Euramet supplementary comparison between inrim and ume in rockwell hardness scales (hra-hrbw-hrc)-euramet.m.h-s1.a.b.c

EURAMET SUPPLEMENTARY COMPARISON BETWEEN INRiM AND UME IN ROCKWELL HARDNESS SCALES (HRA - HRBW - HRC)

Final Report

EURAMET.M.H-S1.a.b.c

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Abstract

This report describes a bilateral EURAMET Supplementary Comparison on Rockwell hardness scales of two national metrology institutes of Italy and Turkey, INRiM and UME, respectively. The pilot laboratory is INRiM in the comparison where three sets of hardness reference blocks for the Rockwell Hardness scales of HRA, HRBW and HRC were used. Each set of blocks consists of four hardness reference blocks for HRA and HRBW and five blocks for HRC hardness scales. The comparison was realized as planned in the Technical Protocol with some delay. The measurement results and uncertainty assessments declared by INRiM and UME are in consistency with each other.

1. Introduction

A bilateral supplementary comparison between INRiM (Istituto Nazionale di Ricerca Metrologica) and UME (TÜBİTAK Ulusal Metroloji Enstitüsü) was carried out in the field of Hardness Metrology to determine the consistency of the national hardness standards used in both countries realizing Rockwell Hardness measurements in accordance with the ISO 6508-1:2016 [1] and the ISO 6508-3:2015 [2] standards, including the new definition of Rockwell scales accepted by CIPM/CCM WGH [3]. The most widely used Rockwell Hardness scales such as HRA, HRBW and HRC constitute the scope of the comparison which was piloted by INRiM.

The blocks used in the comparison were provided by UME. Each NMI measured five hardness levels for HRC and four hardness levels for HRA and HRBW scales on the same transfer standards, using both their own and common indenters which also were provided by UME. Measurements were carried out first by UME as the provider of the blocks, then by the pilot laboratory INRiM, then again by UME for checking the stability of the transfer standards. UME supplies its own indenter to be used also as common indenter.

The NMIs were requested to realize the traceability of each component constituting the hardness scales on their national standards to the base SI units and constitute their uncertainty budgets before the comparison measurements.

2. Participating Institutes

Organizer	:	The European Association of National Metrology Institutes, **EURAMET**
Pilot Lab.	:	**Alessandro GERMAK** **INRiM** – Istituto Nazionale di Ricerca Metrologica Strada delle Cacce, 91 10135 Torino / **ITALY** Tel: +39 011 3919 924 a.germak@inrim.it

Participating Lab.	:	**Cihan KUZU** **UME** – TÜBİTAK Ulusal Metroloji Enstitüsü TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 P.K. 54, 41470 Gebze – Kocaeli / **TURKEY** Tel: +90 262 679 5000 Ext: 5606 / 5651 cihan.kuzu@tubitak.gov.tr

3. Reference Standards of Participating Institutes

INRiM - National Metrology Institute of Italy,

A Rockwell-Brinell-Vickers hardness standard machine (INRiM-PHSM, own made and commercialized by LTF S.p.A. as GALILEO® "Primary Dead-Weight Hardness Standardazing Machines" [4]) and indenter are used as the national standard of Italy to provide traceability in hardness measurements in the most important and most widely used hardness scales of Rockwell, Superficial Rockwell, Brinell and Vickers. The machine specifications are all in accordance with the relevant ISO and ASTM hardness standards, particularly in regard to this comparison with the ISO 6508-1:2016 [1], the ISO 6508-3:2015 [2] and it can realize the measurement cycles defined by the CCM WGH [3]. The specifications of the machine are as mentioned below.

Scales realized	:	HRA, HRBW, HRC, HRD, HREW, HRFW, HRGW, HRHW, HRKW, HR15N, HR30N, HR45N, HR15TW, HR30TW, HR45TW.
Indenters	:	Rockwell Diamond sphero-conical and Tungsten Carbide ball indenters (DKM s/n 33871)
Force application	:	Dead weight force application system
Depth measurement	:	Laser interferometer optic system
Measurement cycle	:	Laser interferometer optic system and force measurement sensor
Operation	:	PC Controlled, special software, automatic testing cycle and hardness measurement
Calibration procedure	:	in accordance with the ISO 6508-1:2016, the ISO 6508-3:2015 and the ASTM E-18:2020 Standards for Rockwell scales.

UME - National Metrology Institute of Turkey

A Primary Rockwell Hardness Standard Machine (was designed by UME, produced and installed by a Turkish company) and indenter are used as the national standard of Turkey to provide traceability in hardness measurements in the most important and most widely used hardness scales of Rockwell and Superficial Rockwell. The

machine specifications are all in accordance with the relevant ISO and ASTM hardness standards, particularly in regard to this comparison with the ISO 6508-1:2016 [1], the ISO 6508-3:2015 [2] and it can realize the measurement cycles defined by the CCM WGH [3]. The specifications of the machine are as mentioned below.

Scales realized	:	HRA, HRBW, HRC, HRD, HREW, HRFW, HRGW, HRHW, HRKW, HR15N, HR30N, HR45N, HR15TW, HR30TW, HR45TW.
Indenters	:	Rockwell Diamond sphero-conical and Tungsten Carbide ball indenters (LTF s/n 5867)
Force application	:	Dead weight force application system
Depth measurement	:	Laser interferometer optic system
Measurement cycle	:	Laser interferometer optic system and force measurement sensor
Operation	:	PC Controlled, special software, automatic testing cycle and hardness measurement
Calibration procedure	:	in accordance with the ISO 6508-1:2016, the ISO 6508-3:2015 and the ASTM E-18:2020 Standards for Rockwell scales.

