement in HV20: For Block Artifact (Reference Hardness Block)

Nominal value		Measurement data of each participant (HV), Xi					Uncertainty *(k=2)* of each participant (HV), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV20	100	105.98	-	-	105.20	-	0.76	-	-	3.20	-	0.71	-	-	3.04	-
	200	218.02	-	-	217.16	-	1.41	-	-	6.60	-	0.64	-	-	3.04	-
	300	298.86	-	-	297.24	-	2.19	-	-	9.00	-	0.73	-	-	3.03	-
	400	413.63	-	-	412.13	-	3.52	-	-	12.40	-	0.85	-	-	3.01	-
	500	517.25	-	-	511.52	-	5.01	-	-	15.40	-	0.97	-	-	3.01	-
	600	631.75	-	-	620.83	-	6.60	-	-	18.70	-	1.04	-	-	3.01	-
	700	726.21	-	-	715.41	-	8.01	-	-	21.50	-	1.10	-	-	3.01	-
	800	830.85	-	-	817.49	-	9.71	-	-	24.60	-	1.17	-	-	3.01	-
	900	912.26	-	-	908.06	-	11.43	-	-	27.40	-	1.25	-	-	3.02	-

Table 14 The results of the measurement in HV30: For Block Artifact (Reference Hardness Block)

Nominal value		Measurement data of each participant (HV), Xi					Uncertainty *(k=2)* of each participant (HV), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV30	100	102.64	-	103.14	103.80	-	0.69	-	2.58	3.20	-	0.67	-	2.50	3.08	-
	200	218.49	219.10	219.85	218.24	-	1.54	4.38	3.74	6.60	-	0.70	2.00	1.70	3.02	-
	300	304.82	308.88	306.48	307.51	-	2.12	6.18	5.52	9.30	-	0.70	2.00	1.80	3.02	-
	400	413.93	418.41	412.75	412.67	-	3.20	8.37	7.02	12.40	-	0.77	2.00	1.70	3.00	-
	500	511.91	515.91	513.05	511.86	-	4.26	10.32	8.72	15.50	-	0.83	2.00	1.70	3.03	-
	600	625.73	630.08	626.11	621.29	-	5.59	12.60	11.27	18.70	-	0.89	2.00	1.80	3.01	-
	700	721.69	722.94	718.50	719.91	-	6.80	14.46	9.34	21.70	-	0.94	2.00	1.30	3.01	-
	800	828.35	821.12	822.76	819.19	-	8.22	16.42	7.40	24.70	-	0.99	2.00	0.90	3.02	-
	900	907.51	899.77	902.43	909.23	-	9.33	18.00	8.12	27.40	-	1.03	2.00	0.90	3.01	-

Table 15 The results of the measurement in HV50: For Block Artifact (Reference Hardness Block)

Nominal value		Measurement data of each participant (HV), Xi					Uncertainty *(k=2)* of each participant (HV), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV50	100	103.85	-	103.25	-	-	0.46	-	2.58	-	-	0.45	-	2.50	-	-
	200	218.63	-	219.20	-	-	1.50	-	3.73	-	-	0.69	-	1.70	-	-
	300	305.80	-	305.97	-	-	1.82	-	5.20	-	-	0.59	-	1.70	-	-
	400	414.50	-	413.28	-	-	2.70	-	7.03	-	-	0.65	-	1.70	-	-
	500	512.07	-	511.41	-	-	3.58	-	8.69	-	-	0.70	-	1.70	-	-
	600	627.93	-	624.52	-	-	5.99	-	10.62	-	-	0.95	-	1.70	-	-
	700	720.34	-	717.58	-	-	5.95	-	8.61	-	-	0.83	-	1.20	-	-
	800	827.37	-	821.78	-	-	6.81	-	7.40	-	-	0.82	-	0.90	-	-
	900	902.97	-	898.51	-	-	7.66	-	10.41	-	-	0.85	-	1.16	-	-

Table 16 The results of the measurement in HV100: For Block Artifact (Reference Hardness Block)

Nominal value		Measurement data of each participant (HV), Xi					Uncertainty *(k=2)* of each participant (HV), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV100	100	102.21	-	-	-	102.54	0.41	-	-	-	0.41	0.40	-	-	-	0.40
	200	218.35	-	-	-	218.27	0.99	-	-	-	1.35	0.45	-	-	-	0.62
	300	295.89	-	-	-	296.50	1.44	-	-	-	2.16	0.49	-	-	-	0.73
	400	410.40	-	-	-	412.93	2.18	-	-	-	3.88	0.53	-	-	-	0.94
	500	509.26	-	-	-	511.16	3.13	-	-	-	5.17	0.62	-	-	-	1.01
	600	624.18	-	-	-	625.25	3.73	-	-	-	6.98	0.60	-	-	-	1.12
	700	715.74	-	-	-	717.81	4.46	-	-	-	9.13	0.62	-	-	-	1.27
	800	821.25	-	-	-	821.48	5.42	-	-	-	10.70	0.66	-	-	-	1.30
	900	897.43	-	-	-	897.79	6.58	-	-	-	12.50	0.73	-	-	-	1.39

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 Vickers hardness APMP.M.H-S6 [1, 4, 5].

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:

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

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

- Its deviation from CRV

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

- $u(d_i)$ was given by

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

- 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.

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

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 17 -

Table **28**.

The comparison graphs categorized based on the hardness scales and participants were shown in Figure **4** - Figure 21 and Figure 22 - Figure 31, respectively.

Table 17 The deviation from comparison reference value in HV5: For Block Artifact (Reference Indentation)

Nominal value		CRV (μm), X_{crv}	Deviation from reference value (% of d), d_i				
			NIMT	NMIJ	KRISS	ITRI	SASO
HV5	100	297.04	-0.11	-	-	0.11	-
	200	205.98	0.29	-0.44	-	0.14	-
	300	173.37	0.62	-0.68	-	0.05	-
	400	148.84	0.49	-0.79	-	0.29	-
	500	133.51	0.34	-0.87	-	0.52	-
	600	120.87	0.49	-0.78	-	0.28	-
	700	112.84	0.45	-1.16	-	0.69	-
	800	105.39	0.13	-1.24	-	1.08	-
	900	100.49	-0.05	-0.01	-	0.06	-

Table 18 The deviation from comparison reference value in HV10: For Block Artifact (Reference Indentation)

Nominal value		CRV (μm), X_{crv}	Deviation from reference value (% of d), d_i				
			NIMT	NMIJ	KRISS	ITRI	SASO
HV10	100	421.05	0.02	-	0.15	-0.17	-
	200	290.77	0.28	-0.52	0.04	0.20	-
	300	245.10	0.50	-0.74	0.19	0.05	-
	400	211.35	0.83	-0.78	-0.09	0.03	-
	500	189.61	0.69	-0.68	-0.29	0.27	-
	600	171.13	0.92	-0.72	-0.38	0.17	-
	700	159.69	0.68	-0.83	-0.29	0.42	-
	800	149.10	0.56	-1.11	-0.42	0.94	-
	900	141.60	0.76	-0.59	-0.50	0.31	-

Table 19 The deviation from comparison reference value in HV20: For Block Artifact (Reference Indentation)

Nominal value		CRV (μm), X_{crv}	Deviation from reference value (% of d), d_i				
			NIMT	NMIJ	KRISS	ITRI	SASO
HV20	100	594.48	0.15	-	-	-0.15	-
	200	412.14	0.08	-	-	-0.08	-
	300	347.19	0.07	-	-	-0.07	-
	400	299.33	0.16	-	-	-0.16	-
	500	268.44	0.01	-	-	-0.01	-
	600	242.32	-0.01	-	-	0.01	-
	700	226.65	0.05	-	-	-0.05	-
	800	212.29	-0.31	-	-	0.31	-
	900	201.35	0.19	-	-	-0.19	-

Table 20 The deviation from comparison reference value in HV30: For Block Artifact (Reference Indentation)

Nominal value		CRV (μm), X_{crv}	Deviation from reference value (% of d), d_i				
			NIMT	NMIJ	KRISS	ITRI	SASO
HV30	100	727.80	0.08	-	0.04	-0.13	-
	200	503.04	0.07	-0.09	-0.06	0.08	-
	300	424.53	0.12	-0.20	0.07	0.01	-
	400	365.70	0.35	-0.58	0.19	0.04	-
	500	327.89	0.18	-0.42	0.04	0.20	-
	600	296.25	0.43	-0.55	-0.10	0.22	-
	700	276.60	0.15	-0.45	-0.15	0.45	-
	800	258.65	0.31	-0.37	-0.54	0.59	-
	900	246.00	0.32	-0.24	-0.04	-0.04	-

Table 21 The deviation from comparison reference value in HV50: For Block Artifact (Reference Indentation)

Nominal value		CRV (μm), X_{crv}	Deviation from reference value (% of d), d_i				
			NIMT	NMIJ	KRISS	ITRI	SASO
HV50	100	938.83	-0.01	-	0.01	-	-
	200	651.50	-0.13	-	0.13	-	-
	300	548.87	-0.11	-	0.11	-	-
	400	472.20	0.07	-	-0.07	-	-
	500	423.54	-0.02	-	0.02	-	-
	600	383.27	0.05	-	-0.05	-	-
	700	357.74	0.04	-	-0.04	-	-
	800	335.07	-0.14	-	0.14	-	-
	900	318.71	0.01	-	-0.01	-	-

Table 22 The deviation from comparison reference value in HV100: For Block Artifact (Reference Indentation)

Nominal value		CRV (μm), X_{crv}	Deviation from reference value (% of d), d_i				
			NIMT	NMIJ	KRISS	ITRI	SASO
HV100	100	1334.17	-0.02	-	-	-	0.02
	200	920.90	-0.03	-	-	-	0.03
	300	778.83	0.09	-	-	-	-0.09
	400	671.29	-0.06	-	-	-	0.06
	500	602.56	0.06	-	-	-	-0.06
	600	545.32	-0.02	-	-	-	0.02
	700	508.92	0.11	-	-	-	-0.11
	800	476.26	-0.01	-	-	-	0.01
	900	455.22	0.07	-	-	-	-0.07

Table 23 The deviation from comparison reference value and E_n numbers in HV5: For Block Artifact (Reference Hardness Block)

Nominal value		Xcrv (HV)	Deviation from reference value (% of HV), di					$U(X_{crv})$ (%)	Uncertainty of Deviation *(k=2)* (% of HV), U(di)					E_n numbers				
			NIMT	NMIJ	KRISS	ITRI	SASO		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV5	100	105.95	0.10	-	-	-1.17	-	0.90	0.26	-	-	3.12	-	0.38	-	-	-0.37	-
	200	216.61	-0.53	1.74	-	-0.89	-	1.01	0.77	1.73	-	2.85	-	-0.69	1.0	-	-0.31	-
	300	296.51	-0.56	1.39	-	-0.19	-	1.11	0.90	1.83	-	2.83	-	-0.63	0.76	-	-0.07	-
	400	410.19	-0.62	1.76	-	-0.31	-	1.16	0.94	2.03	-	2.80	-	-0.66	0.86	-	-0.11	-
	500	512.32	-0.41	1.54	-	-0.80	-	1.25	1.06	2.16	-	2.76	-	-0.39	0.71	-	-0.29	-
	600	626.68	0.10	0.92	-	-1.47	-	1.32	1.16	2.30	-	2.73	-	0.09	0.40	-	-0.54	-
	700	720.59	-0.07	1.12	-	-1.12	-	1.39	1.29	2.40	-	2.68	-	-0.05	0.47	-	-0.42	-
	800	825.34	0.35	0.41	-	-1.26	-	1.43	1.34	2.51	-	2.66	-	0.26	0.16	-	-0.48	-
	900	905.71	0.58	-1.57	-	0.40	-	1.47	1.41	2.57	-	2.64	-	0.41	-0.61	-	0.15	-

Table 24 The deviation from comparison reference value and E_n numbers in HV10: For Block Artifact (Reference Hardness Block)

Nominal value		Xcrv (HV)	Deviation from reference value (% of HV), di					$U(X_{crv})$ (%)	Uncertainty of Deviation *(k=2)* (% of HV), U(di)					E_n numbers				
			NIMT	NMIJ	KRISS	ITRI	SASO		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV10	100	104.39	0.11	-	-0.72	-0.52	-	0.71	0.29	-	2.19	3.00	-	0.38	-	-0.33	-0.17	-
	200	217.92	-0.04	0.77	-0.13	-1.00	-	0.76	0.63	1.85	1.52	2.96	-	-0.06	0.42	-0.09	-0.34	-
	300	306.26	-0.07	0.90	-0.34	-0.27	-	0.77	0.69	1.85	1.40	2.95	-	-0.10	0.49	-0.24	-0.09	-
	400	413.79	-0.20	1.12	-0.01	-1.14	-	0.83	0.81	1.82	1.48	2.91	-	-0.25	0.62	-0.01	-0.39	-
	500	513.62	-0.18	0.63	0.10	-0.76	-	0.85	0.99	1.87	1.23	2.90	-	-0.19	0.34	0.08	-0.26	-
	600	627.01	0.13	0.78	-0.21	-1.44	-	0.91	1.01	1.97	1.44	2.89	-	0.13	0.39	-0.15	-0.50	-
	700	722.44	0.32	0.51	-0.29	-0.77	-	0.85	1.15	2.09	0.98	2.89	-	0.28	0.24	-0.29	-0.27	-
	800	828.07	-0.04	-0.11	0.23	-1.30	-	0.81	1.27	2.19	0.78	2.90	-	-0.03	-0.05	0.30	-0.45	-
	900	910.87	0.15	-0.62	0.14	-0.32	-	0.89	1.34	2.23	0.95	2.90	-	0.11	-0.28	0.15	-0.11	-

Table 25 The deviation from comparison reference value and E_n numbers in HV20: For Block Artifact (Reference Hardness Block)

Nominal value		Xcrv (HV)	Deviation from reference value (% of HV), di					$U(X_{crv})$ (%)	Uncertainty of Deviation *(k=2)* (% of HV), U(di)					E_n numbers				
			NIMT	NMIJ	KRISS	ITRI	SASO		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV20	100	105.94	0.04	-	-	-0.71	-	0.69	0.16	-	-	2.96	-	0.24	-	-	-0.24	-
	200	217.99	0.02	-	-	-0.38	-	0.63	0.13	-	-	2.97	-	0.13	-	-	-0.13	-
	300	298.77	0.03	-	-	-0.51	-	0.71	0.17	-	-	2.94	-	0.18	-	-	-0.17	-
	400	413.51	0.03	-	-	-0.34	-	0.82	0.23	-	-	2.90	-	0.12	-	-	-0.12	-
	500	516.70	0.11	-	-	-1.01	-	0.92	0.30	-	-	2.87	-	0.36	-	-	-0.35	-
	600	630.54	0.19	-	-	-1.56	-	0.99	0.34	-	-	2.85	-	0.56	-	-	-0.55	-
	700	724.89	0.18	-	-	-1.33	-	1.04	0.38	-	-	2.82	-	0.48	-	-	-0.47	-
	800	829.05	0.22	-	-	-1.41	-	1.09	0.42	-	-	2.81	-	0.51	-	-	-0.50	-
	900	911.64	0.07	-	-	-0.39	-	1.16	0.48	-	-	2.79	-	0.14	-	-	-0.14	-

Table 26 The deviation from comparison reference value and E_n numbers in HV30: For Block Artifact (Reference Hardness Block)

Nominal value		Xcrv (HV)	Deviation from reference value (% of HV), di					$U(X_{crv})$ (%)	Uncertainty of Deviation *(k=2)* (% of HV), U(di)					E_n numbers				
			NIMT	NMIJ	KRISS	ITRI	SASO		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV30	100	102.72	-0.08	-	0.40	1.04	-	0.63	0.22	-	2.42	3.02	-	-0.35	-	0.17	0.34	-
	200	218.71	-0.10	0.18	0.52	-0.21	-	0.61	0.36	1.91	1.59	2.96	-	-0.28	0.10	0.33	-0.07	-
	300	305.48	-0.22	1.10	0.33	0.66	-	0.61	0.34	1.91	1.70	2.96	-	-0.62	0.58	0.19	0.22	-
	400	414.16	-0.06	1.02	-0.34	-0.36	-	0.65	0.42	1.89	1.57	2.93	-	-0.13	0.54	-0.22	-0.12	-
	500	512.55	-0.12	0.65	0.10	-0.14	-	0.68	0.48	1.88	1.56	2.95	-	-0.26	0.35	0.06	-0.05	-
	600	626.09	-0.06	0.63	0.00	-0.77	-	0.72	0.53	1.87	1.65	2.92	-	-0.11	0.34	0.00	-0.26	-
	700	720.83	0.12	0.29	-0.32	-0.13	-	0.69	0.64	1.88	1.10	2.93	-	0.19	0.16	-0.30	-0.04	-
	800	824.61	0.45	-0.42	-0.22	-0.66	-	0.62	0.78	1.90	0.65	2.95	-	0.58	-0.22	-0.34	-0.22	-
	900	904.34	0.35	-0.51	-0.21	0.54	-	0.63	0.81	1.90	0.65	2.95	-	0.43	-0.27	-0.33	0.18	-

Table 27 The deviation from comparison reference value and E_n numbers in HV50: For Block Artifact (Reference Hardness Block)

Nominal value		Xcrv	Deviation from reference value (% of HV), di					$U(X_{crv})$	Uncertainty of Deviation *(k=2)* (% of HV), U(di)					E_n numbers				
		(HV)	NIMT	NMIJ	KRISS	ITRI	SASO	(%)	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV50	100	103.83	0.02	-	-0.56	-	-	0.44	0.08	-	2.46	-	-	0.23	-	-0.23	-	-
	200	218.71	-0.04	-	0.22	-	-	0.64	0.26	-	1.58	-	-	-0.14	-	0.14	-	-
	300	305.81	-0.01	-	0.05	-	-	0.56	0.20	-	1.60	-	-	-0.03	-	0.03	-	-
	400	414.34	0.04	-	-0.26	-	-	0.61	0.23	-	1.59	-	-	0.16	-	-0.16	-	-
	500	511.97	0.02	-	-0.11	-	-	0.65	0.27	-	1.57	-	-	0.07	-	-0.07	-	-
	600	627.11	0.13	-	-0.41	-	-	0.83	0.47	-	1.48	-	-	0.28	-	-0.28	-	-
	700	719.45	0.12	-	-0.26	-	-	0.68	0.47	-	0.99	-	-	0.26	-	-0.26	-	-
	800	824.81	0.31	-	-0.37	-	-	0.61	0.55	-	0.66	-	-	0.56	-	-0.55	-	-
	900	901.40	0.17	-	-0.32	-	-	0.68	0.50	-	0.94	-	-	0.35	-	-0.34	-	-

Table 28 The deviation from comparison reference value and E_n numbers in HV100: For Block Artifact (Reference Hardness Block)

Nominal value		Xcrv	Deviation from reference value (% of HV), di					$U(X_{crv})$	Uncertainty of Deviation *(k=2)* (% of HV), U(di)					E_n numbers				
		(HV)	NIMT	NMIJ	KRISS	ITRI	SASO	(%)	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV100	100	102.37	-0.16	-	-	-	0.16	0.29	0.28	-	-	-	0.29	-0.55	-	-	-	0.55
	200	218.33	0.01	-	-	-	-0.02	0.36	0.27	-	-	-	0.50	0.05	-	-	-	-0.05
	300	296.07	-0.06	-	-	-	0.14	0.40	0.27	-	-	-	0.61	-0.24	-	-	-	0.24
	400	411.00	-0.15	-	-	-	0.47	0.46	0.26	-	-	-	0.82	-0.57	-	-	-	0.57
	500	509.77	-0.10	-	-	-	0.27	0.53	0.32	-	-	-	0.86	-0.31	-	-	-	0.32
	600	624.41	-0.04	-	-	-	0.13	0.53	0.28	-	-	-	0.98	-0.13	-	-	-	0.14
	700	716.14	-0.06	-	-	-	0.23	0.56	0.27	-	-	-	1.14	-0.20	-	-	-	0.20
	800	821.30	-0.01	-	-	-	0.02	0.59	0.30	-	-	-	1.16	-0.02	-	-	-	0.02
	900	897.51	-0.01	-	-	-	0.03	0.65	0.34	-	-	-	1.23	-0.03	-	-	-	0.03