4. Transfer Standards Used in the Comparison

In the bilateral comparison a total of three sets of hardness reference blocks were used, one set for each hardness scale of HRA, HRBW and HRC, separately. Five blocks for HRC scale and four blocks for each of HRA and HRBW scales, a total of 13 hardness reference blocks were used. Some information related to the hardness reference blocks used in the comparison is given below.

Table 1. Hardness blocks for HRA Scale.

No	Hardness Value	Serial Number	Producer
1	27 HRA	668-385	YAMAMOTO
2	46 HRA	666-752	YAMAMOTO
3	66 HRA	293-733	YAMAMOTO
4	87 HRA	284-385	YAMAMOTO

Table 2. Hardness blocks for HRBW Scale.

No	Hardness Value	Serial Number	Producer
1	32 HRBW	668-326	YAMAMOTO
2	53 HRBW	661-029	YAMAMOTO
3	73 HRBW	666-251	YAMAMOTO
4	95 HRBW	666-850	YAMAMOTO

Table 3. Hardness blocks for HRC Scale.

No	Hardness Value	Serial Number	Producer
1	25 HRC	492-096	YAMAMOTO
2	36 HRC	489-678	YAMAMOTO
3	45 HRC	369-719	YAMAMOTO
4	57 HRC	454-774	YAMAMOTO
5	67 HRC	486-336	YAMAMOTO

The first measurements were carried out by UME as the provider of the blocks and common indenters, then the transfer standards and common indenters were sent to the pilot laboratory INRiM and INRiM performed its measurements with INRiM own and common indenters; furtherly, the hardness blocks and common indenters were sent back to UME. Then UME performed its second measurements with UME indenters (in the case of UME common and own indenters coincide) for checking the stability of the transfer standards.

UME was responsible for providing blocks and common indenters used in the comparison. Below are some pictures of the transfer standards used in the comparison.

S/N: 668-385, 27 HRA

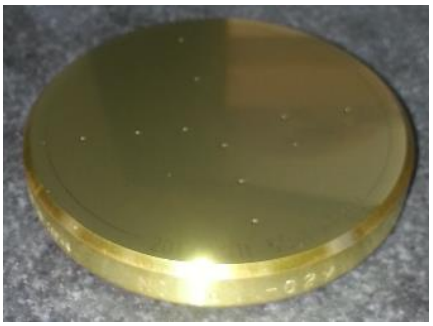
S/N: 666-752, 46 HRA

S/N: 293-733, 66 HRA

S/N: 284-385, 87 HRA

Figure 1. Transfer Standards for HRA Scale.

S/N: 668-326, 32 HRBW

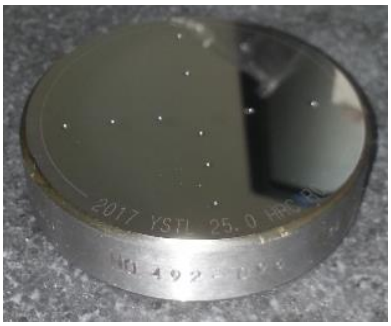


S/N: 661-029, 53 HRBW

S/N: 666-251, 73 HRBW

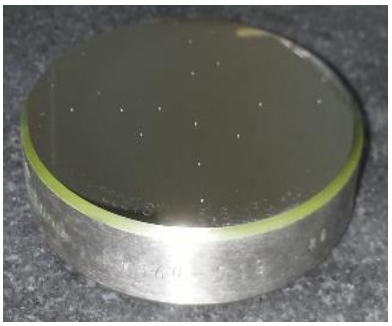
S/N: 666-850, 95 HRBW

Figure 2. Transfer Standards for HRBW Scale.



S/N: 492-096, 25 HRC

S/N: 489-678, 36 HRC



S/N: 369-719, 45 HRC

S/N: 454-774, 57 HRC

S/N: 486-336, 67 HRC

Figure 3. Transfer Standards for HRC Scale.

5. Procedure

Each participant assured that the national standards to be used in the comparison at least was in accordance with the ISO 6508-1:2016 [1] and the ISO 6508-3:2015 [2] standards. Under these circumstances the components to be calibrated/verified are as follows;

- Force (preliminary load, total load, preliminary load after removal of the total load).
- Testing cycle (in accordance with the new definition of HRC scale accepted by CCM WGH [3] or at least in accordance with the ISO 6508-1:2016 [1] and the ISO 6508-3:2015 [2] standards).
- Indenter geometrical parameters (in accordance with the ISO 6508-3:2015 [2] standard).
- Depth measurement system (in accordance with the ISO 6508-3:2015 [2] standard).

After management of calibration of the components given above, the blocks were placed in the laboratory one day before the measurements for temperature equilibrium. The measurement steps are as follows;

- Before starting the measurements, it was assured that the standardizing machines were working properly in accordance with their design parameters and the relevant ISO standards requirements.
- It was assured that the anvil where the blocks are seated on and both surfaces of the reference blocks were clean.
- It was assured that the relevant scale and related indenter and other requirements were mounted/selected etc.
- The ambient temperature was recorded.
- Two sets of 7 measurements (with the two indenters, one common and one own) uniformly distributed on the surface of the block were made and recorded on the data form.
- The ambient temperature was recorded.

Seven measurements were carried out: the first two were discarded in order to eliminate the effects coming from adaptation of the machine and the blocks. In the calculations the last five indentations were taken into consideration. The first two indentations had been recorded but not used in the calculations.

6. Reference Values of Influence Parameters

To perform measurements under the same or very similar conditions by the participants it has been significant to agree on reference values of the influence parameters and testing cycles and realize them as much as possible. In this comparison the reference values were chosen according to the HRC definition decided by the CIPM/CCM WGH [3]. Deviations from these values were taken into the uncertainty calculations. Below are the reference values and measurement cycle used in the HRA, HRBW and HRC measurements.

Table 4. Reference Values for Rockwell Hardness Scales HRA, HRBW and HRC.

Symbol	Test parameter		Reference value	Start measurement	Stop measurement
F_0	Preliminary force		98.0665 N	-	-
F	Total test force for HRA		588.399 N	-	-
	Total test force for HRBW		980.665 N	-	-
	Total test force for HRC		1470.998 N	-	-
α	Angle of the indenter (HRA, HRC)		120°	Blend point of the sphere and cone	±400 µm
D	Diameter of ball indenter (HRBW)		1.5875 mm	-	-
R_a	Spherical tip radius of the indenter (HRA, HRC)		200 µm	-30° (from the axis)	+30° (from the axis)
V_{fis}	Final indentation speed of additional load application		30 µm·s^{-1}	~80% F	~99% F
T_p	Total time of preliminary test force	$T_p = \frac{T_a}{2} + T_{pm}$	3 s	-	-
T_a	Application time of preliminary test force		-	~1% F_0	~99% F_0
T_{pm}	Duration time of preliminary test force			~99% F_0	Reading
T_{df}	Duration of the total force		5 s	~99% F	~99% F
T_{rf}	Final reading time		4 s	~101% F_0	Reading
T	Temperature of test		23°C	Beginning of the test	End of the test

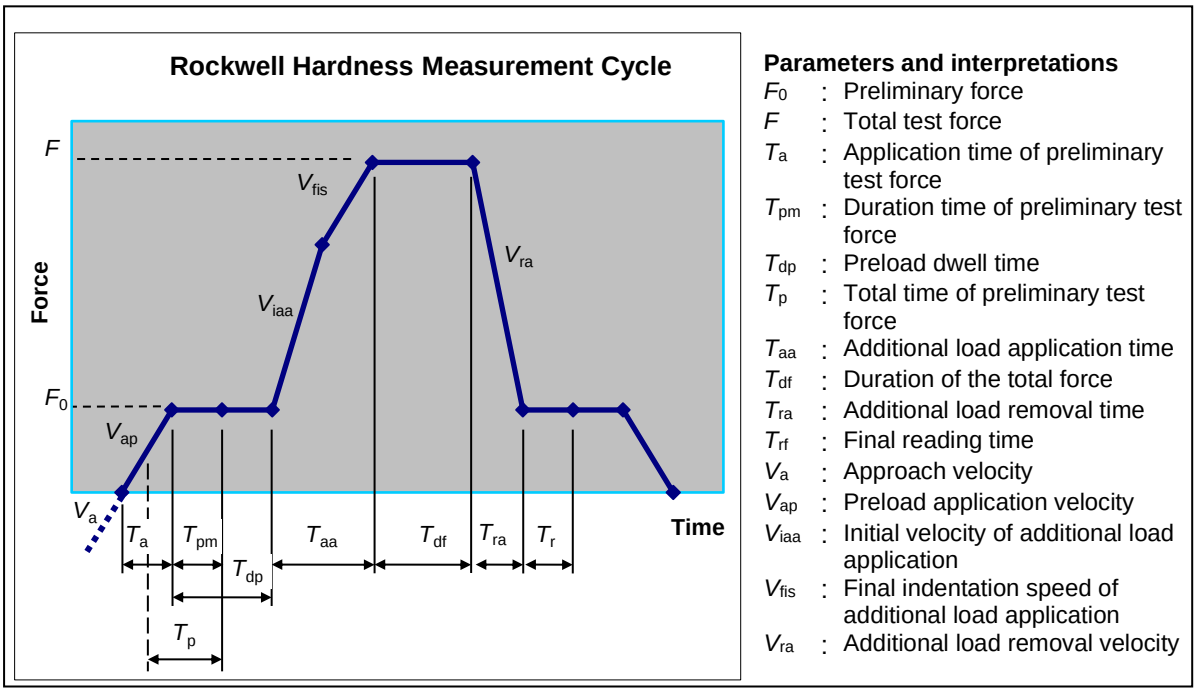


Figure 4. Identification of the HRA, HRBW and HRC Measurement Cycle [3].

7. Uncertainty Evaluation

Before the measurements, each participant laboratory carried out the calibration of the hardness standardizing machine in order to estimate their uncertainties. The following parameters were calibrated:

- test forces (preloads and total loads),
- depth measuring system,
- cone angle of the indenter (HRA, HRC),
- spherical tip of the indenter (HRA, HRC),
- diameter of the ball indenter (HRBW),
- final indentation speed of additional force application,
- total time of preliminary test force,
- duration of the total force,
- final reading time,
- reproducibility of the primary hardness machine.

The uncertainty budget calculations were made following the EURAMET/cg-16/v.02 [5] and JCGM 100 [6] guidelines. Each laboratory had the responsibility for determining their own uncertainty budget and uncertainty value for each measurement. The uncertainty budget was presented to the pilot laboratory together with the measurement results.