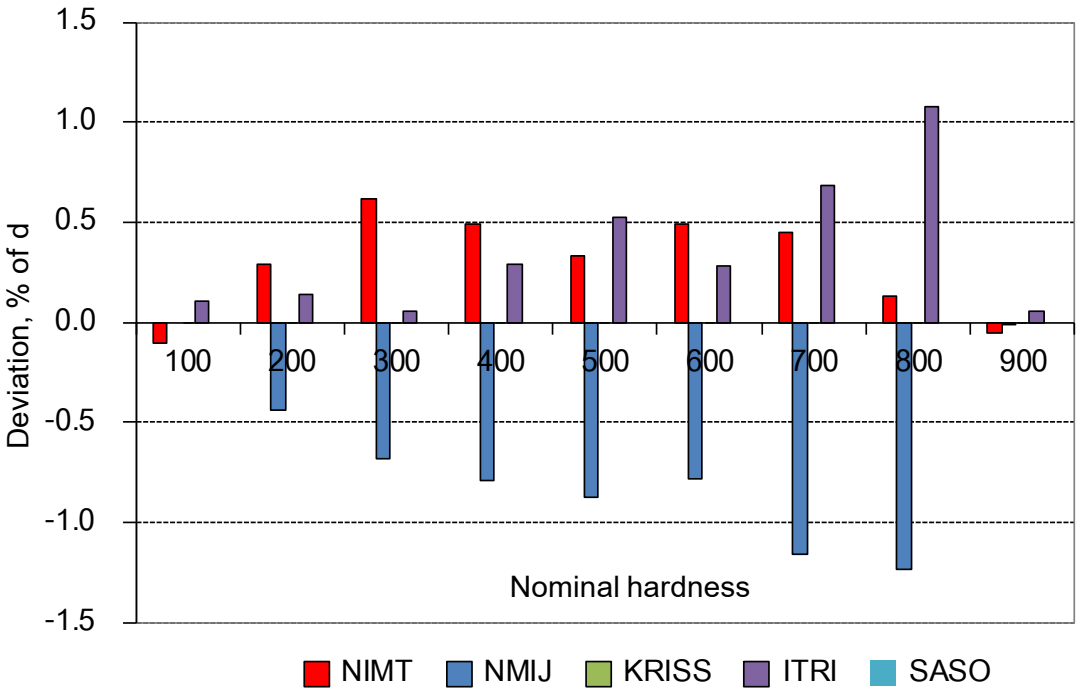


Figure 4 The overview of the deviation from the comparison reference value of Block artifact (Reference Indentation) for HV5

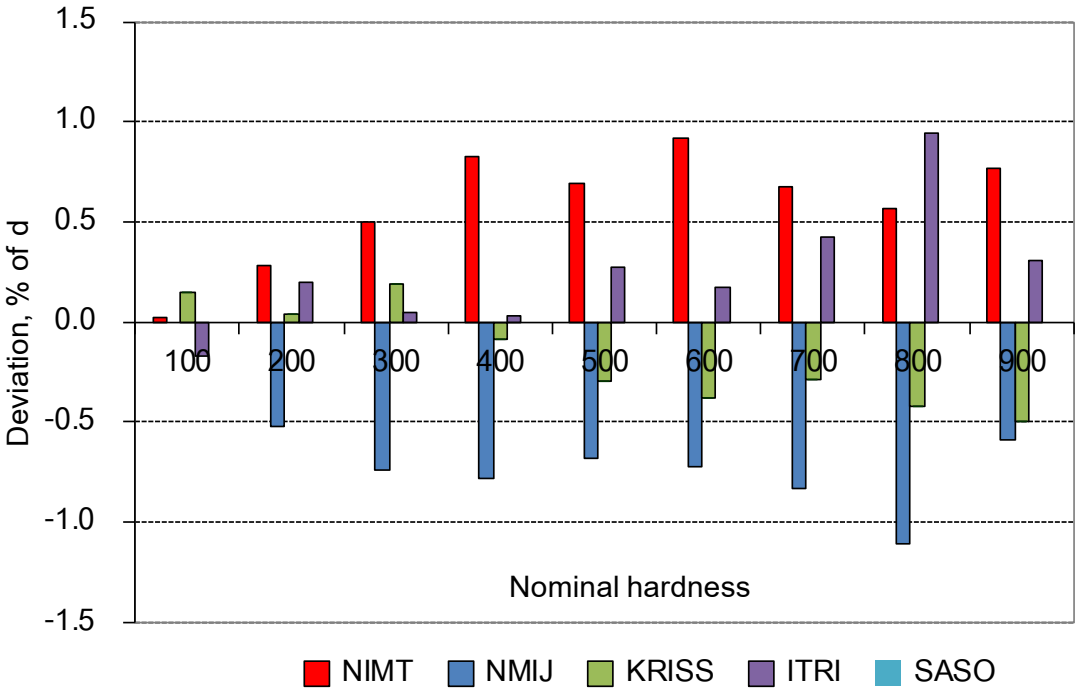


Figure 5 The overview of the deviation from the comparison reference value of Block artifact (Reference Indentation) for HV10

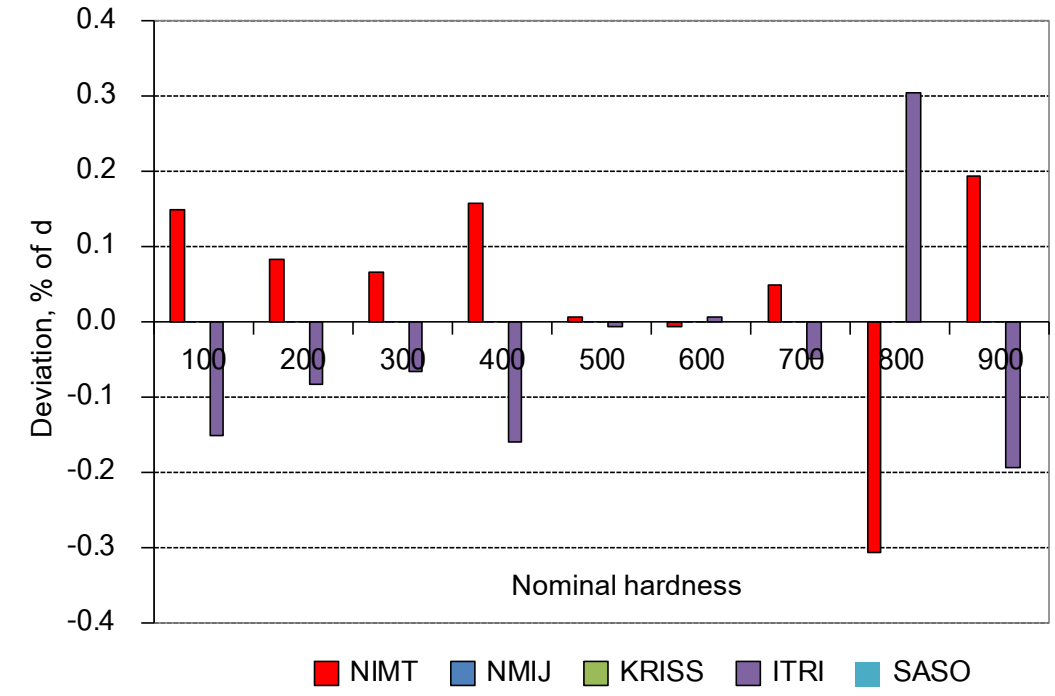


Figure 6 The overview of the deviation from the comparison reference value of Block artifact (Reference Indentation) for HV20

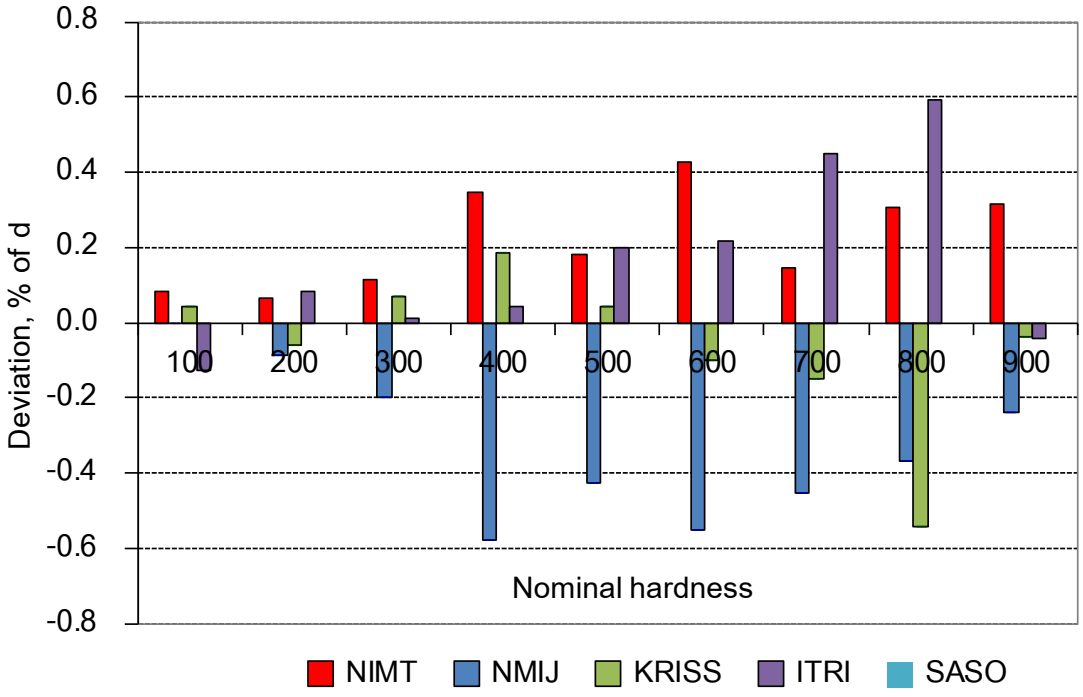


Figure 7 The overview of the deviation from the comparison reference value of Block artifact (Reference Indentation) for HV30

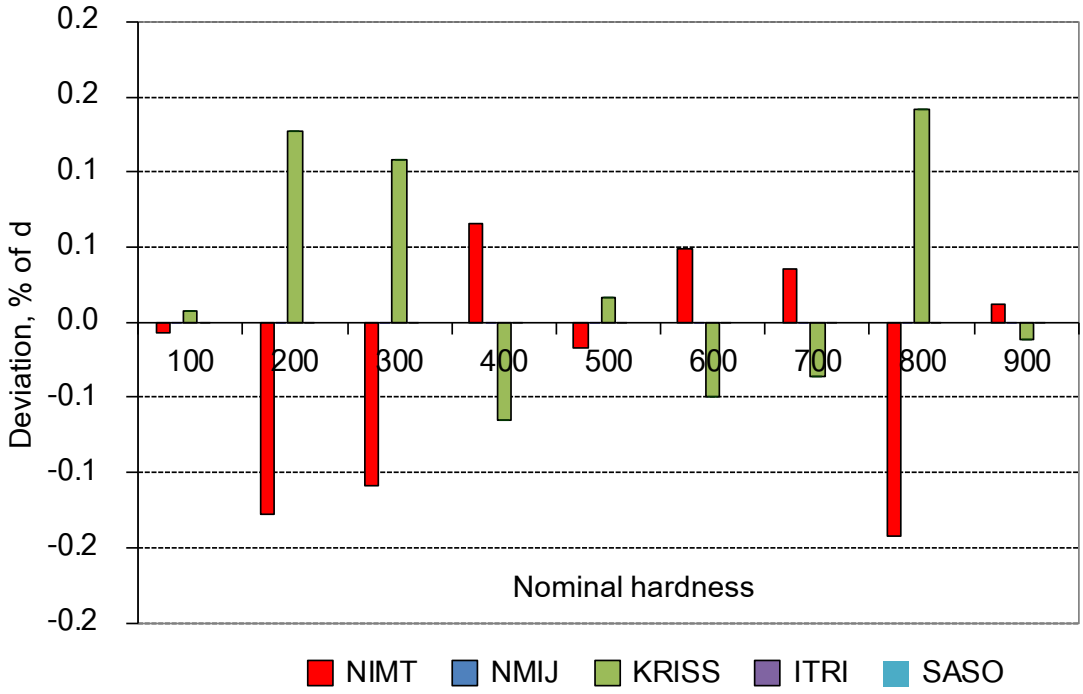


Figure 8 The overview of the deviation from the comparison reference value of Block artifact (Reference Indentation) for HV50

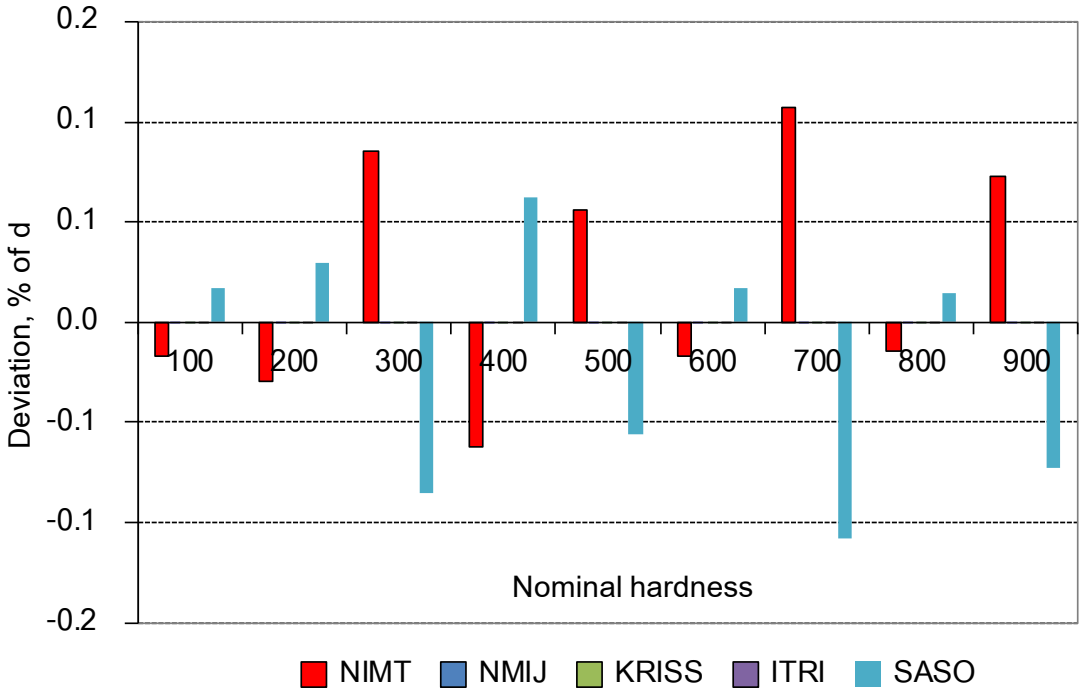


Figure 9 The overview of the deviation from the comparison reference value of Block artifact (Reference Indentation) for HV100