8. Time Table of the Measurements

The measurements were made first by UME as the provider of the reference hardness blocks, then by the pilot laboratory INRiM and finally by UME again for checking the stability of the transfer standards. The measurements plan was the following:

Table 5. Schedule of the measurements.

Institute/Country	Lab	Date of measurements
UME, Turkey	Participant	May, 2018
INRiM, Italy	Pilot	July, 2018
UME, Turkey	Participant	September, 2018

9. Transportation

The travelling standards, hardness reference blocks and the common indenters, were transported in a wooden box protective case which was prepared by UME. When the blocks were sent/transported the receiving institute checked them and notified the sending laboratory by email. Before packing the blocks for transportation to the next participant (after measurements are finished) they were cleaned with Isopropyl alcohol and wrapped in their anti-rusting paper, put in their original case and placed in the transportation box in order to prevent any damage during transportation.

10. Data Compilation

Each laboratory entered the measurement results and uncertainty values in the data sheet provided in the annex of the Technical Protocol for each hardness reference block. The pilot laboratory was responsible for collecting the measurement data from the participants, compiling and preparing the reports.
The results will be used to support the CMCs of the participating laboratories declared in Appendix C of the MRA.

11. Data Elaboration

The measurement results are used to compute the degree of equivalence with Comparison Reference Value (CRV) and E_n ratio. The calculation is shown in following steps and made by making use of the following equations.

- Calculation of Comparison Reference Value (CRV)
  The pilot laboratory determined CRV by calculating the weighted mean of measurements of all participants (x_{ref}) by making use of the following equation,

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

- The uncertainty of the CRV (x_{ref}) is calculated by the following expression,

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

  where,

  x_i : measured value of participating institute, i ($i = 1, 2, ..., n$)
  $u(x_i)$: standard uncertainty of x_i
  $u(x_{ref})$: standard uncertainty of x_{ref}

- The deviation from the CRV is calculated by,

$$d_i = x_i - x_{ref} \quad (3)$$

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

$$U(d_i) = k \cdot u(d_i) \quad (4)$$

  Where $u(d_i)$ is calculated by,

$$u^2(d_i) = u^2(x_i) - u^2(x_{ref}) \quad (5)$$

  and $k = 2$.

- The coefficient E_n is the equivalence between the measurements of participating institutes, is calculated as given below,

$$E_n = \frac{|x_i - x_{ref}|}{\sqrt{U^2(x_i) - U^2(x_{ref})}} \quad (6)$$

where,

$$U(x_i) = k \cdot u(x_i) \quad (7)$$

$$U(x_{ref}) = k \cdot u(x_{ref}) \quad (8)$$

- The x_i is equivalent with x_{ref} (CRV) at 95% confidence level, if $|E_{\mathrm{n}}| \leq 1$,

  where,

  X_{INRiM} is INRiM measurement value,

  U_{INRiM} is the expanded uncertainty value that declared by INRiM,

  X_{UME} is UME measurement value,

  U_{UME} is the expanded uncertainty value that declared by UME,

  X_{ref} is the Comparison Reference Value (CRV),

  U_{ref} is the uncertainty value of CRV,

  d_{INRiM} is the deviation value of INRiM from the CRV,

  $U_{\mathrm{d\text{-}INRiM}}$ is the uncertainty of the deviation value of INRiM from the CRV,

  $E_{\mathrm{n\text{-}INRiM}}$ is the degree of equivalence of INRiM expressed in E_{n} ratio,

  d_{UME} is the deviation value of UME from the CRV,

  $U_{\mathrm{d\text{-}UME}}$ is the uncertainty of the deviation value of UME from the CRV,

  $E_{\mathrm{n\text{-}UME}}$ is the degree of equivalence of UME expressed in E_{n} ratio.

12. Stability of the Transfer Standards

The stability of hardness reference blocks during the comparison measurements was calculated as the difference between the first and second measurements made by UME as the blocks provider. There was no significant deviation in the block values as seen below and it was taken into account in the measurement results.

Table 6. Stability of the Transfer Standards in HRA Scale.

Scale	Block S. N.	Meas. values		Non uniformity		Deviation	Mean value	Uncert.
		1st Meas.	2nd Meas.	1st Meas.	2nd Meas.			
HRA	668-385	26.77	26.59	0.21	0.24	0.18	26.68	0.29
	666-752	44.95	44.80	0.16	0.14	0.15	44.87	0.30
	293-733	65.71	65.59	0.07	0.07	0.12	65.65	0.30
	284-385	87.08	87.07	0.12	0.12	0.01	87.08	0.30

Table 7. Stability of the Transfer Standards in HRBW Scale.

Scale	Block S. N.	Meas. values		Non uniformity		Deviation	Mean value	Uncert.
		1st Meas.	2nd Meas.	1st Meas.	2nd Meas.			
HRBW	668-326	31.30	31.28	0.23	0.15	0.02	31.29	0.43
	661-029	53.22	53.21	0.27	0.31	0.01	53.22	0.41
	666-251	72.53	72.71	0.45	0.30	-0.18	72.62	0.39
	666-850	94.93	95.13	0.19	0.21	-0.20	95.03	0.40

Table 8. Stability of the Transfer Standards in HRC Scale.

Scale	Block S. N.	Meas. values		Non uniformity		Deviation	Mean value	Uncert.
		1st Meas.	2nd Meas.	1st Meas.	2nd Meas.			
HRC	492-096	24.72	24.74	0.10	0.09	-0.02	24.73	0.31
	489-678	35.10	35.11	0.15	0.14	0.00	35.10	0.28
	369-719	45.55	45.60	0.08	0.21	-0.05	45.57	0.34
	454-774	55.63	55.62	0.10	0.11	0.01	55.63	0.30
	486-336	67.40	67.44	0.02	0.02	-0.03	67.42	0.32

13. Comparison Results

The bilateral comparison between INRiM and UME in the most widely used Rockwell hardness scales HRA, HRBW and HRC is completed without any unexpected phenomena in any stage of it. The stability of the transfer standards during the comparison measurements was calculated and included in the measurement results. The participating institutes declared similar uncertainty values and there was a significant consistency between the measured values of the transfer standards. The comparison reference values (CRVs), the deviation value of INRiM and UME from CRV and their uncertainties, d_{INRiM}, d_{UME}, $U_{d\text{-}INRiM}$, $U_{d\text{-}UME}$, and E_n ratios were calculated and shown in Tables 1 to 6 and Figures 1 to 6 in the Annex. The degree of equivalence shows a significant consistency between INRiM and UME hardness standards in HRA, HRBW and HRC Rockwell hardness scales and this report is supporting the present and possible new CMC submissions.

14. References

[1] EN ISO 6508-1: 2016, Metallic Materials – Rockwell Hardness Test - Part1: Test Method (scales A, B, C, D, E, F, G, H, K, N, T).

[2] EN ISO 6508-3: 2015, Metallic Materials - Rockwell Hardness Test - Part3: Calibration of Reference Blocks (scales A, B, C, D, E, F, G, H, K, N, T).

[3] https://www.bipm.org/wg/CCM/CCM-WGH/Allowed/International_definitions/HRC_definition.pdf

[4] http://www.ltf.it/en/prodotti.php?b=3&c=636&p=3361

[5] EURAMET/cg-16/v.02, Guidelines on the Estimation of Uncertainty in Hardness Measurements, 2011.

[6] JCGM 100: 2008, Evaluation of measurement data - Guide to the expression of uncertainty in measurement.

Annex: Measurement Data

Table 9. Degree of Equivalence of INRiM and UME (wrt. CRV) - HRA with Common Indenter.

X_{UME}	U_{UME}	X_{INRiM}	U_{INRiM}	X_{ref}	U_{ref}	d_{UME}	$U_{d\text{-}UME}$	$E_{n\text{-}UME}$	d_{INRiM}	$U_{d\text{-}INRiM}$	$E_{n\text{-}INRiM}$
26.68	0.29	26.35	0.30	26.52	0.21	0.16	0.21	0.77	-0.16	0.21	0.77
44.87	0.30	44.66	0.30	44.77	0.21	0.11	0.21	0.51	-0.11	0.21	0.51
65.65	0.30	65.53	0.30	65.59	0.21	0.06	0.21	0.28	-0.06	0.21	0.28
87.08	0.30	87.10	0.30	87.09	0.21	-0.01	0.21	0.05	0.01	0.21	0.05

Table 10. Degree of Equivalence of INRiM and UME (wrt. CRV) - HRBW with Common Indenter.

X_{UME}	U_{UME}	X_{INRiM}	U_{INRiM}	X_{ref}	U_{ref}	d_{UME}	$U_{d\text{-}UME}$	$E_{n\text{-}UME}$	d_{INRiM}	$U_{d\text{-}INRiM}$	$E_{n\text{-}INRiM}$
31.29	0.43	30.94	0.42	31.12	0.30	0.18	0.30	0.59	-0.17	0.30	0.59
53.22	0.41	52.99	0.43	53.11	0.29	0.11	0.28	0.38	-0.12	0.31	0.38
72.62	0.39	72.74	0.42	72.68	0.29	-0.06	0.27	0.22	0.07	0.31	0.22
95.03	0.40	95.27	0.41	95.15	0.29	-0.12	0.28	0.42	0.13	0.29	0.42

Table 11. Degree of Equivalence of INRiM and UME (wrt. CRV) - HRC with Common Indenter.

X_{UME}	U_{UME}	X_{INRiM}	U_{INRiM}	X_{ref}	U_{ref}	d_{UME}	$U_{d\text{-}UME}$	$E_{n\text{-}UME}$	d_{INRiM}	$U_{d\text{-}INRiM}$	$E_{n\text{-}INRiM}$
24.73	0.31	24.89	0.30	24.81	0.22	-0.08	0.22	0.38	0.08	0.21	0.38
35.10	0.28	35.25	0.30	35.17	0.20	-0.07	0.19	0.36	0.08	0.22	0.36
45.57	0.34	45.68	0.30	45.63	0.22	-0.06	0.25	0.24	0.05	0.20	0.24
55.63	0.30	55.66	0.31	55.64	0.22	-0.01	0.21	0.07	0.02	0.22	0.07
67.42	0.32	67.47	0.31	67.45	0.22	-0.03	0.23	0.12	0.03	0.22	0.12

Table 12. Degree of Equivalence of INRiM and UME (wrt. CRV) - HRA with Own Indenter.