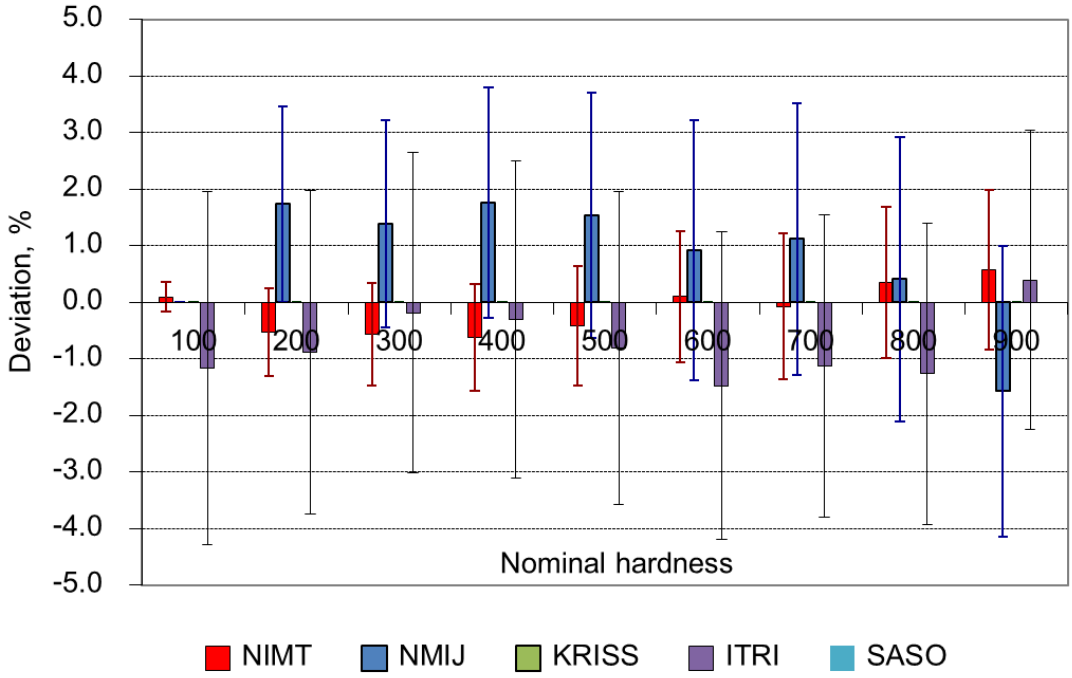


Figure 10 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for HV5

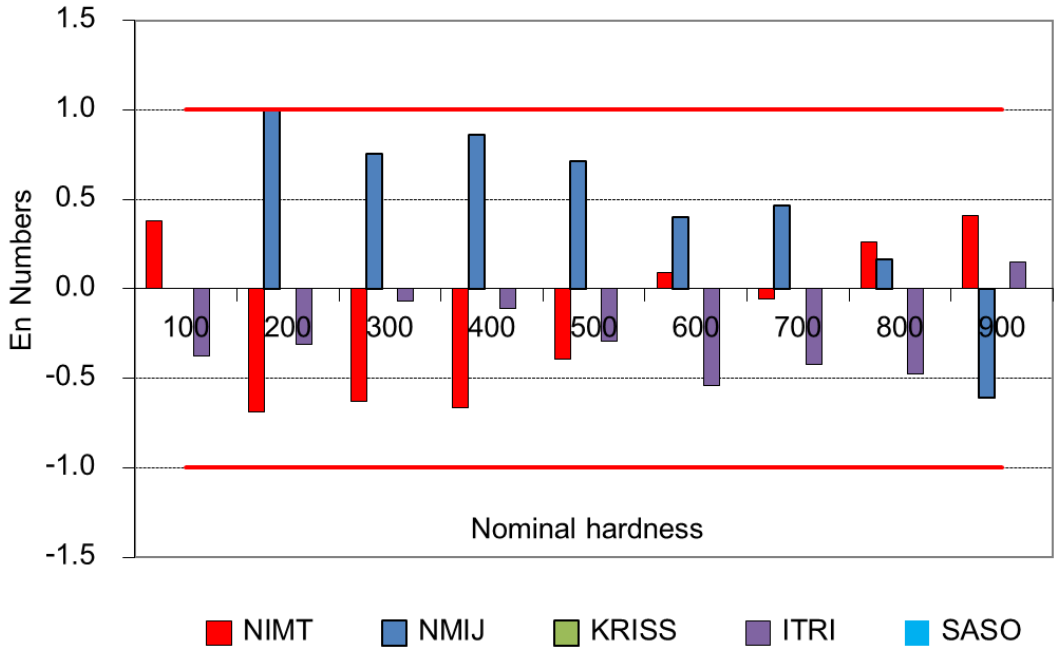


Figure 11 The E_n numbers of Block artifact (Reference Hardness Block) for HV5

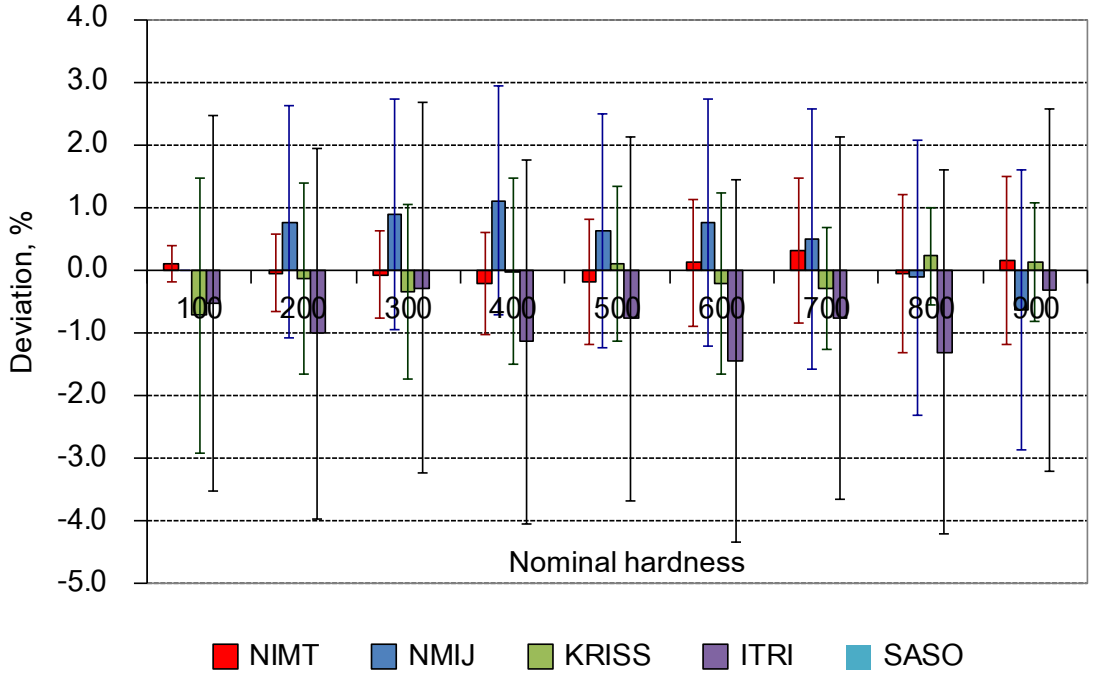


Figure 12 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for HV10

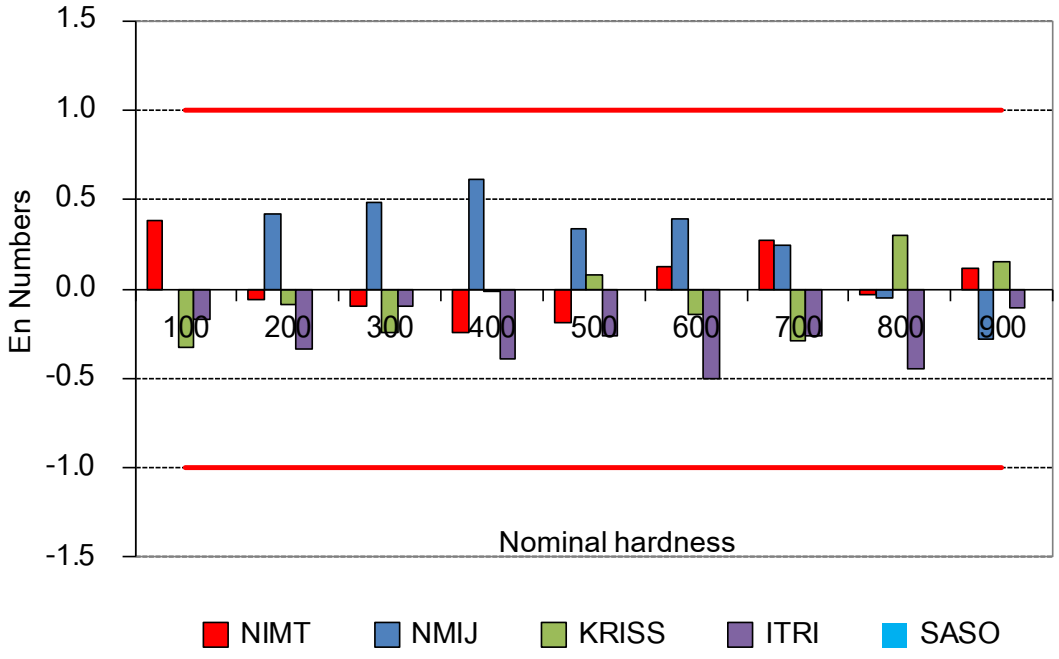


Figure 13 The E_n numbers of Block artifact (Reference Hardness Block) for HV10

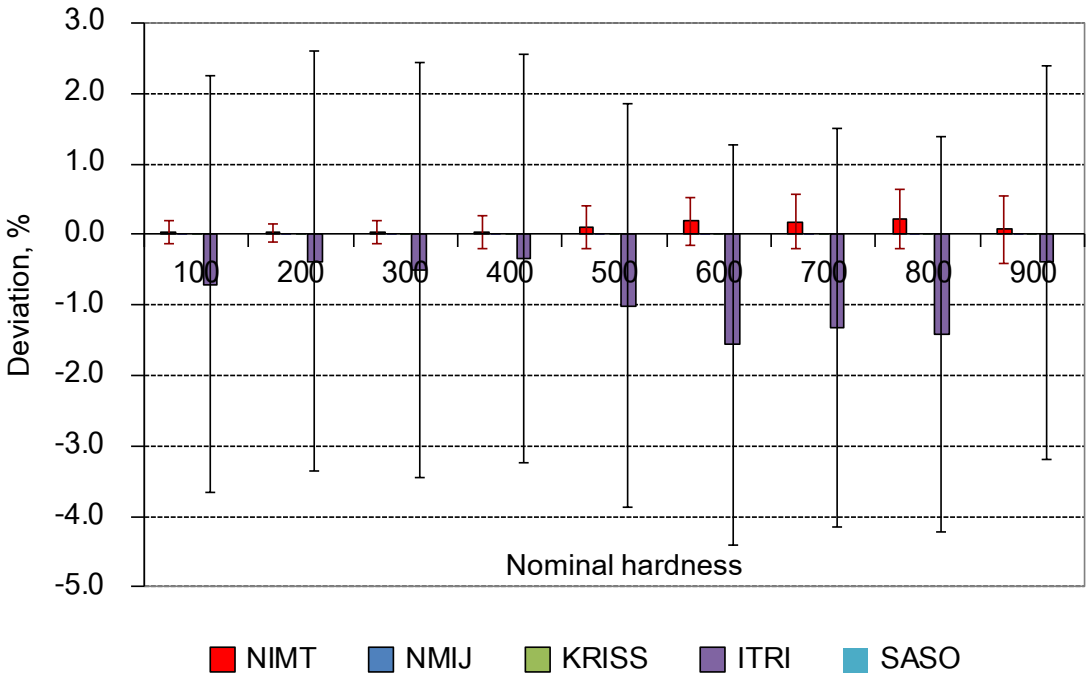


Figure 14 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for HV20

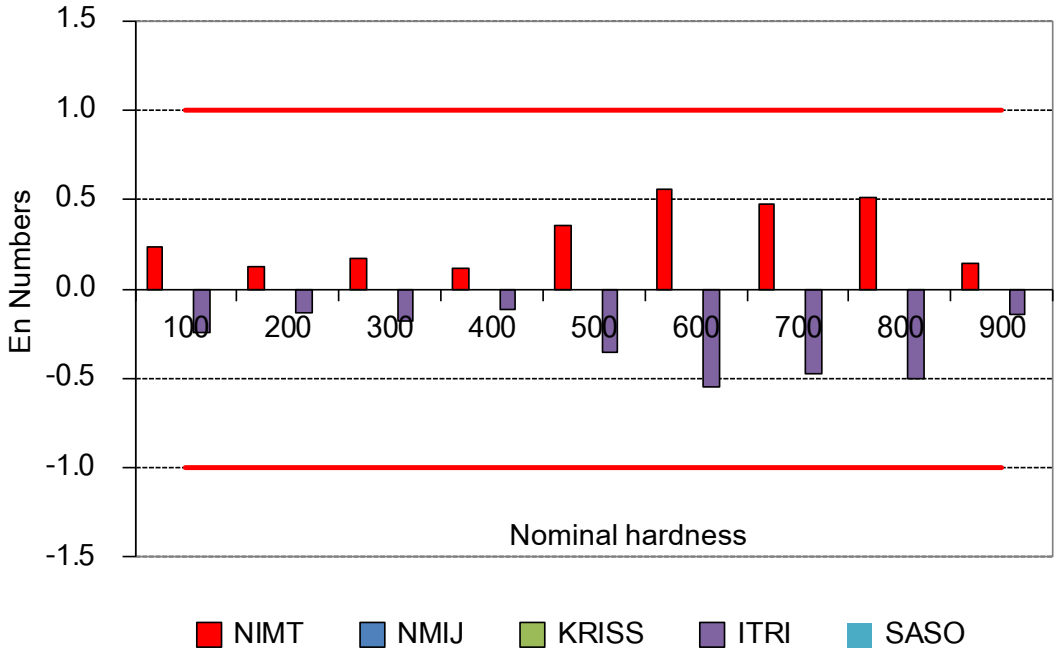


Figure 15 The E_n numbers of Block artifact (Reference Hardness Block) for HV20

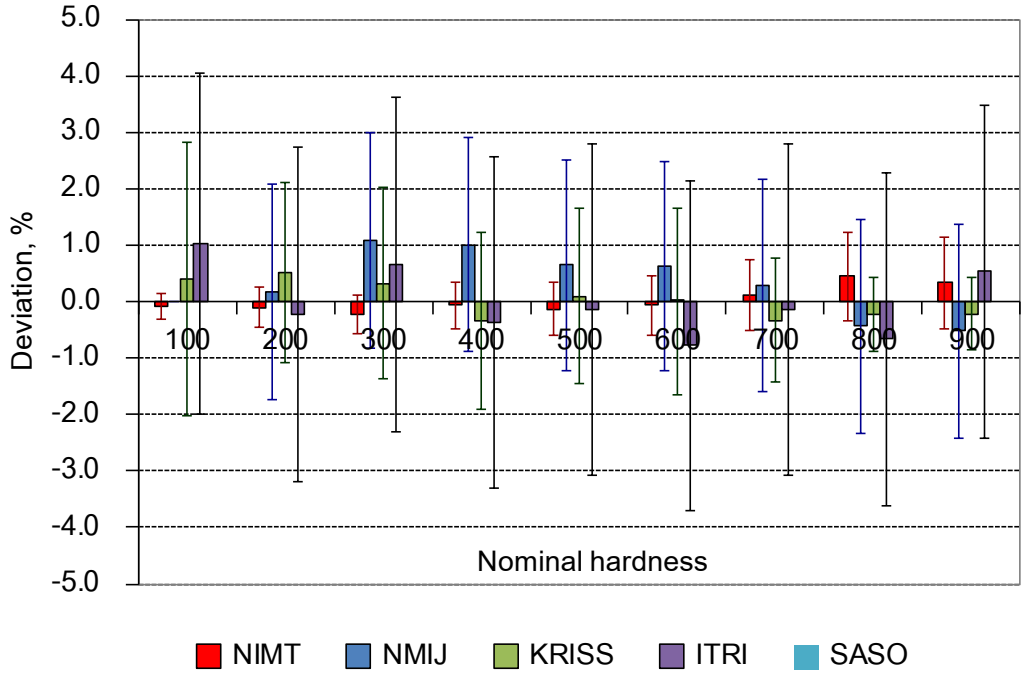


Figure 16 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for HV30

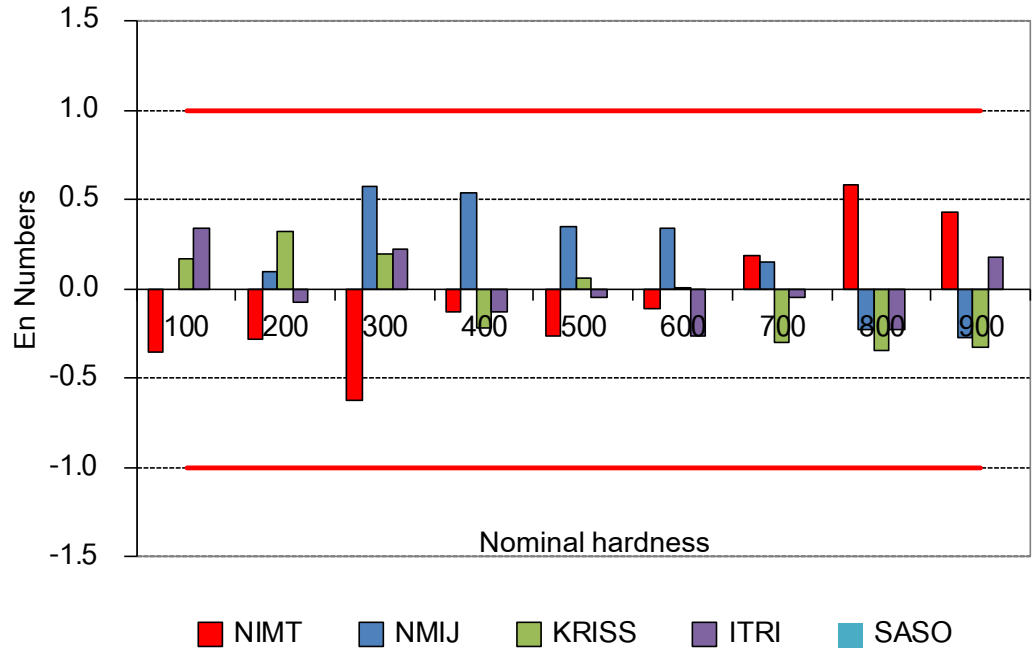


Figure 17 The E_n numbers of Block artifact (Reference Hardness Block) for HV30

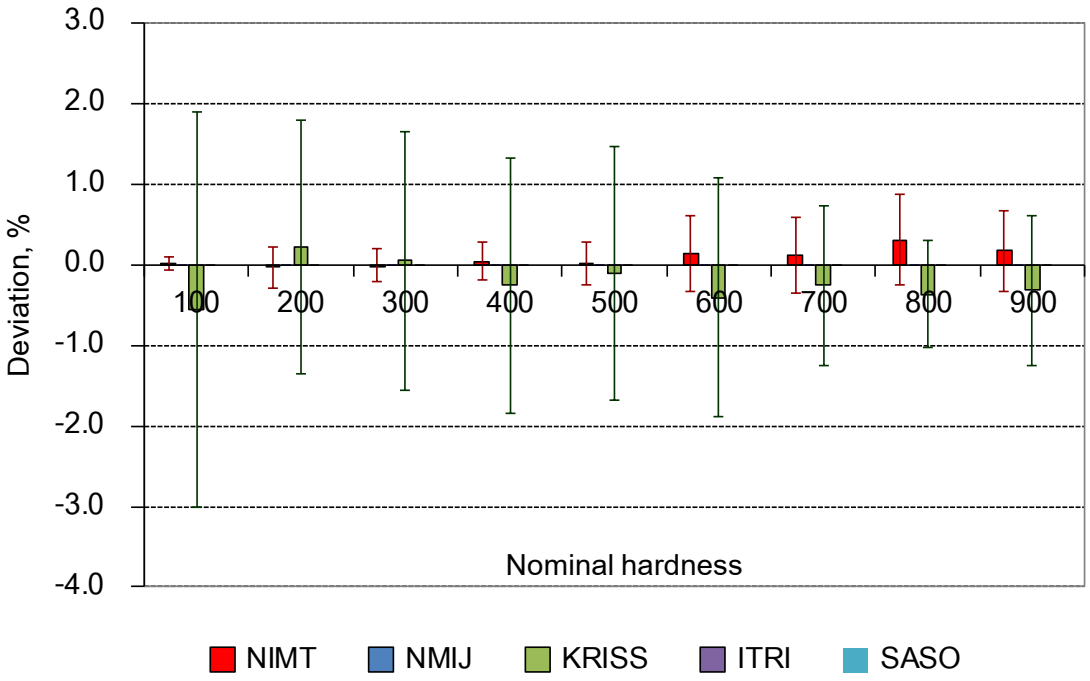


Figure 18 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for HV50

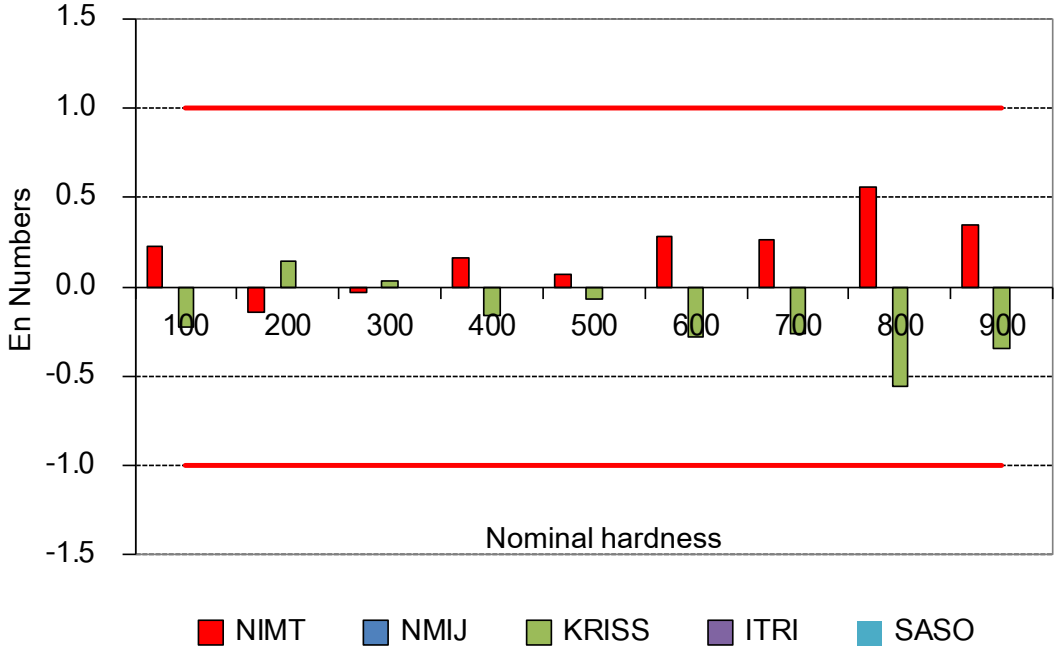


Figure 19 The E_n numbers of Block artifact (Reference Hardness Block) for HV50

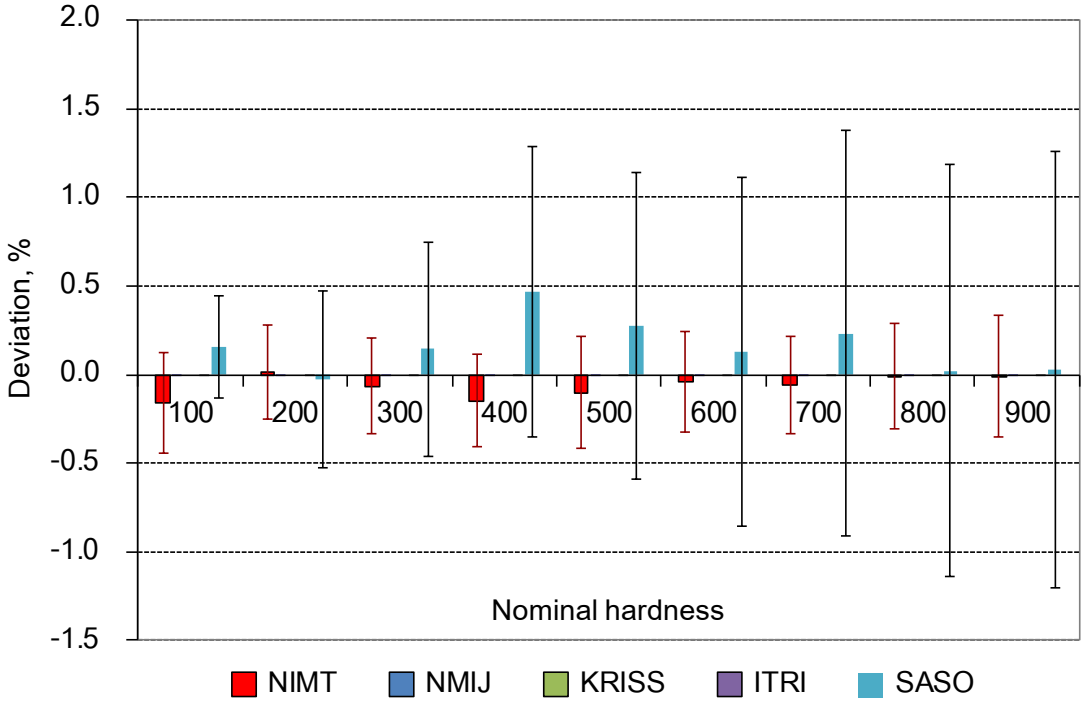


Figure 20 The overview of the deviation from the comparison reference value Block artifact (Reference Hardness Block) for HV100

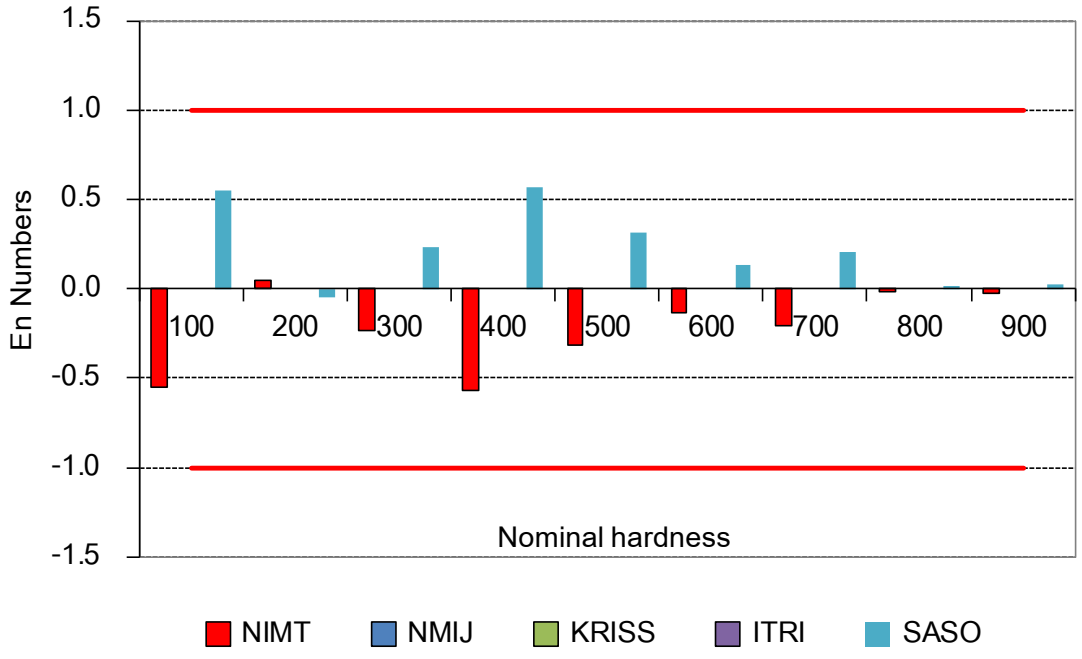


Figure 21 The E_n numbers of Block artifact (Reference Hardness Block) for HV100

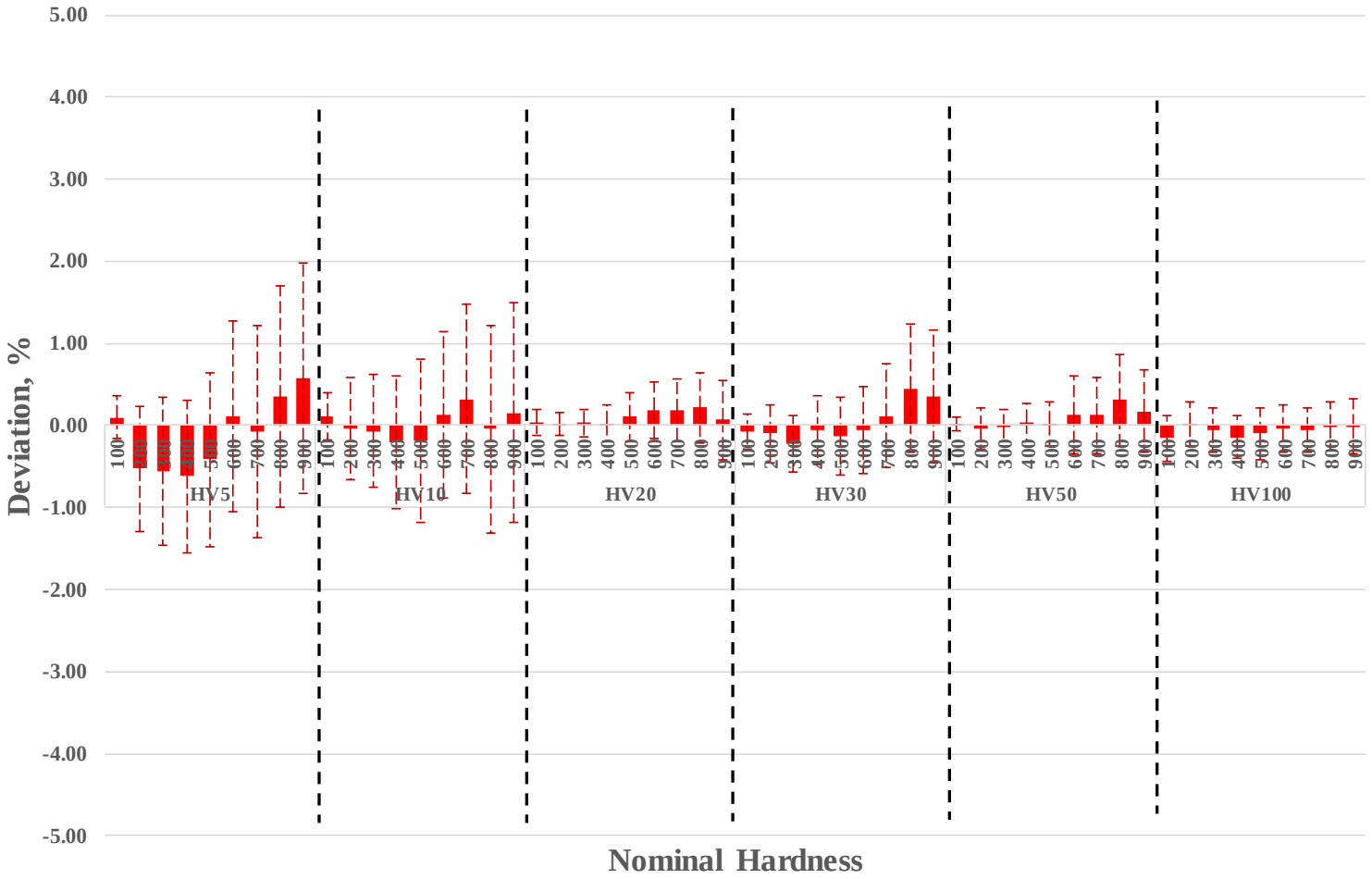


Figure 22 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for NIMT

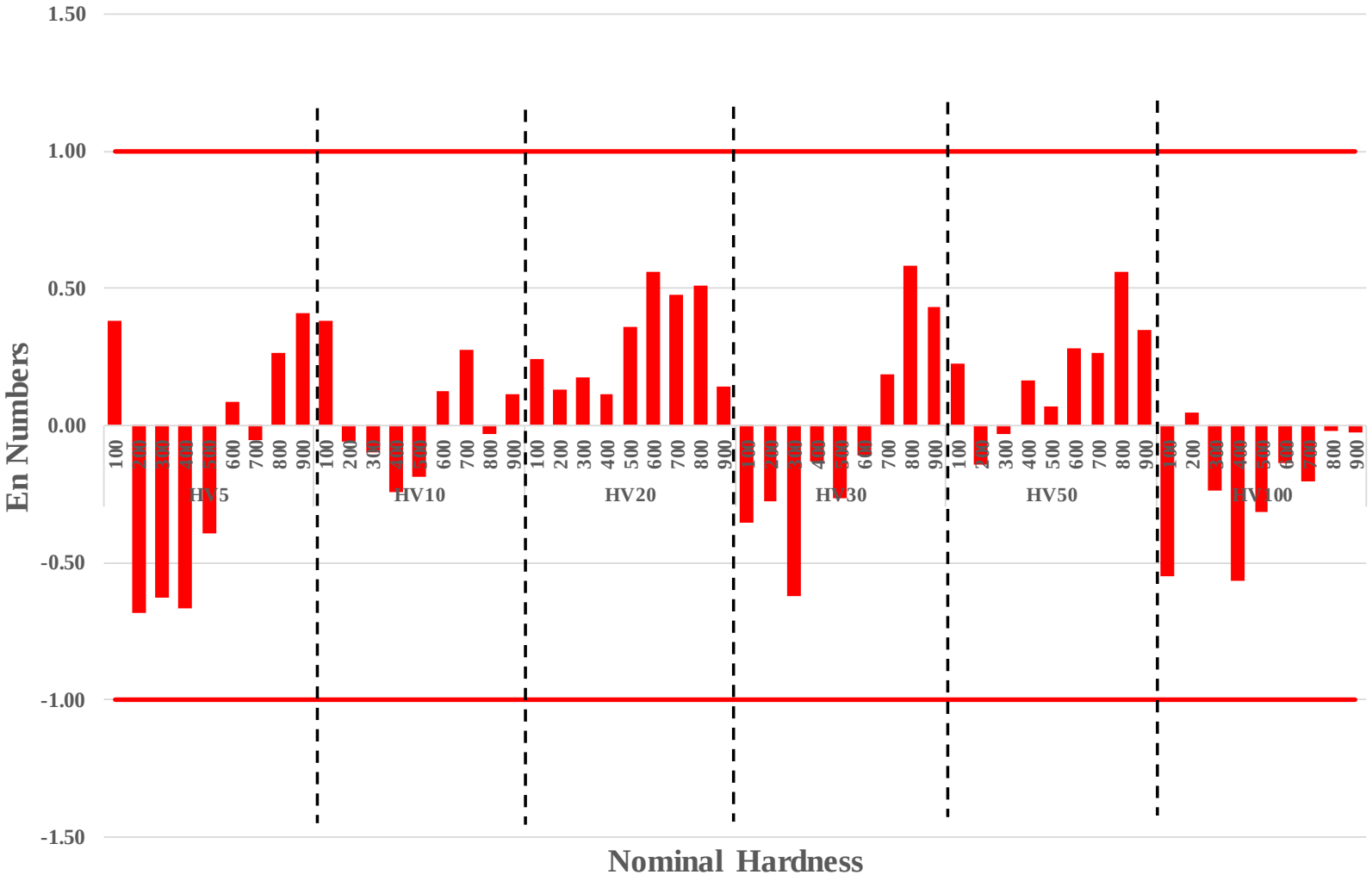


Figure 23 The E_n numbers of Block artifact (Reference Hardness Block) for NIMT

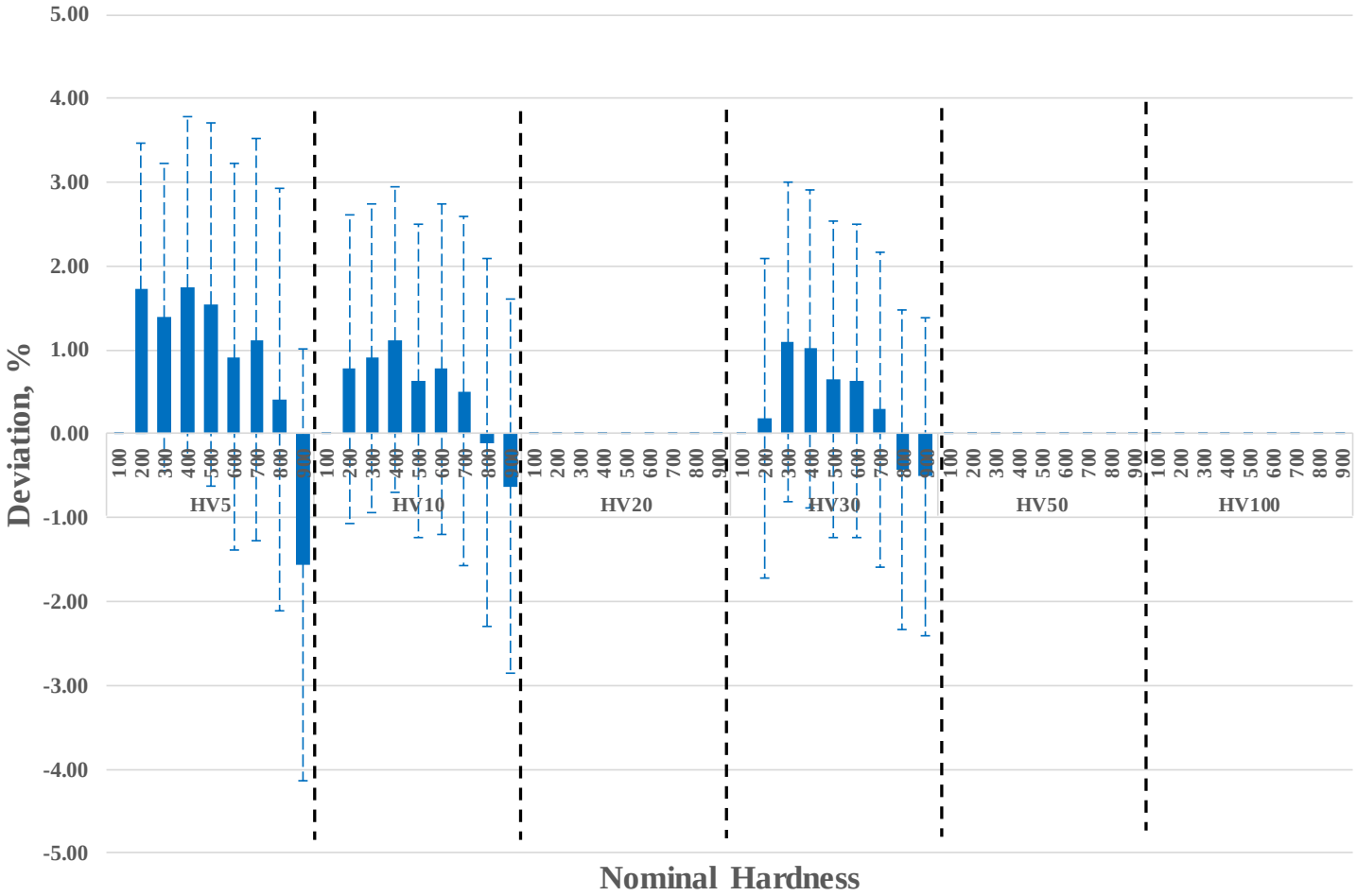


Figure 24 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for NMIJ

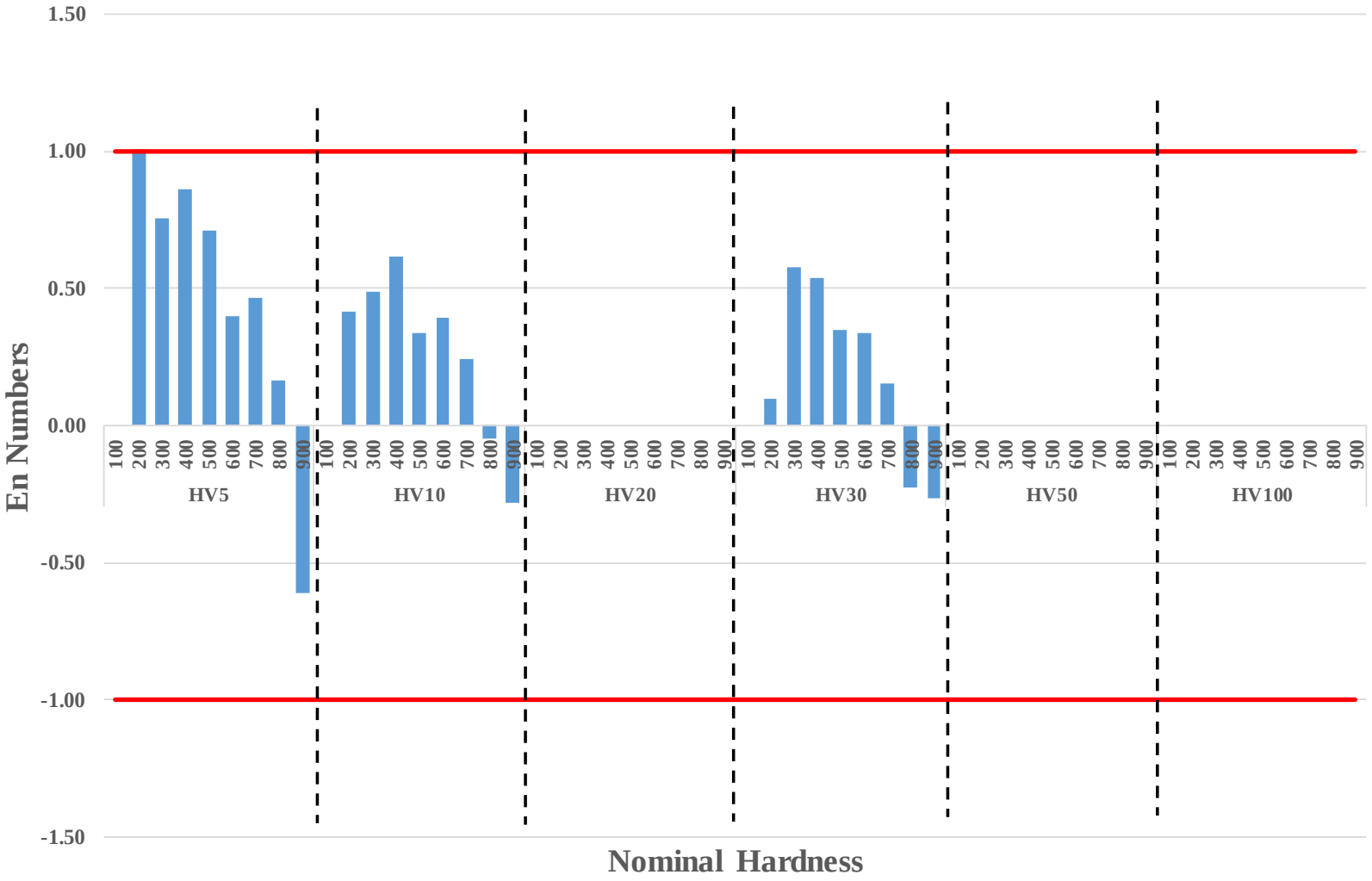


Figure 25 The E_n numbers of Block artifact (Reference Hardness Block) for NMIJ

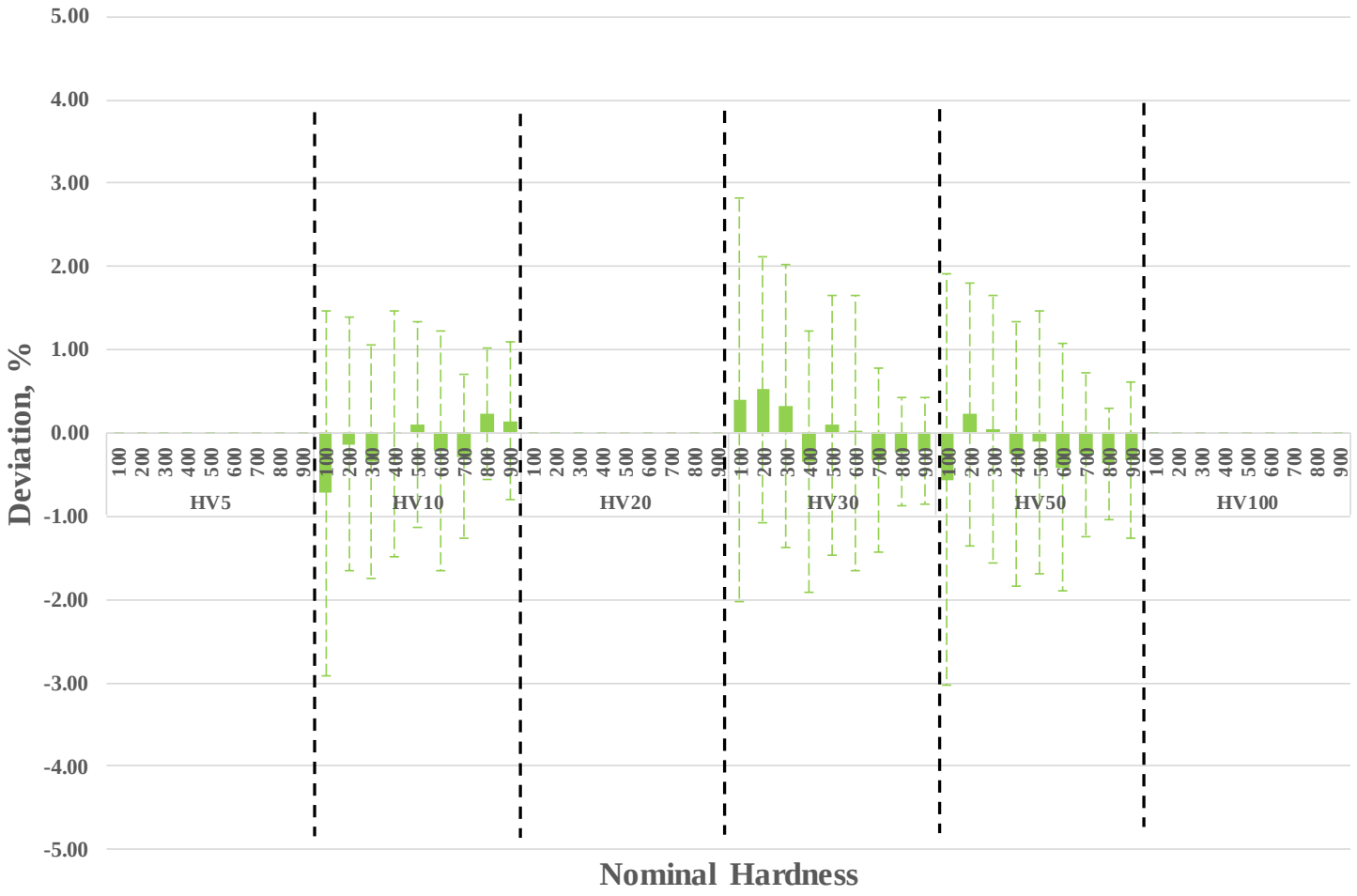


Figure 26 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for KRISS

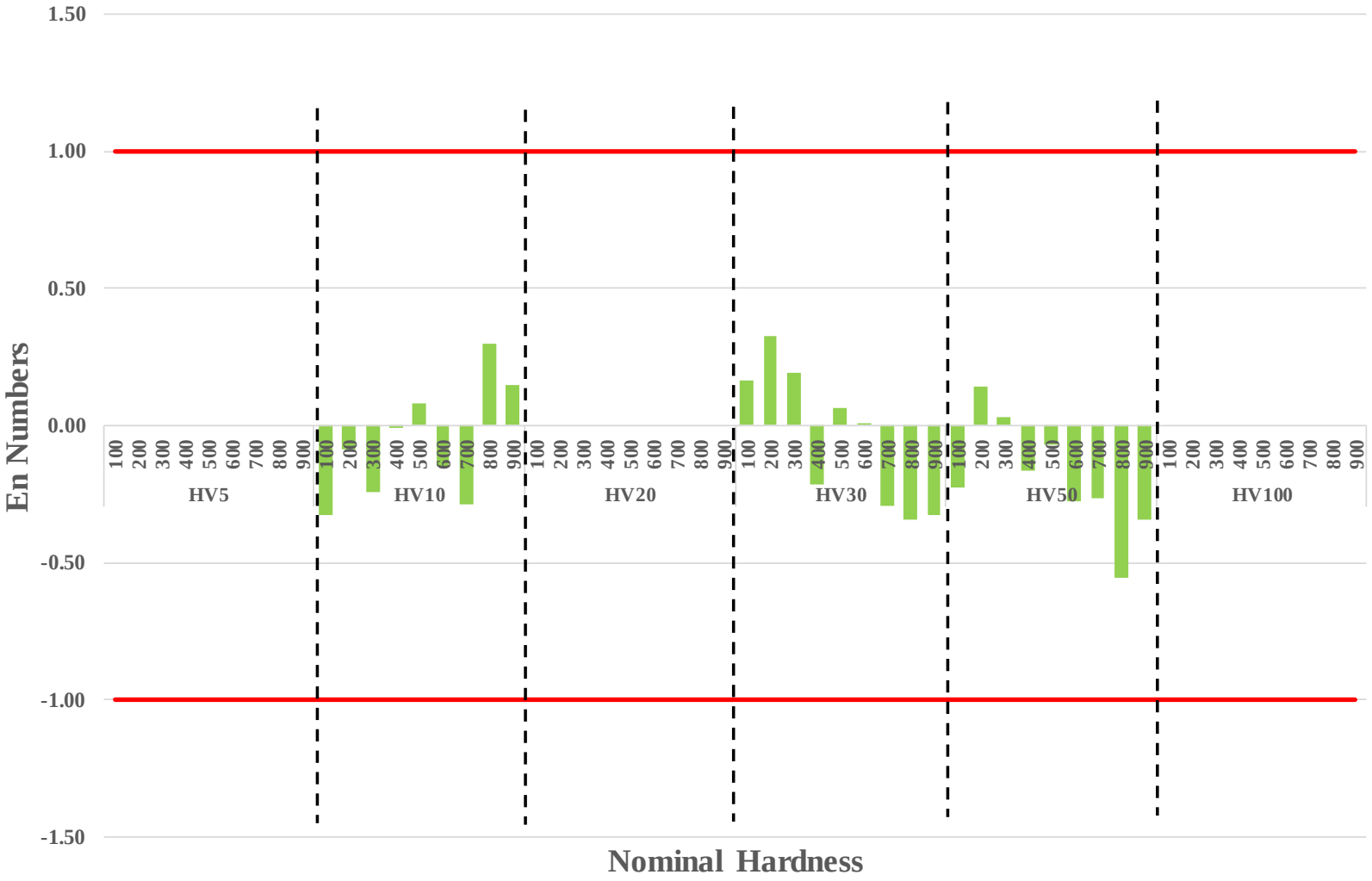


Figure 27 The E_n numbers of Block artifact (Reference Hardness Block) for KRISS

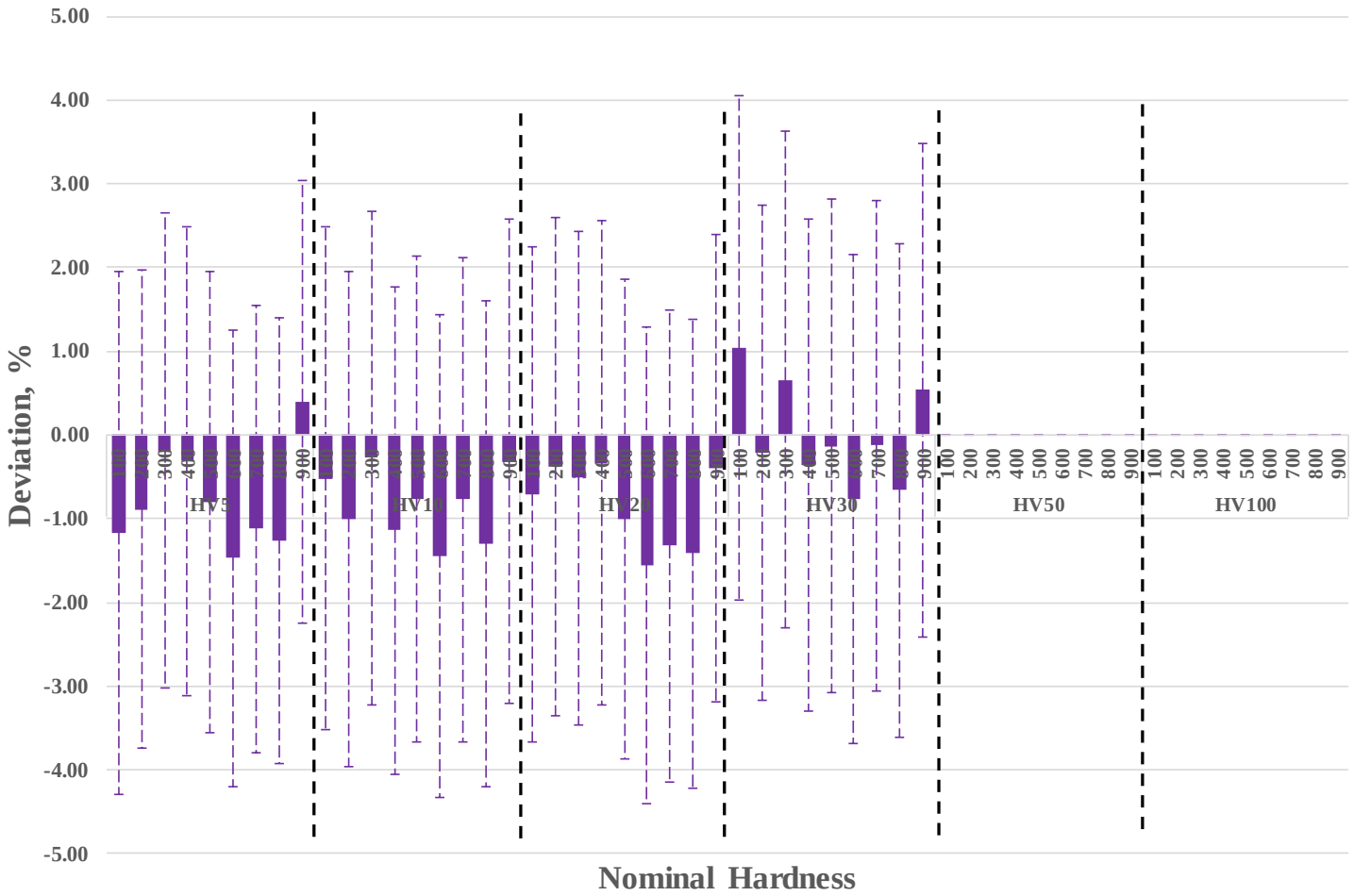


Figure 28 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for ITRI