X_{UME}	U_{UME}	X_{INRiM}	U_{INRiM}	X_{ref}	U_{ref}	d_{UME}	$U_{d\text{-}UME}$	$E_{n\text{-}UME}$	d_{INRiM}	$U_{d\text{-}INRiM}$	$E_{n\text{-}INRiM}$
26.68	0.29	26.42	0.31	26.55	0.21	0.12	0.20	0.61	-0.14	0.22	0.61
44.87	0.30	44.71	0.31	44.79	0.22	0.08	0.21	0.39	-0.09	0.22	0.39
65.65	0.30	65.33	0.30	65.49	0.21	0.16	0.21	0.76	-0.16	0.21	0.76
87.08	0.30	86.96	0.30	87.02	0.21	0.06	0.21	0.28	-0.06	0.21	0.28

Table 13. Degree of Equivalence of INRiM and UME (wrt. CRV) - HRBW with Own Indenter.

X_{UME}	U_{UME}	X_{INRiM}	U_{INRiM}	X_{ref}	U_{ref}	d_{UME}	$U_{d\text{-}UME}$	$E_{n\text{-}UME}$	d_{INRiM}	$U_{d\text{-}INRiM}$	$E_{n\text{-}INRiM}$
31.29	0.43	31.03	0.42	31.16	0.30	0.13	0.30	0.43	-0.13	0.30	0.43
53.22	0.41	53.32	0.43	53.26	0.29	-0.05	0.28	0.17	0.05	0.31	0.17
72.62	0.39	72.74	0.41	72.67	0.28	-0.06	0.27	0.21	0.06	0.30	0.21
95.03	0.40	95.20	0.41	95.11	0.29	-0.08	0.28	0.30	0.09	0.29	0.30

Table 14. Degree of Equivalence of INRiM and UME (wrt. CRV) - HRC with Own Indenter.

X_{UME}	U_{UME}	X_{INRiM}	U_{INRiM}	X_{ref}	U_{ref}	d_{UME}	$U_{d\text{-}UME}$	$E_{n\text{-}UME}$	d_{INRiM}	$U_{d\text{-}INRiM}$	$E_{n\text{-}INRiM}$
24.73	0.31	24.46	0.31	24.60	0.22	0.13	0.22	0.61	-0.13	0.22	0.61
35.10	0.28	34.85	0.30	34.98	0.20	0.12	0.19	0.63	-0.14	0.22	0.63
45.57	0.34	45.28	0.30	45.41	0.22	0.17	0.25	0.66	-0.13	0.20	0.66
55.63	0.30	55.26	0.30	55.44	0.21	0.18	0.21	0.86	-0.18	0.21	0.86
67.42	0.32	67.17	0.30	67.29	0.22	0.13	0.23	0.56	-0.11	0.21	0.56

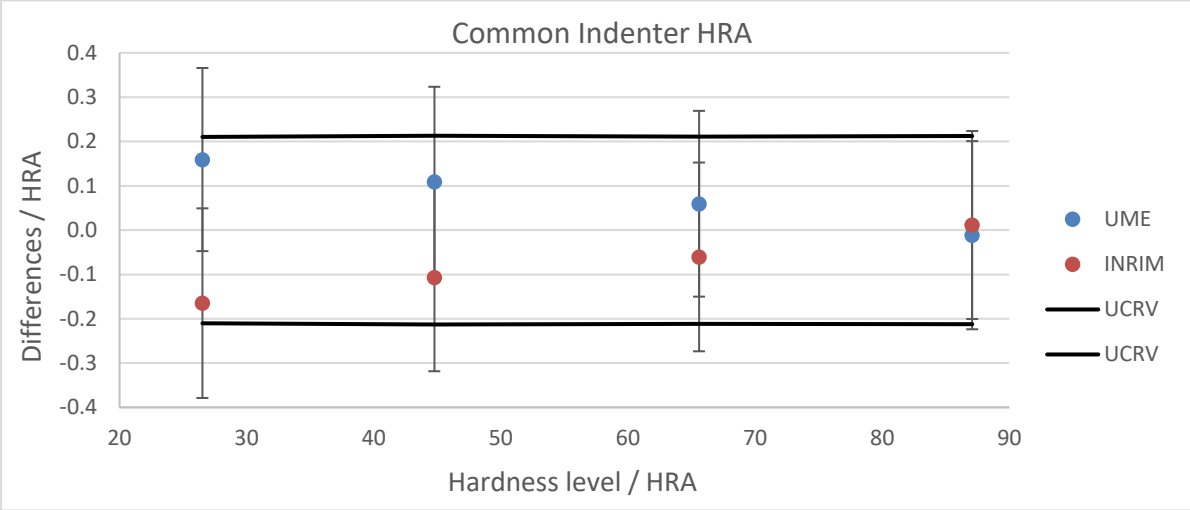


Figure 5. Deviations of INRiM (d_{INRiM}) and UME (d_{UME}) values from the CRV with the associated expanded uncertainty (95% confidence level) ($U_{d\text{-}INRiM}$ and $U_{d\text{-}UME}$) - HRA with Common Indenter.