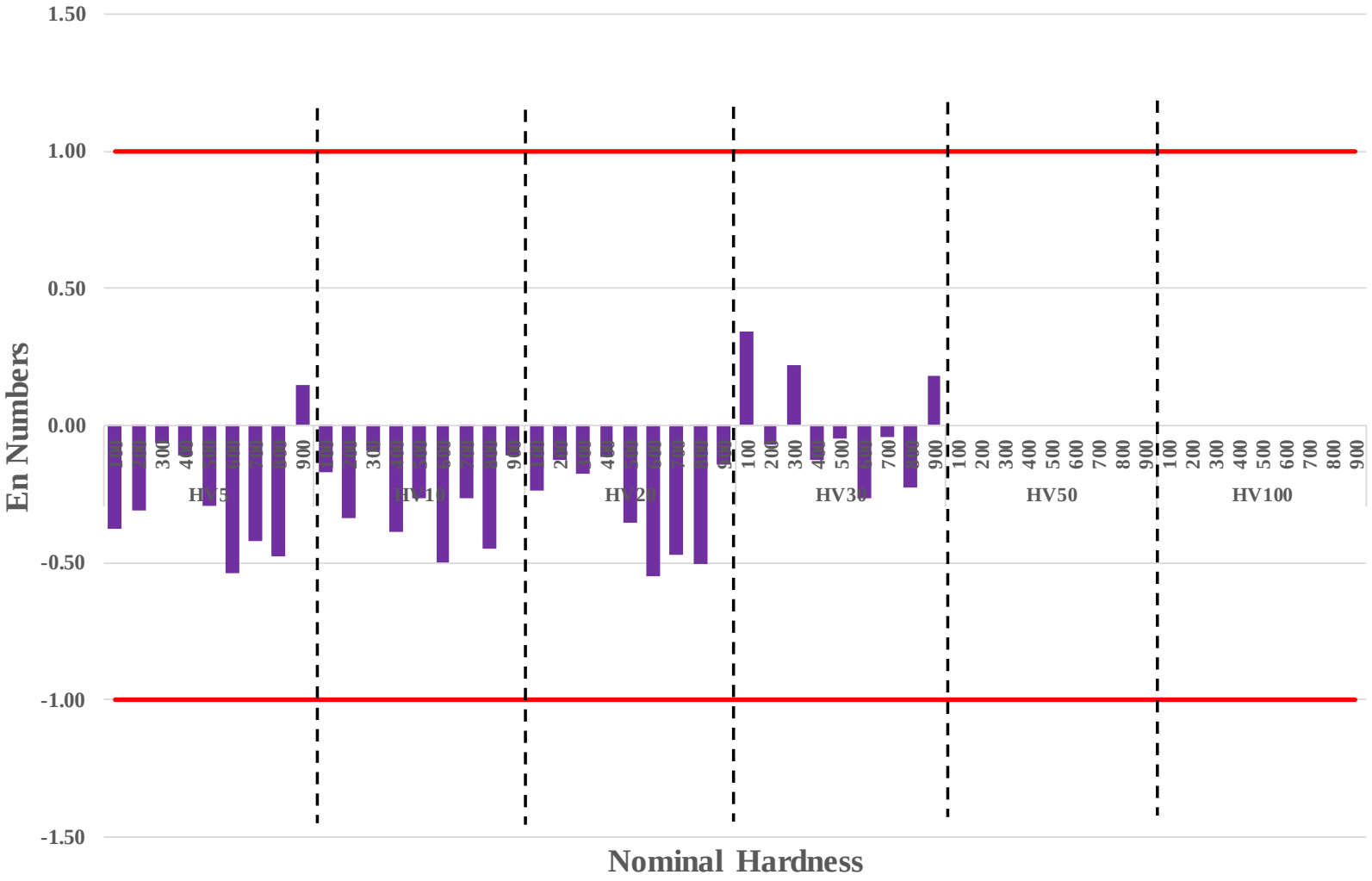


Figure 29 The E_n numbers of Block artifact (Reference Hardness Block) for ITRI

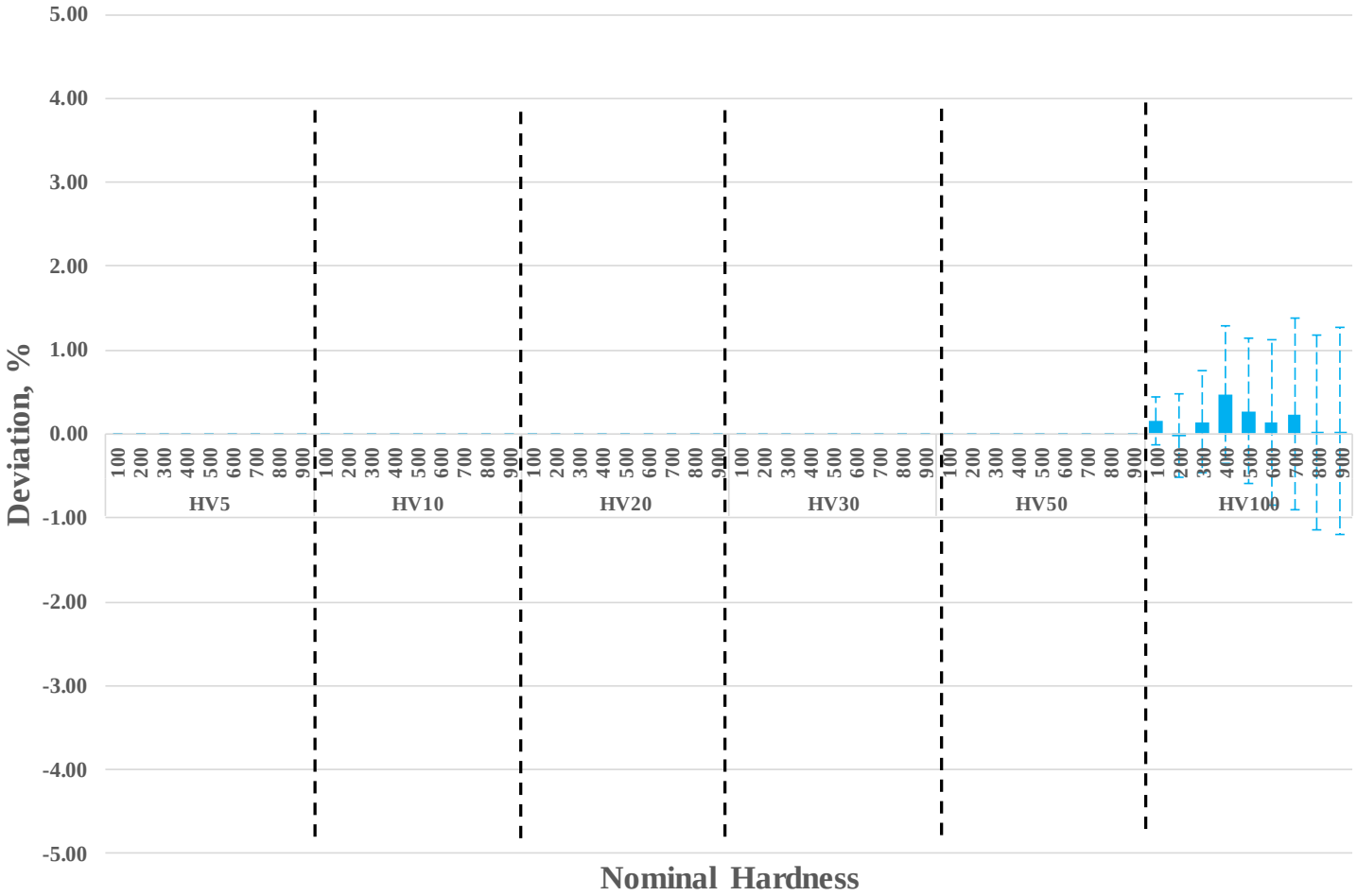


Figure 30 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for SASO

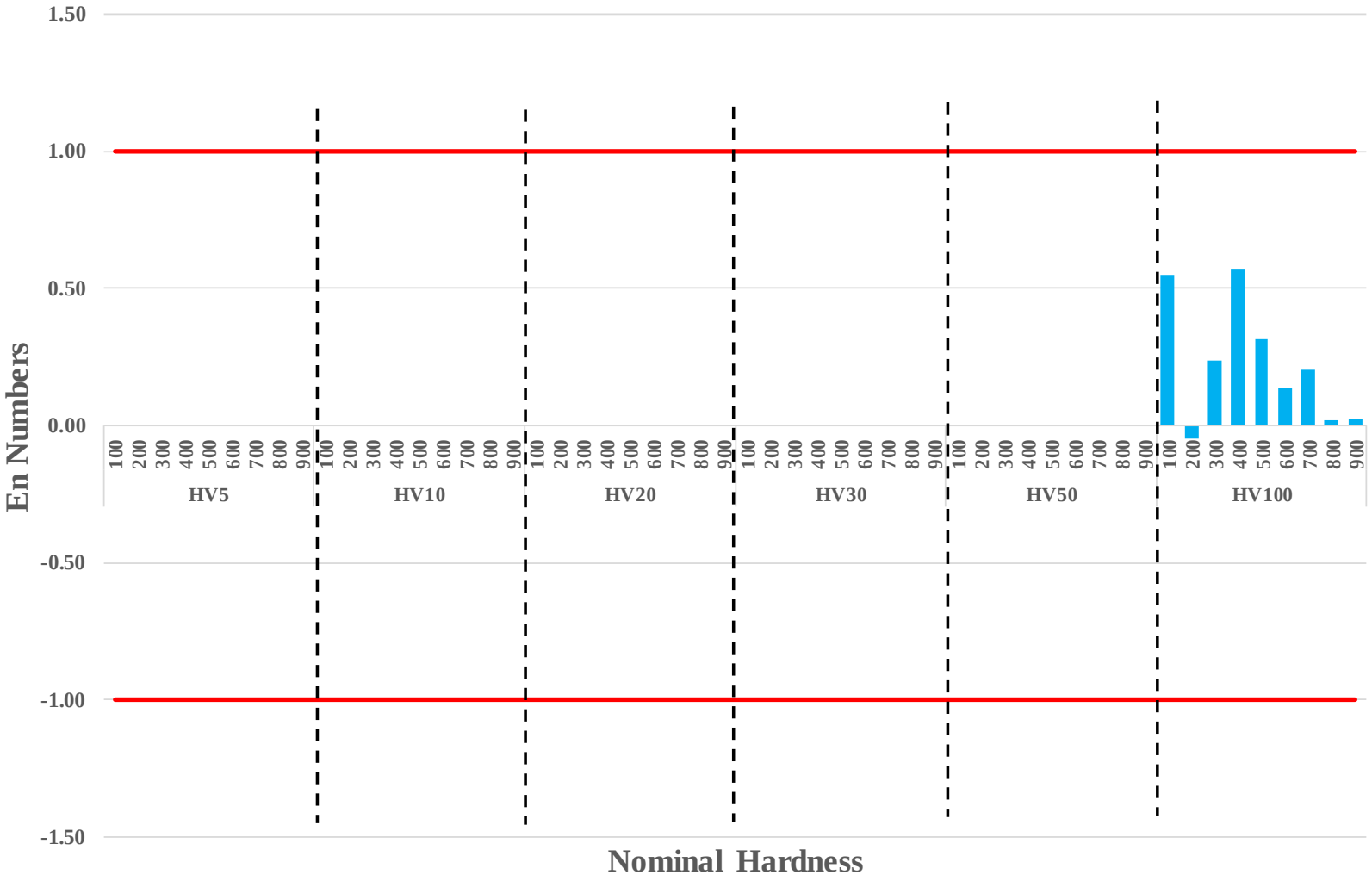


Figure 31 The E_n numbers of Block artifact (Reference Hardness Block) for SASO

8 The results for new approached CMC

Although the participants claimed the existing CMC, some participants had reported the expanded uncertainty smaller than the existing CMC, in case the participant would like to propose for new approached CMC.

In the comparison, KRISS had report the expanded uncertainty as the list in Table 29 for new approached CMC.

Based on the new approached CMC of KRISS results, all measurement results and comparison results were shown in Table 30 - Table 35. The comparison graphs categorized based on the hardness scales and participants were shown in Figure 33- Figure 37.

Table 29 The new approached CMC for KRISS in HV

Scale	Nominal hardness	New approached CMC (k=2) in HV
HV10	100	2.05
	200	2.96
	300	4.10
	400	5.99
	500	6.55
	600	9.16
	700	9.30
	800	9.34
	900	11.84
HV30	100	2.02
	200	2.76
	300	3.76
	400	5.08
	500	6.41
	600	7.97
	700	7.45
	800	7.28
	900	7.91
HV50	100	1.87
	200	2.98
	300	3.67
	400	4.96
	500	6.30
	600	7.72
	700	7.05
	800	6.67
	900	10.41

Table 30 The results of the measurement in HV10: For Block Artifact (Reference Hardness Block) (based on new approach CMC)

Nominal value		Measurement data of each participant (HV), Xi					Uncertainty *(k=2)* of each participant (HV), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV10	100	104.51	-	103.64	103.85	-	0.80	-	2.05	3.20	-	0.76	-	1.98	3.08	-
	200	217.84	219.61	217.63	215.75	-	2.15	4.39	2.96	6.60	-	0.99	2.00	1.36	3.06	-
	300	306.05	309.05	305.23	305.42	-	3.17	6.18	4.10	9.30	-	1.03	2.00	1.34	3.04	-
	400	412.97	418.48	413.75	409.13	-	4.79	8.37	5.99	12.40	-	1.16	2.00	1.45	3.03	-
	500	512.67	516.87	514.13	509.72	-	6.71	10.63	6.55	15.40	-	1.31	2.06	1.27	3.02	-
	600	627.81	631.91	625.70	618.12	-	8.54	13.70	9.16	18.70	-	1.36	2.17	1.46	3.03	-
	700	724.76	726.11	720.39	716.93	-	10.38	16.35	9.30	21.60	-	1.43	2.25	1.29	3.01	-
	800	827.73	827.19	830.00	817.43	-	12.44	19.32	9.34	24.60	-	1.50	2.34	1.13	3.01	-
	900	912.27	905.22	912.17	908.01	-	14.64	21.70	11.84	27.50	-	1.61	2.40	1.30	3.03	-

Table 31 The results of the measurement in HV30: For Block Artifact (Reference Hardness Block) (based on new approach CMC)

Nominal value		Measurement data of each participant (HV), Xi					Uncertainty *(k=2)* of each participant (HV), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV30	100	102.64	-	103.14	103.80	-	0.69	-	2.02	3.20	-	0.67	-	1.95	3.08	-
	200	218.49	219.10	219.85	218.24	-	1.54	4.38	2.76	6.60	-	0.70	2.00	1.25	3.02	-
	300	304.82	308.88	306.48	307.51	-	2.12	6.18	3.76	9.30	-	0.70	2.00	1.23	3.02	-
	400	413.93	418.41	412.75	412.67	-	3.20	8.37	5.08	12.40	-	0.77	2.00	1.23	3.00	-
	500	511.91	515.91	513.05	511.86	-	4.26	10.32	6.41	15.50	-	0.83	2.00	1.25	3.03	-
	600	625.73	630.08	626.11	621.29	-	5.59	12.60	7.97	18.70	-	0.89	2.00	1.27	3.01	-
	700	721.69	722.94	718.50	719.91	-	6.80	14.46	7.45	21.70	-	0.94	2.00	1.04	3.01	-
	800	828.35	821.12	822.76	819.19	-	8.22	16.42	7.28	24.70	-	0.99	2.00	0.89	3.02	-
	900	907.51	899.77	902.43	909.23	-	9.33	18.00	7.91	27.40	-	1.03	2.00	0.88	3.01	-

Table 32 The results of the measurement in HV50: For Block Artifact (Reference Hardness Block) (based on new approach CMC)

Nominal value		Measurement data of each participant (HV), Xi					Uncertainty *(k=2)* of each participant (HV), $U_{(Xi)}$					Uncertainty *(k=2)* of each participant (%), $U_{(Xi)}$				
		NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV50	100	103.85	-	103.25	-	-	0.46	-	1.87	-	-	0.45	-	1.81	-	-
	200	218.63	-	219.20	-	-	1.50	-	2.98	-	-	0.69	-	1.36	-	-
	300	305.80	-	305.97	-	-	1.82	-	3.67	-	-	0.59	-	1.20	-	-
	400	414.50	-	413.28	-	-	2.70	-	4.96	-	-	0.65	-	1.20	-	-
	500	512.07	-	511.41	-	-	3.58	-	6.30	-	-	0.70	-	1.23	-	-
	600	627.93	-	624.52	-	-	5.99	-	7.72	-	-	0.95	-	1.24	-	-
	700	720.34	-	717.58	-	-	5.95	-	7.05	-	-	0.83	-	0.98	-	-
	800	827.37	-	821.78	-	-	6.81	-	6.67	-	-	0.82	-	0.81	-	-
	900	902.97	-	898.51	-	-	7.66	-	10.41	-	-	0.85	-	1.16	-	-

Table 33 The deviation from comparison reference value and E_n numbers in HV10: For Block Artifact (Reference Hardness Block) (based on new approach CMC)

Nominal value		Xcrv	Deviation from reference value (% of HV), di					$U(X_{crv})$	Uncertainty of Deviation *(k=2)* (% of HV), U(di)					E_n numbers				
		(HV)	NIMT	NMIJ	KRISS	ITRI	SASO	(%)	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV10	100	104.36	0.14	-	-0.69	-0.50	-	0.69	0.32	-	1.85	3.00	-	0.42	-	-0.37	-0.17	-
	200	217.89	-0.02	0.78	-0.12	-0.99	-	0.72	0.67	1.87	1.15	2.97	-	-0.03	0.42	-0.10	-0.33	-
	300	306.17	-0.04	0.93	-0.31	-0.24	-	0.74	0.73	1.86	1.12	2.95	-	-0.05	0.50	-0.27	-0.08	-
	400	413.79	-0.20	1.12	-0.01	-1.14	-	0.80	0.84	1.83	1.21	2.92	-	-0.23	0.61	-0.01	-0.39	-
	500	513.67	-0.20	0.62	0.09	-0.78	-	0.80	1.03	1.89	0.99	2.91	-	-0.19	0.33	0.09	-0.27	-
	600	626.89	0.15	0.79	-0.19	-1.42	-	0.87	1.05	1.99	1.18	2.90	-	0.14	0.40	-0.16	-0.49	-
	700	722.43	0.32	0.51	-0.28	-0.77	-	0.85	1.15	2.09	0.97	2.89	-	0.28	0.24	-0.29	-0.27	-
	800	828.07	-0.04	-0.11	0.23	-1.30	-	0.81	1.27	2.19	0.78	2.90	-	-0.03	-0.05	0.30	-0.45	-
	900	910.87	0.15	-0.62	0.14	-0.32	-	0.89	1.34	2.23	0.95	2.90	-	0.11	-0.28	0.15	-0.11	-

Table 34 The deviation from comparison reference value and E_n numbers in HV30: For Block Artifact (Reference Hardness Block) (based on new approach CMC)

Nominal value		Xcrv	Deviation from reference value (% of HV), di					$U(X_{crv})$	Uncertainty of Deviation *(k=2)* (% of HV), U(di)					E_n numbers				
		(HV)	NIMT	NMIJ	KRISS	ITRI	SASO	(%)	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV30	100	102.74	-0.09	-	0.39	1.02	-	0.62	0.25	-	1.85	3.02	-	-0.37	-	0.21	0.34	-
	200	218.82	-0.15	0.13	0.47	-0.26	-	0.58	0.40	1.92	1.11	2.97	-	-0.37	0.07	0.42	-0.09	-
	300	305.59	-0.25	1.06	0.29	0.62	-	0.57	0.40	1.92	1.09	2.97	-	-0.63	0.55	0.27	0.21	-
	400	413.99	-0.02	1.06	-0.30	-0.32	-	0.61	0.47	1.91	1.07	2.94	-	-0.03	0.55	-0.28	-0.11	-
	500	512.61	-0.14	0.64	0.09	-0.15	-	0.64	0.53	1.90	1.07	2.96	-	-0.26	0.34	0.08	-0.05	-
	600	626.10	-0.06	0.63	0.00	-0.77	-	0.67	0.59	1.88	1.08	2.93	-	-0.10	0.34	0.00	-0.26	-
	700	720.50	0.16	0.34	-0.28	-0.08	-	0.64	0.69	1.89	0.81	2.94	-	0.24	0.18	-0.34	-0.03	-
	800	824.58	0.46	-0.42	-0.22	-0.66	-	0.61	0.78	1.90	0.64	2.95	-	0.58	-0.22	-0.35	-0.22	-
	900	904.29	0.36	-0.50	-0.21	0.54	-	0.62	0.82	1.90	0.62	2.95	-	0.43	-0.26	-0.33	0.18	-

Table 35 The deviation from comparison reference value and E_n numbers in HV50: For Block Artifact (Reference Hardness Block) (based on new approach CMC)

Nominal value		Xcrv	Deviation from reference value (% of HV), di					$U(X_{crv})$	Uncertainty of Deviation *(k=2)* (% of HV), U(di)					E_n numbers				
		(HV)	NIMT	NMIJ	KRISS	ITRI	SASO	(%)	NIMT	NMIJ	KRISS	ITRI	SASO	NIMT	NMIJ	KRISS	ITRI	SASO
HV50	100	103.81	0.03	-	-0.54	-	-	0.43	0.11	-	1.76	-	-	0.31	-	-0.31	-	-
	200	218.74	-0.05	-	0.21	-	-	0.61	0.31	-	1.21	-	-	-0.17	-	0.17	-	-
	300	305.83	-0.01	-	0.05	-	-	0.53	0.26	-	1.08	-	-	-0.04	-	0.04	-	-
	400	414.22	0.07	-	-0.23	-	-	0.57	0.31	-	1.06	-	-	0.22	-	-0.22	-	-
	500	511.91	0.03	-	-0.10	-	-	0.61	0.34	-	1.07	-	-	0.09	-	-0.09	-	-
	600	626.65	0.20	-	-0.34	-	-	0.76	0.58	-	0.98	-	-	0.35	-	-0.35	-	-
	700	719.19	0.16	-	-0.22	-	-	0.63	0.53	-	0.75	-	-	0.30	-	-0.30	-	-
	800	824.52	0.34	-	-0.33	-	-	0.58	0.59	-	0.57	-	-	0.59	-	-0.58	-	-
	900	901.40	0.17	-	-0.32	-	-	0.68	0.50	-	0.94	-	-	0.35	-	-0.34	-	-

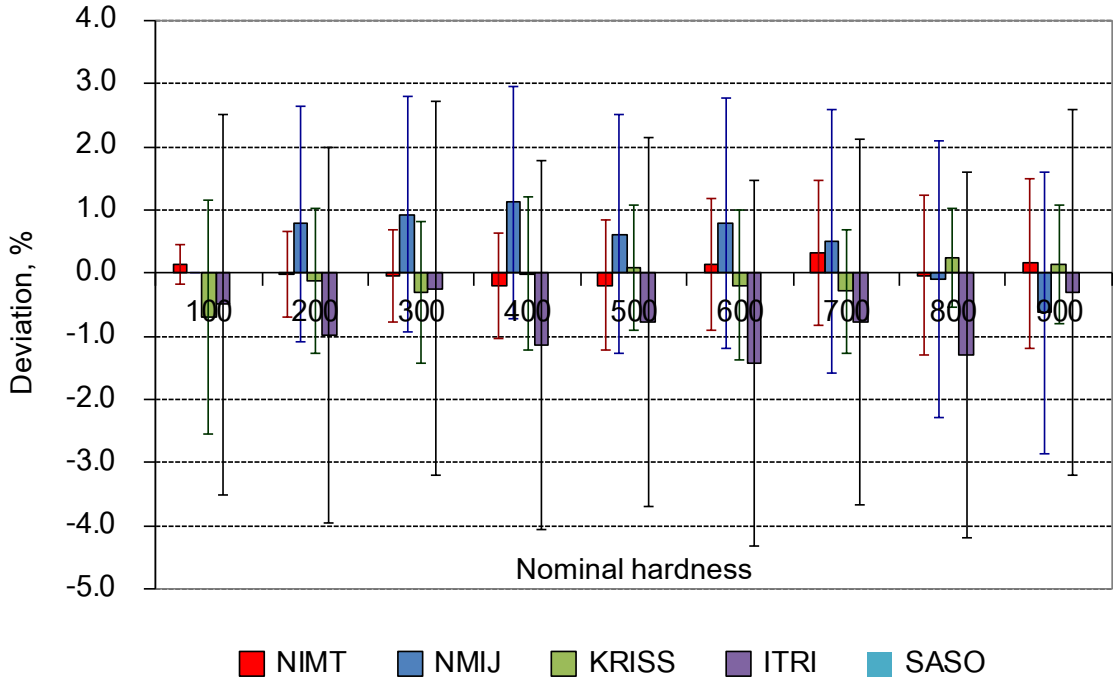


Figure 32 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for HV10 (based on new approach CMC)

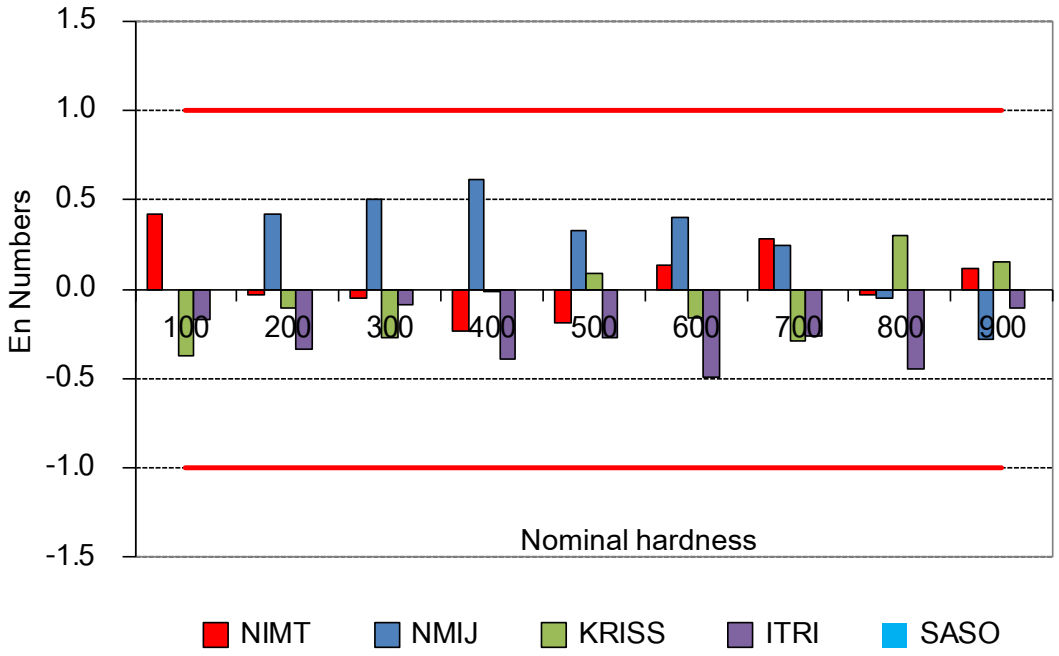


Figure 33 The E_n numbers of Block artifact (Reference Hardness Block) for HV10 (based on new approach CMC)

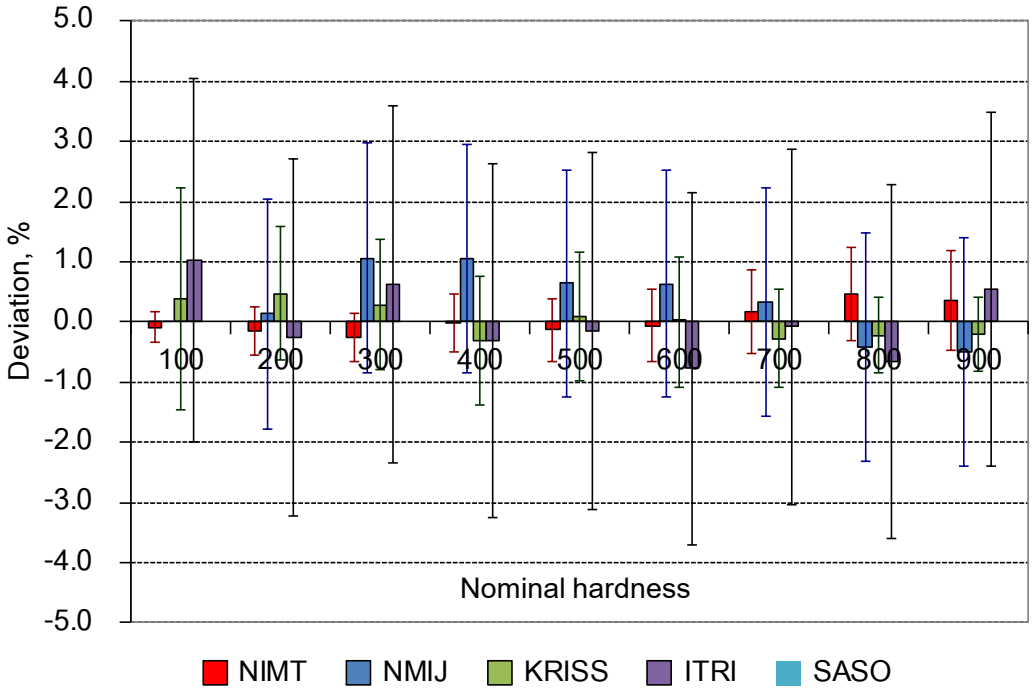


Figure 34 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for HV30 (based on new approach CMC)

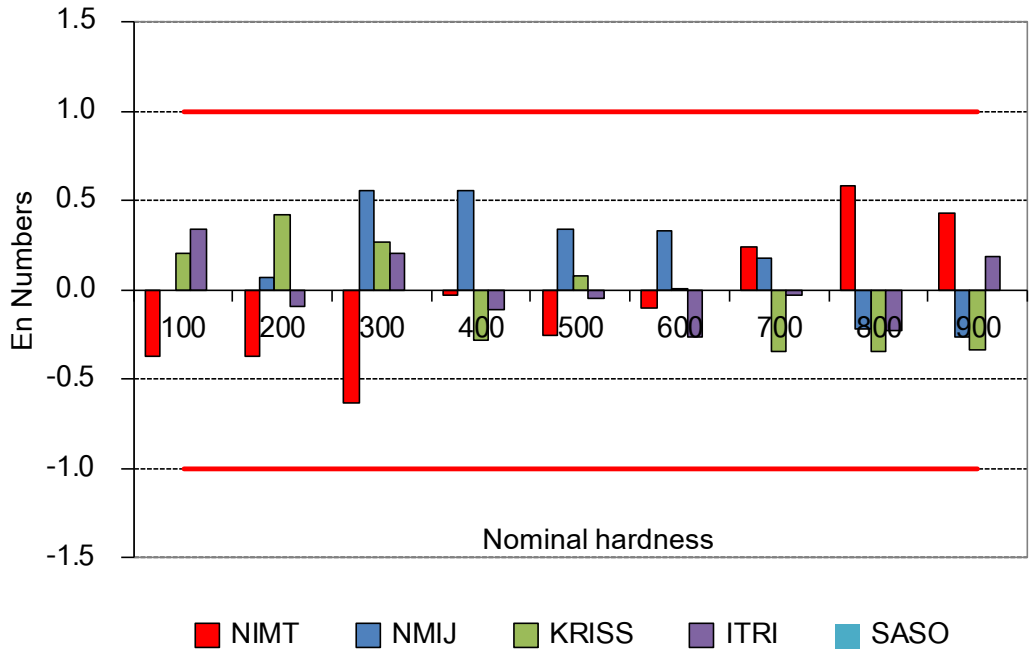


Figure 35 The E_n numbers of Block artifact (Reference Hardness Block) for HV30 (based on new approach CMC)

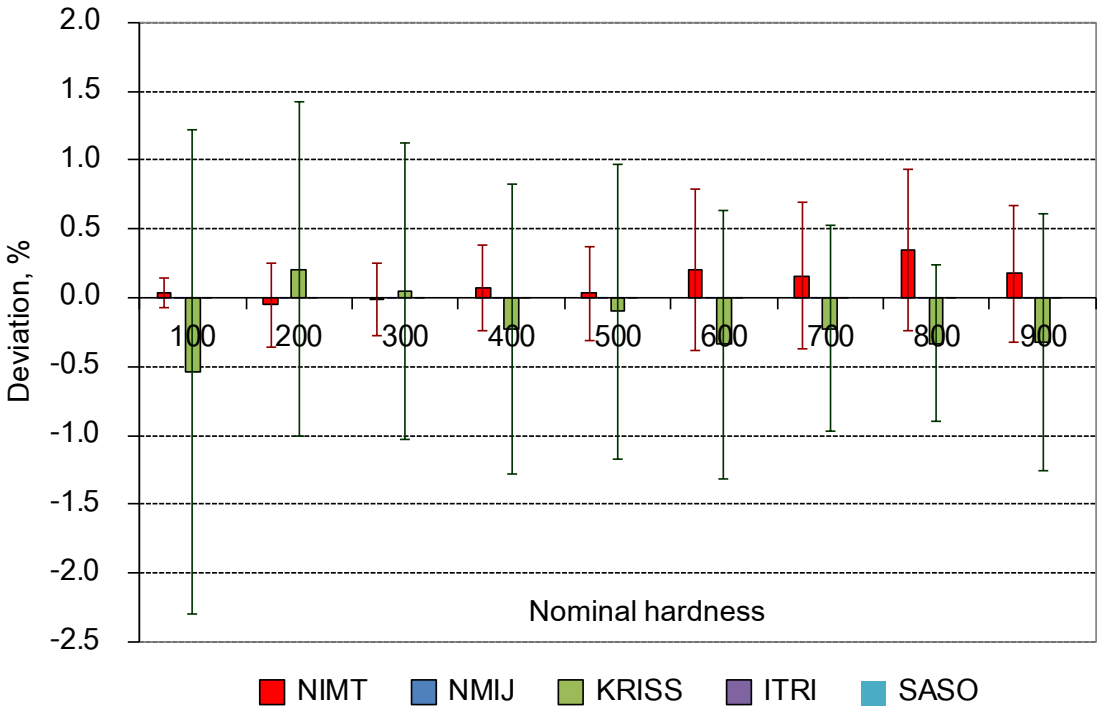


Figure 36 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for HV50 (based on new approach CMC)