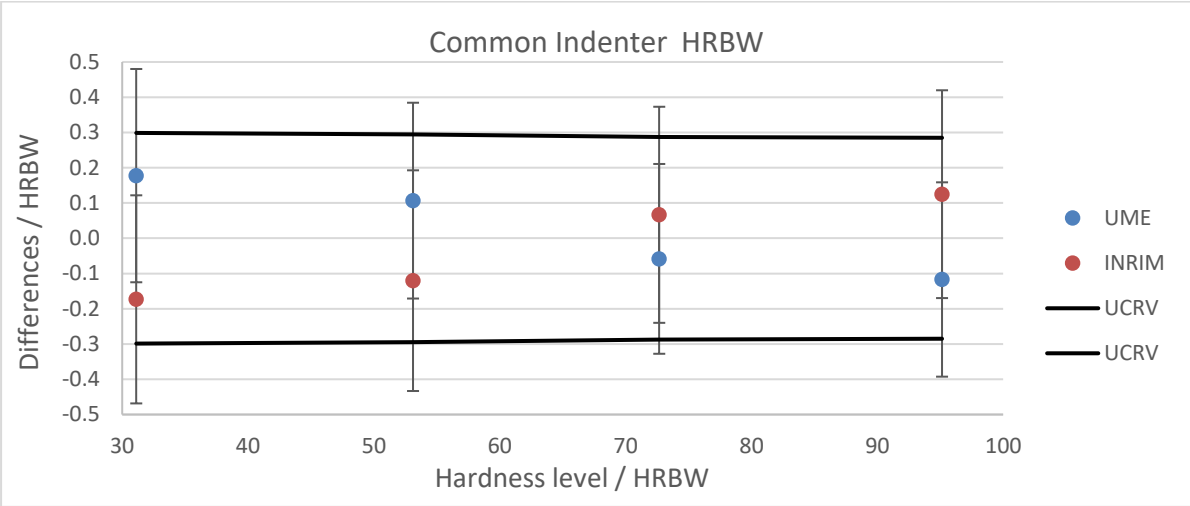


Figure 6. Deviations of INRiM (d_{INRiM}) and UME (d_{UME}) values from the CRV with the associated expanded uncertainty (95% confidence level) ($U_{d\text{-}INRiM}$ and $U_{d\text{-}UME}$) - HRBW with Common Indenter.

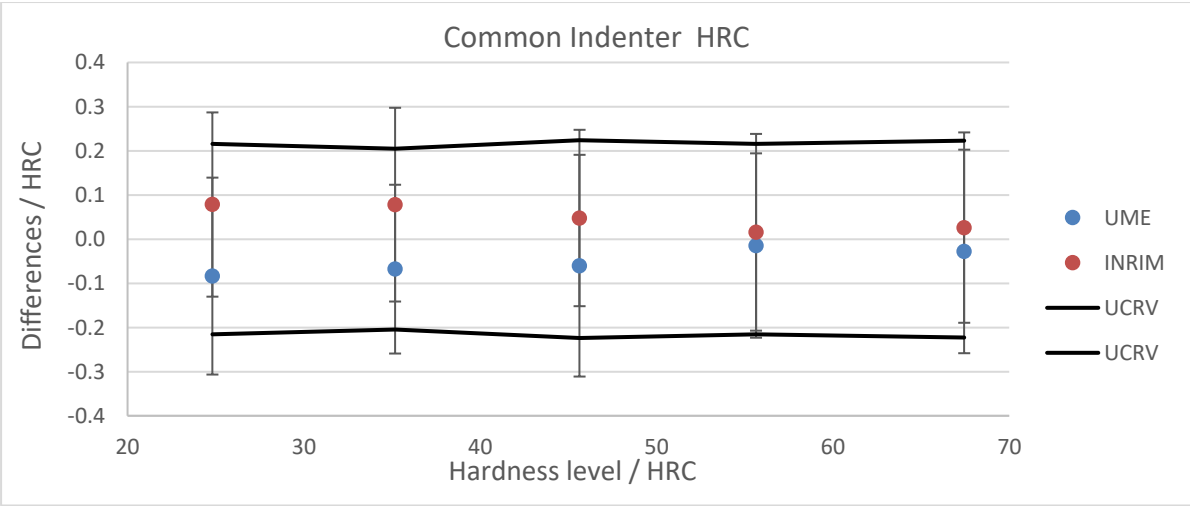


Figure 7. Deviations of INRiM (d_{INRiM}) and UME (d_{UME}) values from the CRV with the associated expanded uncertainty (95% confidence level) ($U_{d\text{-}INRiM}$ and $U_{d\text{-}UME}$) - HRC with Common Indenter.

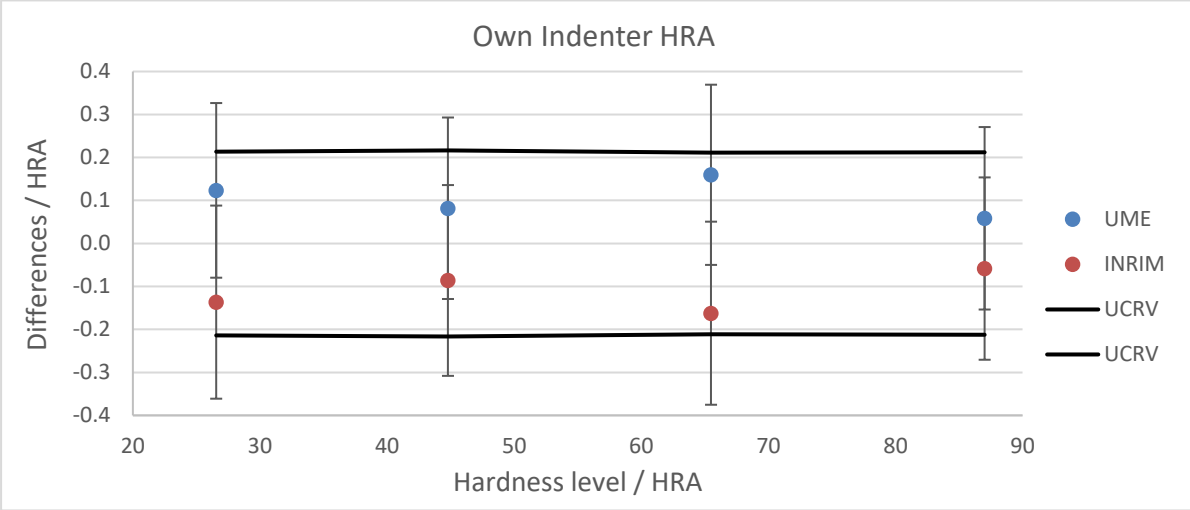


Figure 8. Deviations of INRiM (d_{INRiM}) and UME (d_{UME}) values from the CRV with the associated expanded uncertainty (95% confidence level) ($U_{d\text{-}INRiM}$ and $U_{d\text{-}UME}$) - HRA with Own Indenter.