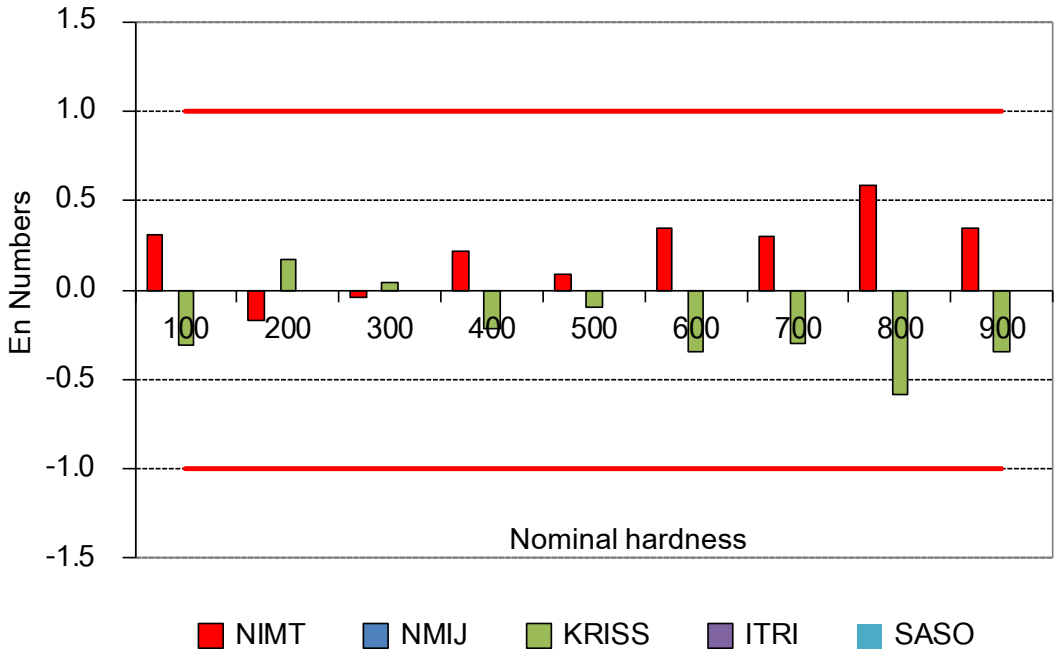


Figure 37 The E_n numbers of Block artifact (Reference Hardness Block) for HV50 (based on new approach CMC)

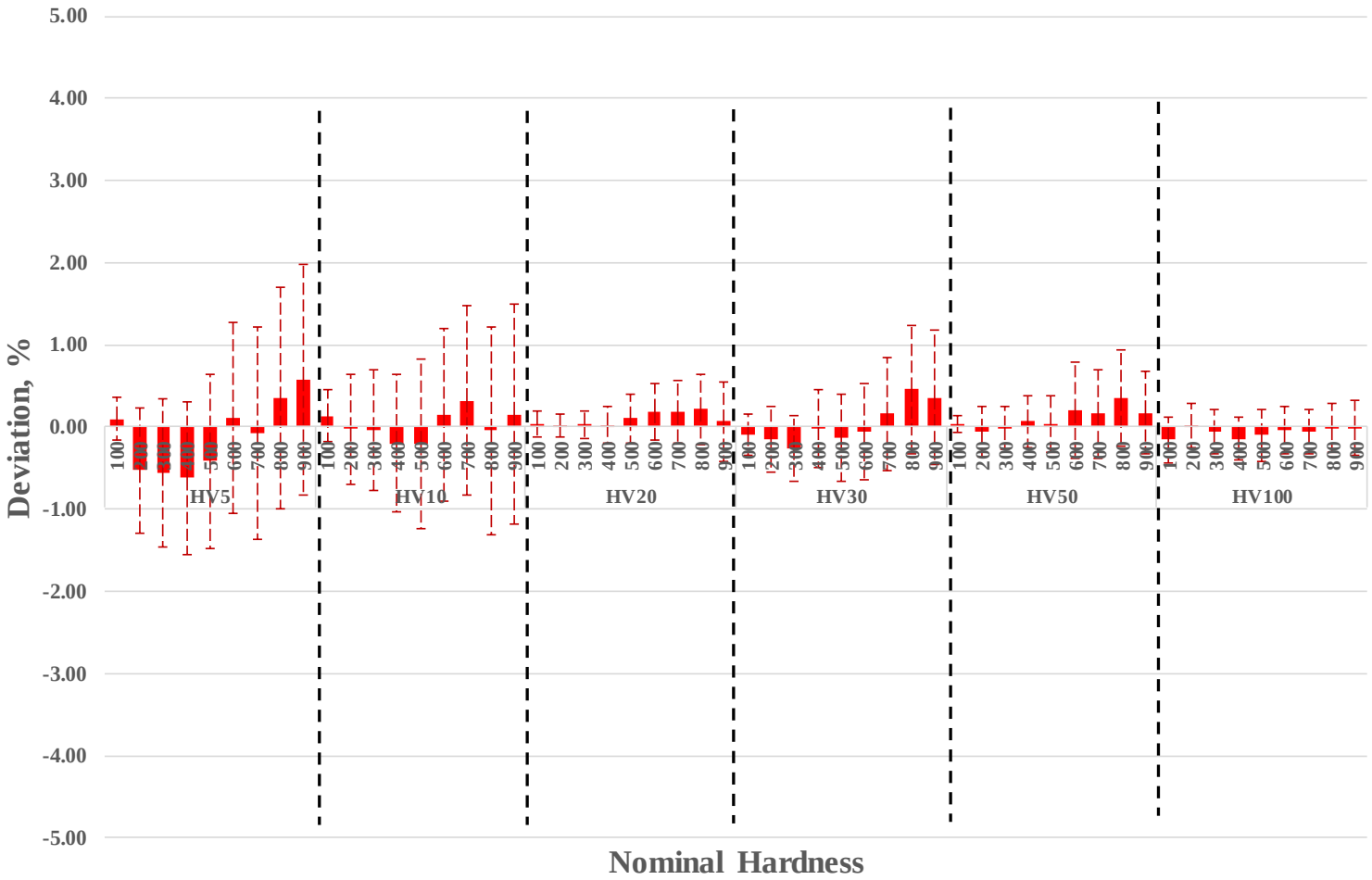


Figure 38 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for NIMT (based on new approach CMC)

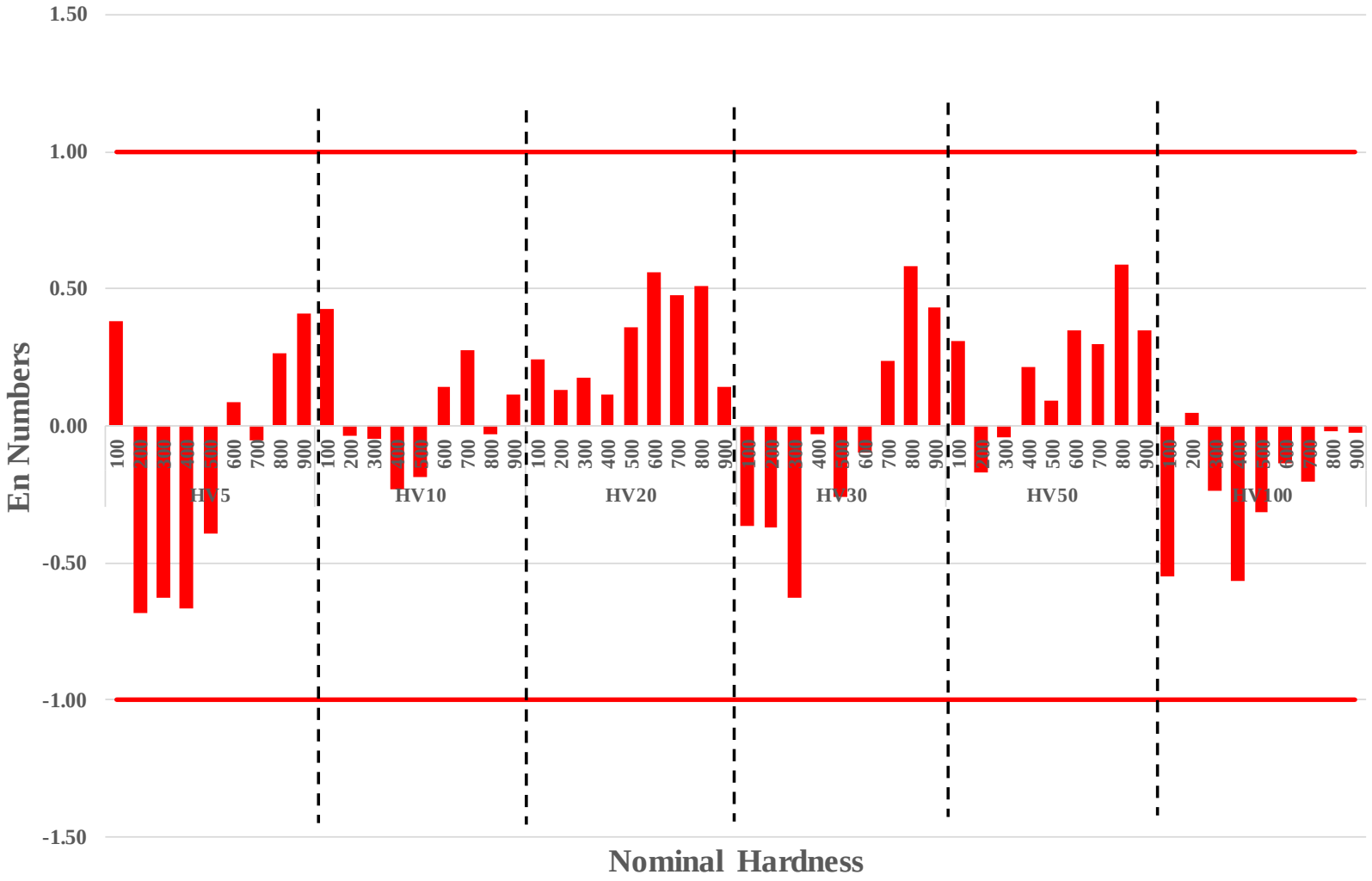


Figure 39 The E_n numbers of Block artifact (Reference Hardness Block) for NIMT (based on new approach CMC)

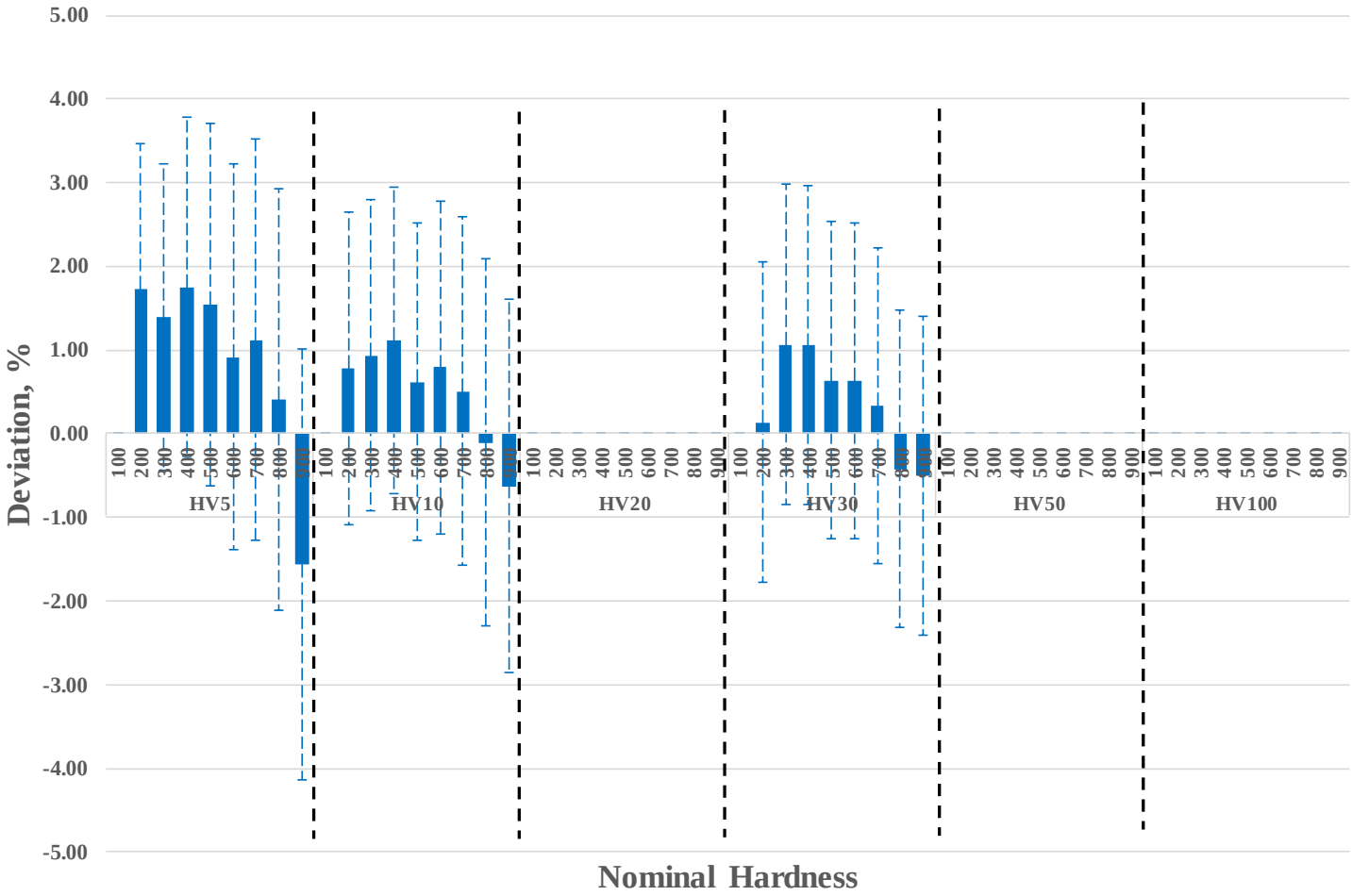


Figure 40 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for NMIJ (based on new approach CMC)

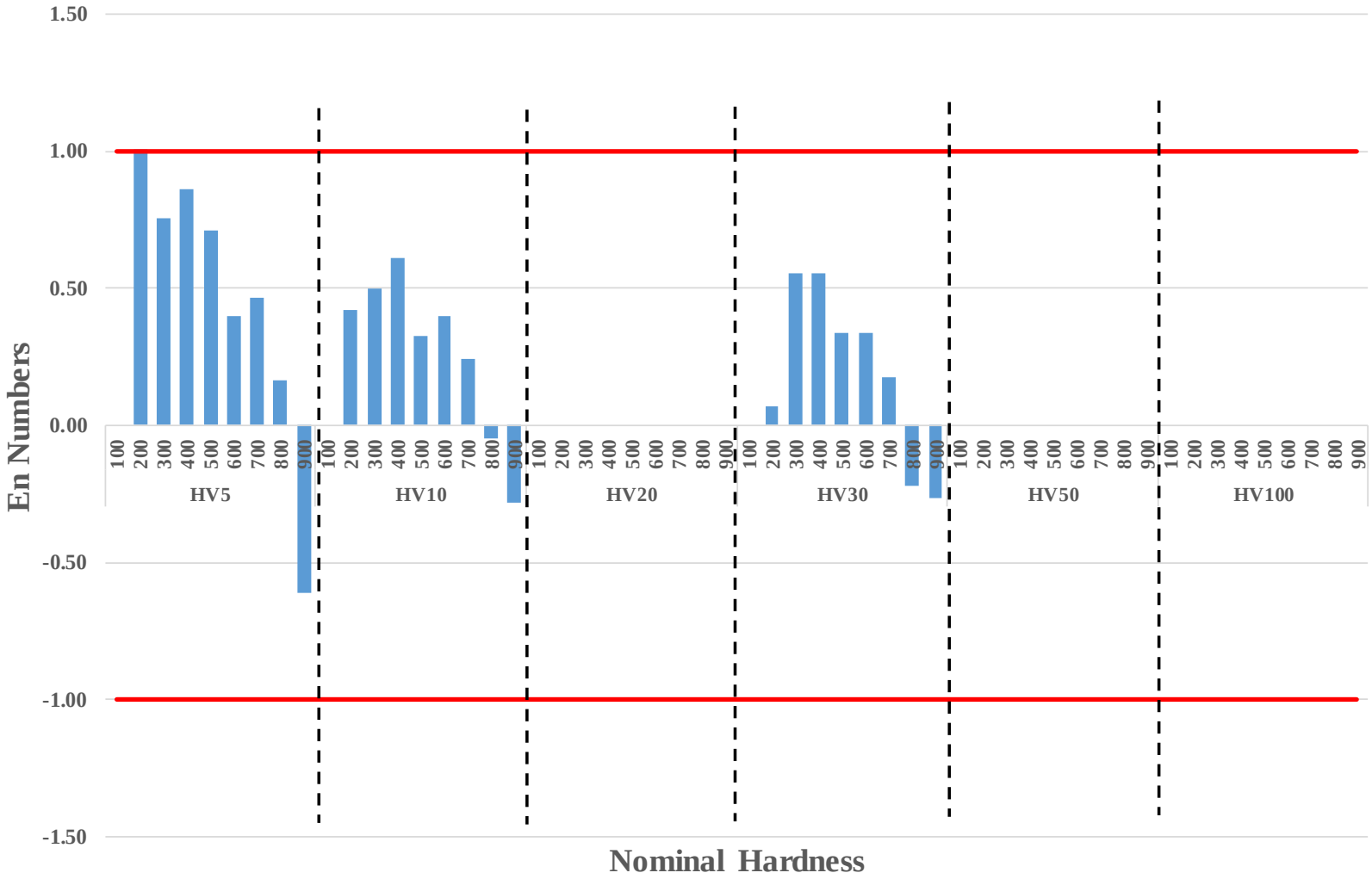


Figure 41 The E_n numbers of Block artifact (Reference Hardness Block) for NMIJ (based on new approach CMC)

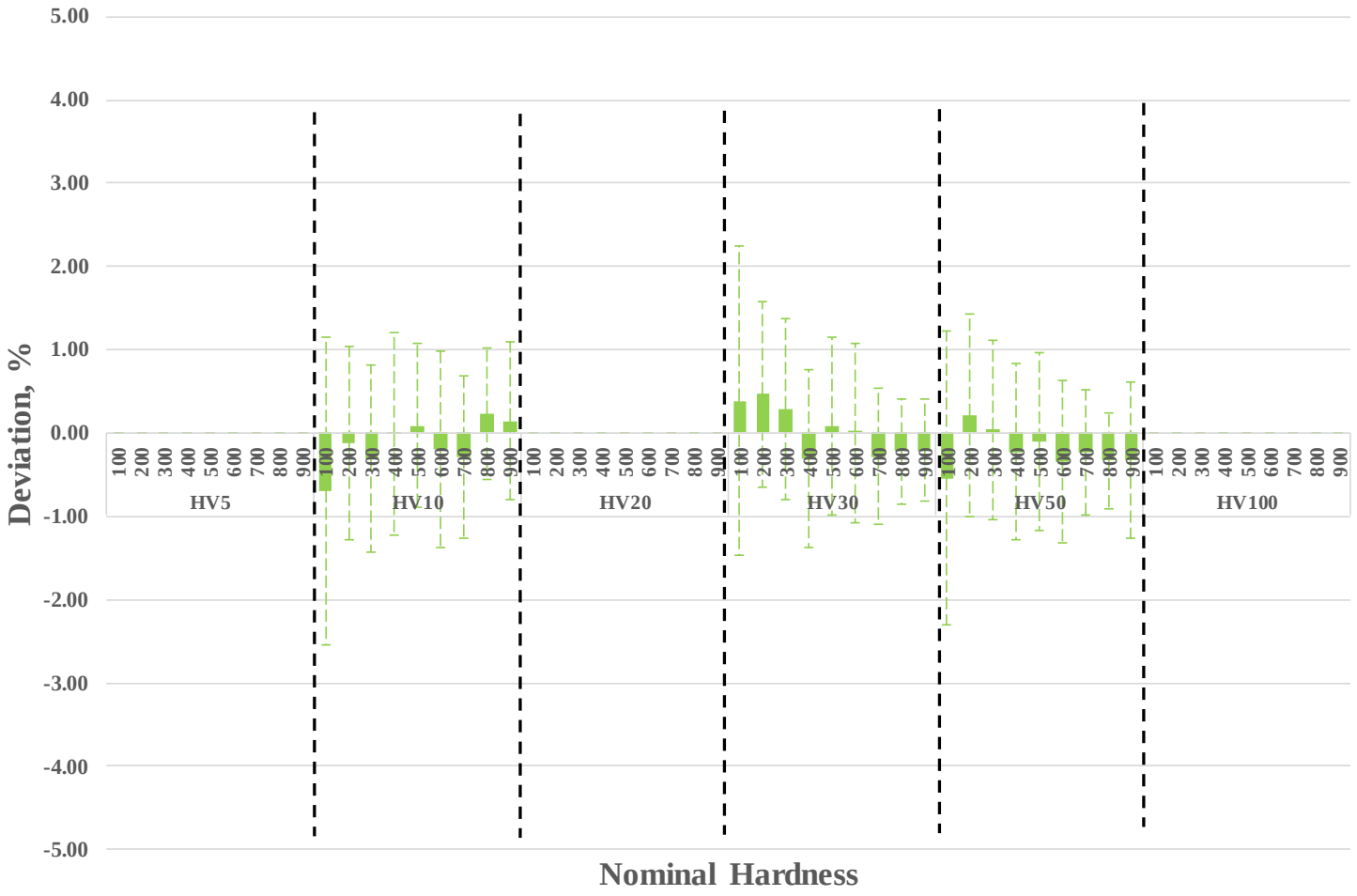


Figure 42 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for KRISS (based on new approach CMC)