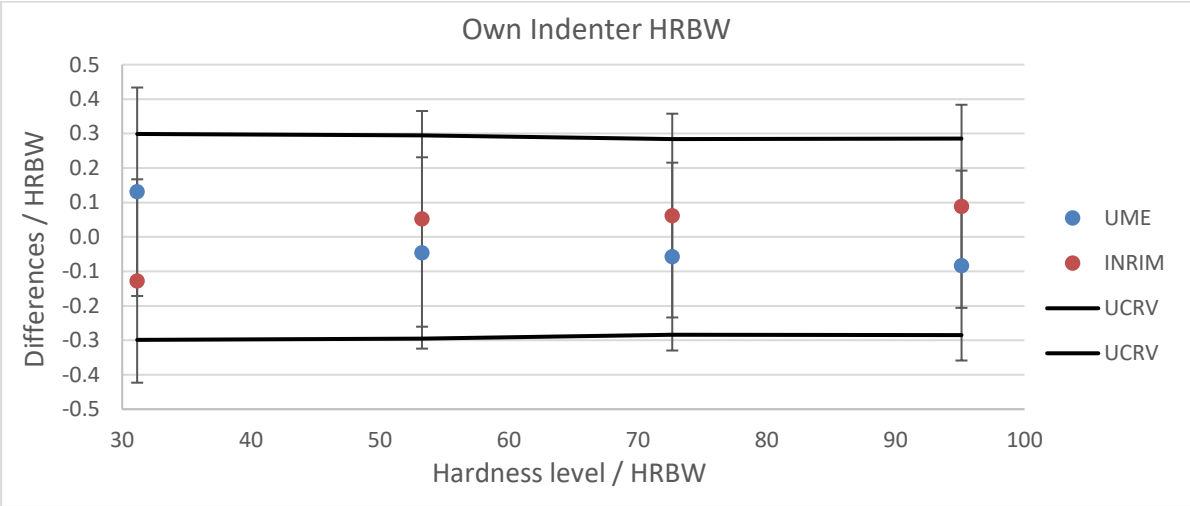


Figure 9. Deviations of INRiM (d_{INRiM}) and UME (d_{UME}) values from the CRV with the associated expanded uncertainty (95% confidence level) ($U_{d\text{-}INRiM}$ and $U_{d\text{-}UME}$) - HRBW with Own Indenter.

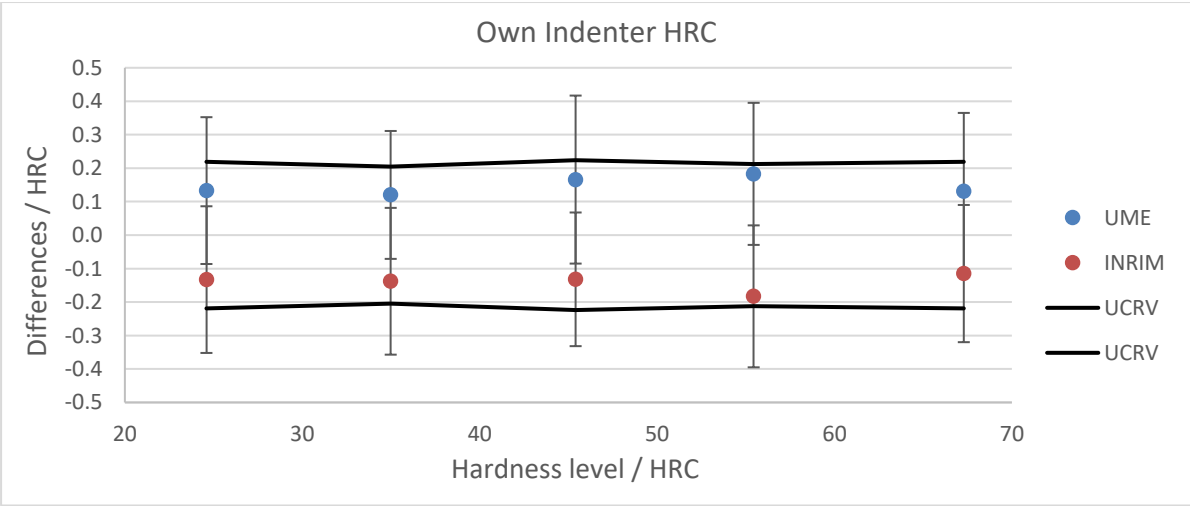


Figure 10. Deviations of INRiM (d_{INRiM}) and UME (d_{UME}) values from the CRV with the associated expanded uncertainty (95% confidence level) ($U_{d\text{-}INRiM}$ and $U_{d\text{-}UME}$) - HRC with Own Indenter.