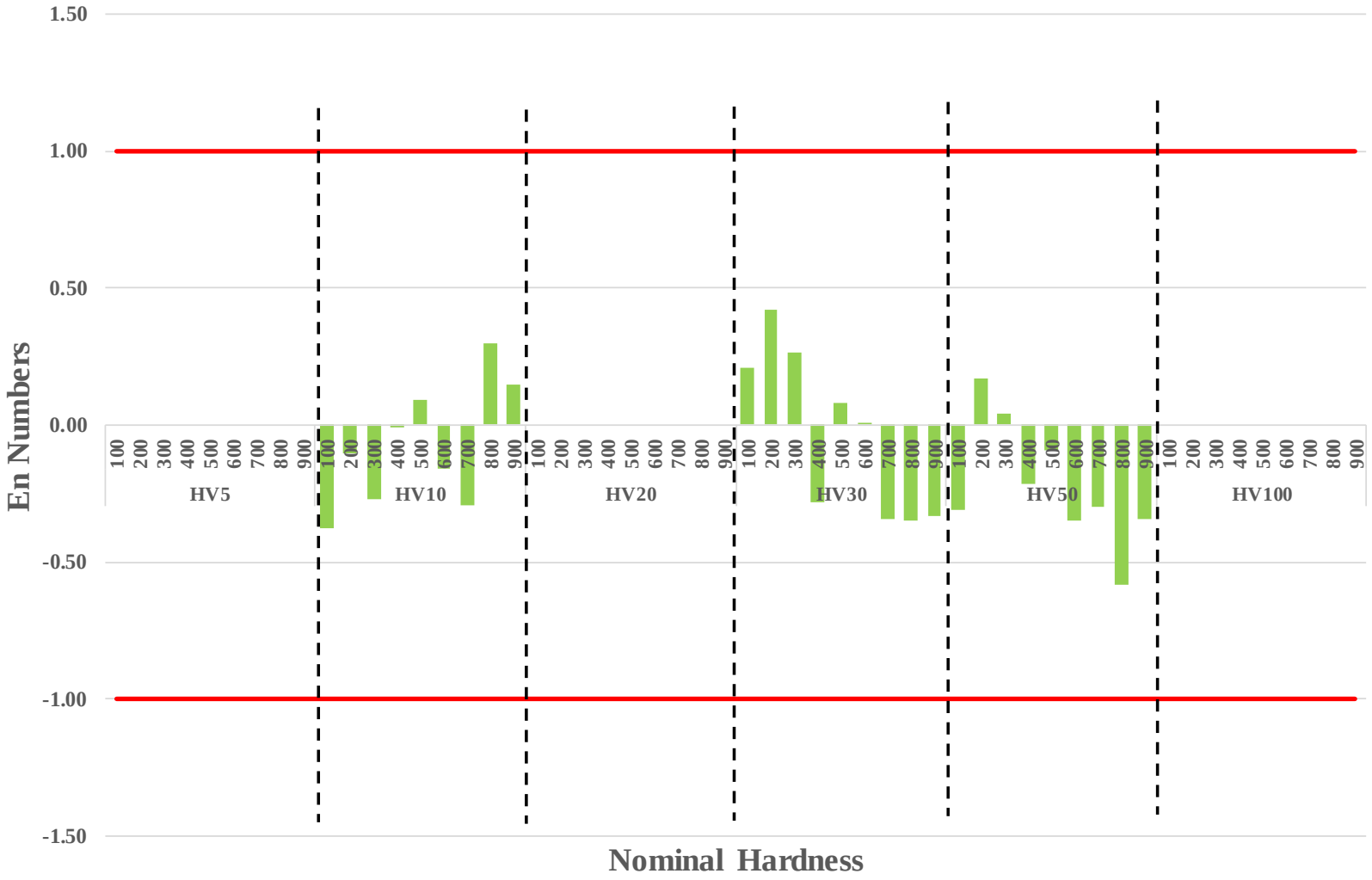


Figure 43 The E_n numbers of Block artifact (Reference Hardness Block) for KRISS (based on new approach CMC)

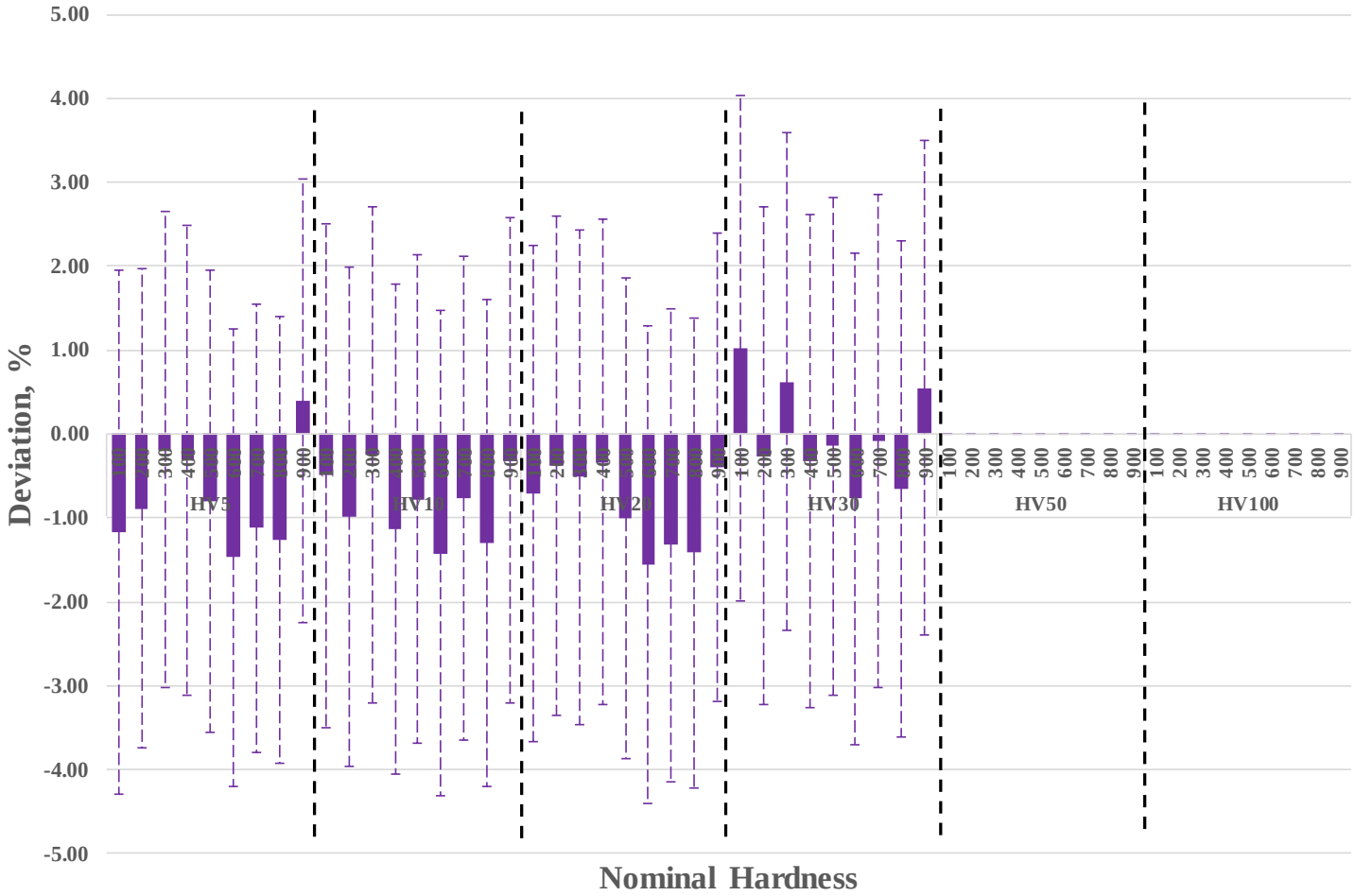


Figure 44 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for ITRI (based on new approach CMC)

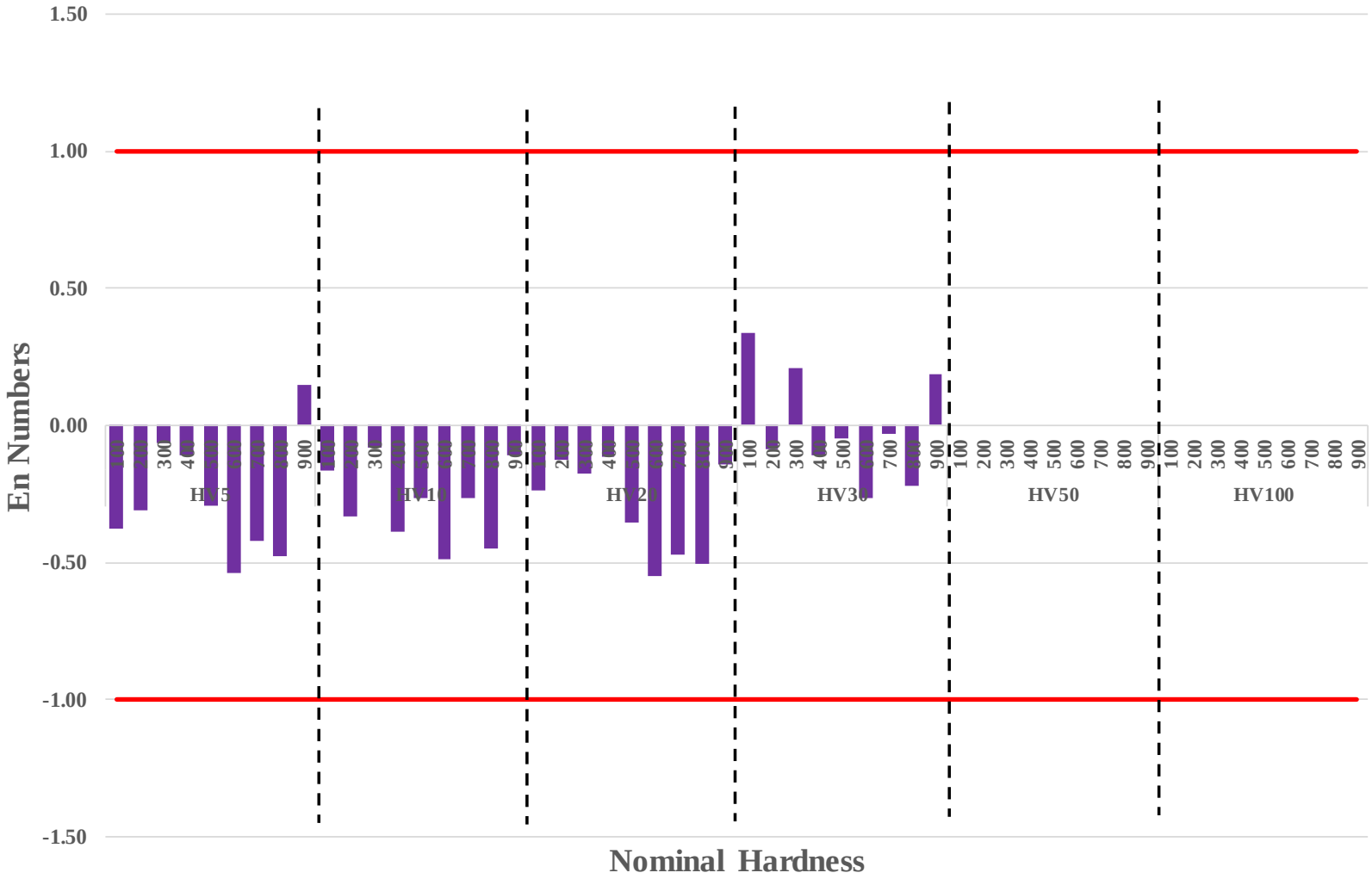


Figure 45 The E_n numbers of Block artifact (Reference Hardness Block) for ITRI (based on new approach CMC)

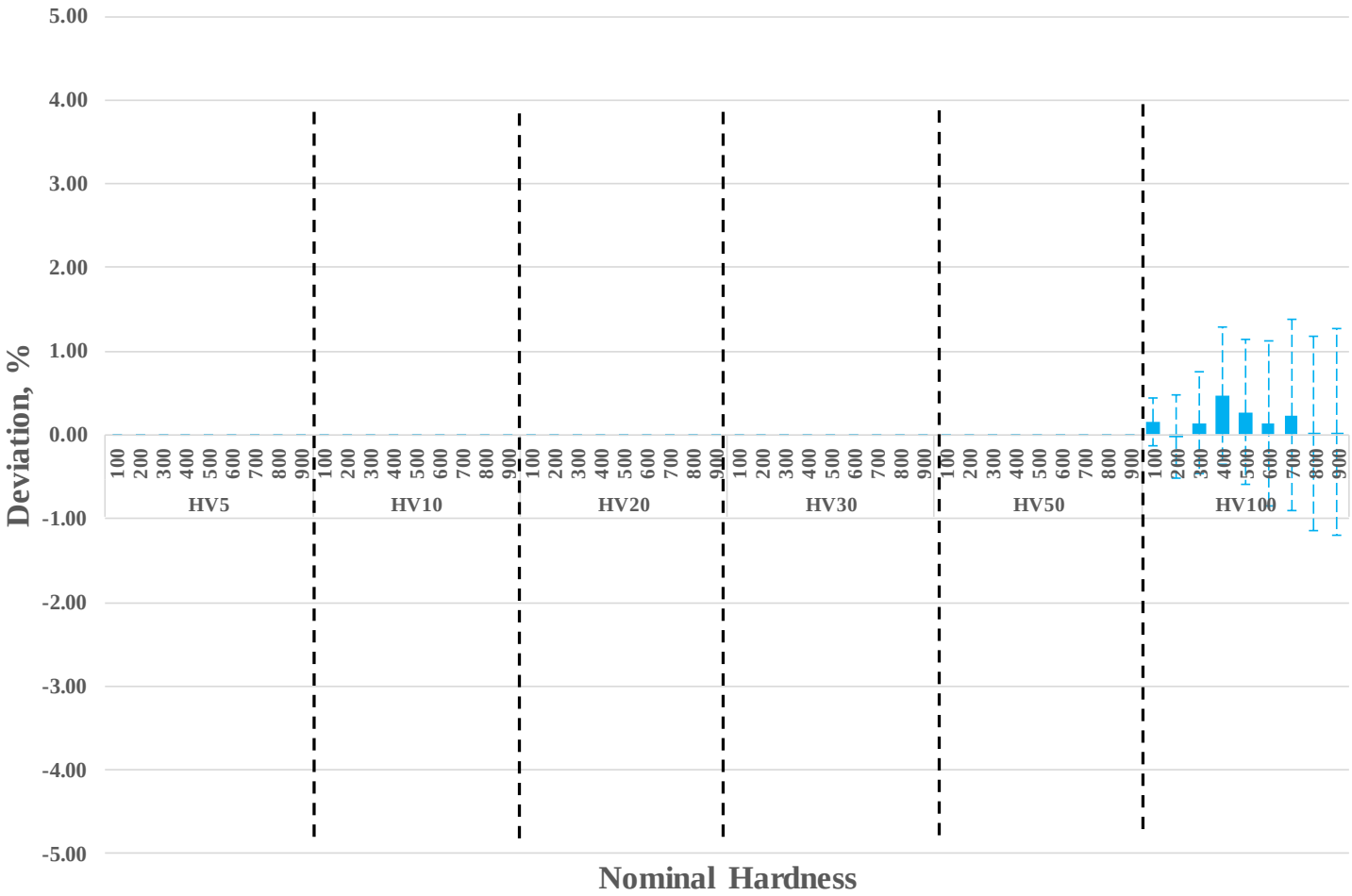


Figure 46 The overview of the deviation from the comparison reference value of Block artifact (Reference Hardness Block) for SASO (based on new approach CMC)

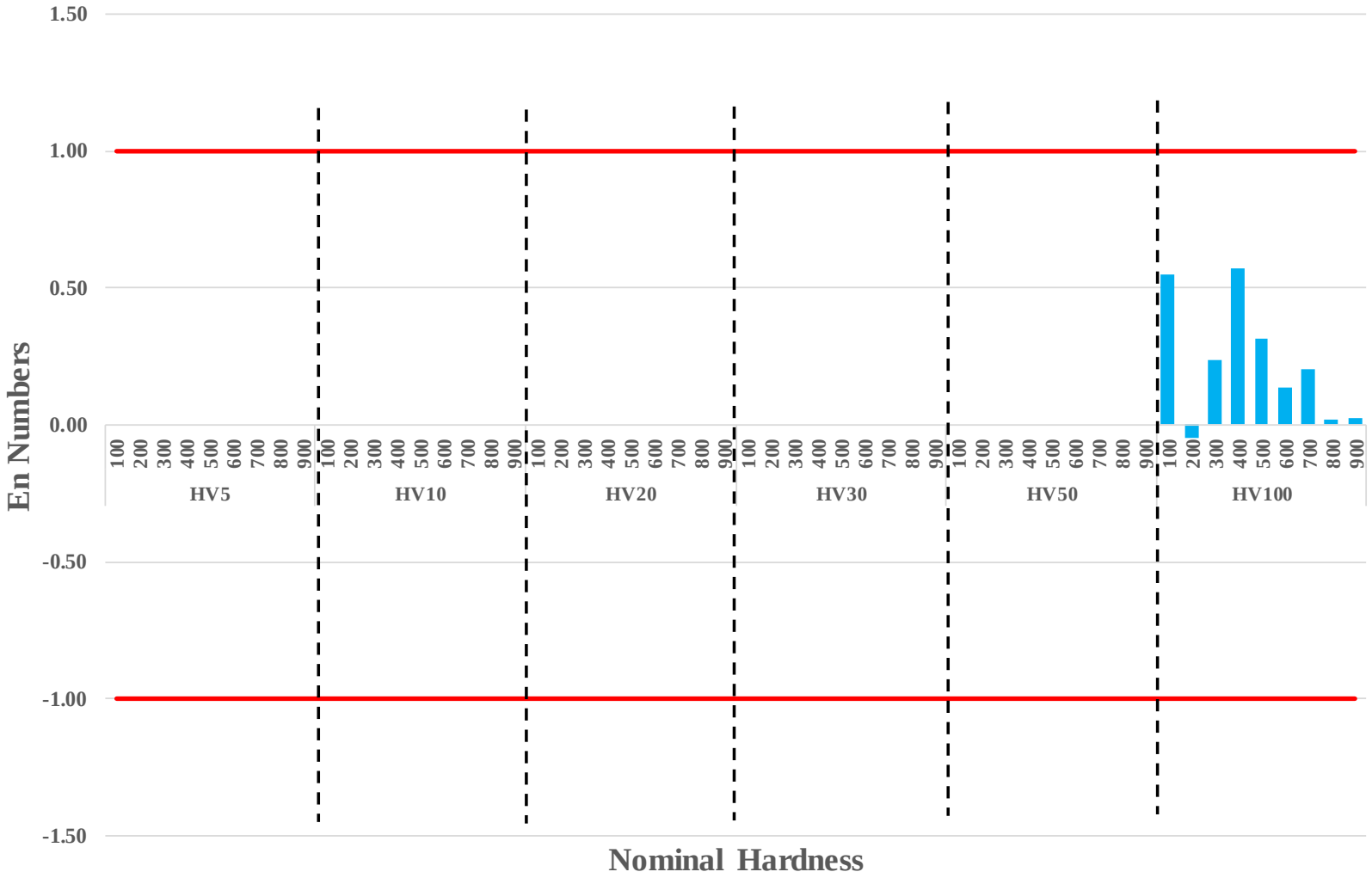


Figure 47 The E_n numbers of Block artifact (Reference Hardness Block) for SASO (based on new approach CMC)

9 Conclusion and discussion

In case of reference hardness block, the deviation from comparison reference value and E_n number of all participants was presented in Table 36.

Table 36 The deviation from comparison reference value and E_n numbers for different scales

Scale	Existing CMC		New approached CMC	
	The deviation from comparison reference value (% of HV)	E_n	The deviation from comparison reference value (% of HV)	E_n
HV5	-1.57 to 1.76	-0.69 to 1.0	-	-
HV10	-1.44 to 1.12	-0.50 to 0.62	-1.42 to 1.12	-0.49 to 0.61
HV20	-1.56 to 0.22	-0.55 to 0.56	-	-
HV30	-0.77 to 1.10	-0.62 to 0.58	-0.77 to 1.06	-0.63 to 0.58
HV50	-0.56 to 0.31	-0.55 to 0.56	-0.54 to 0.34	-0.58 to 0.59
HV100	-0.16 to 0.47	-0.57 to 0.57	-	-

The supplementary comparison of Vickers hardness for scale HV5, HV10, HV20, HV30, HV50 and HV100 of all participant gave the $|E_n| \leq 1$, which was totally acceptable.

10 References

[1] Technical protocol of the Supplementary Comparison of Vickers Hardness (APMP.M.H-S6)
[2] ISO 6507-2: Metallic materials-Vickers hardness test-Part 2: Verification and calibration of testing machines.
[3] ISO 6507-3: Metallic materials-Vickers hardness test-Part 3: Calibration of reference blocks
[4] GUM: Guide to the Expression of "Uncertainty in Measurement"; edition 1993, corrected and reprinted 1995, International Organization for Standardization, Geneva, Switzerland
[5] M. G. Cox Metrologia 2002, The evaluation of key comparison data, 2002, 39, 589-595