EURAMET key comparison between INRiM and UME in Vickers hardness scales (HV1 - HV30) - EURAMET.M.H-K1.b and c

EURAMET KEY COMPARISON BETWEEN INRiM AND UME IN VICKERS HARDNESS SCALES (HV1 - HV30)

Final Report

EURAMET.M.H-K1.b.c

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Abstract

This report describes the method and results of a bilateral EURAMET Key Comparison in Vickers hardness scales of two National Metrology Institutes (NMIs) of Italy and Turkey, INRiM and UME, respectively. The Pilot Laboratory (PL) is INRiM in the comparison in which one set of hardness reference blocks with three hardness levels for the Vickers Hardness scales of both HV1 and HV30 was used. The comparison was realized as planned in the Technical Protocol with some delay. The aim of this comparison is to link the UME measurement results to the CCM.H-K1.b.c through the PL (INRiM) as a participant of the CCM key comparison. The measurement results and uncertainty assessments declared by INRiM and UME are in consistency with each other and UME results are also in consistency with the CCM.H-K1.b.c Key Comparison Reference Values (KCRVs). The CCM.H-K1.b.c was realized during 2001 to 2003 to investigate the metrological equivalence of national standards among national metrology institutes (NMIs) within the CCM.

1. Introduction

A bilateral key 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 in both countries realizing Vickers Hardness measurements in accordance with ISO 6507-1:2018 [1] and ISO 6507-3:2018 [2] standards. The most widely used Vickers Hardness scales such as HV1 and HV30 constitute the scope of the comparison which was piloted by INRiM.

The blocks used in the comparison were provided by UME. Each NMI measured three hardness levels for both HV1 and HV30 scales on the same transfer standards, using their own indenters. Measurements were carried out first by UME as the provider of the blocks, then by the PL (INRiM), then again by UME for checking the stability of transfer standards.

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 and a Microvickers hardness standard machine (INRiM-PHSM, own made and commercialized by LTF S.p.A. as GALILEO® "Primary Dead-Weight Hardness Standardazing Machines" [3]) and an indentation measurement system (own made and commercialized by LTF S.p.A. as GALILEO® GalVision [3]) are used as the national standards 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 hardness. The machines' specifications are all in accordance with the relevant ISO and ASTM hardness standards, particularly in regard to this comparison with ISO 6507-1:2018 [1] and ISO 6507-3:2018 [2] standards. The specifications of the machines are mentioned below.

Scales realized	:	HV0.05, HV0.1, HV0.2, HV0.3, HV0.5, HV1, HV2, HV3, HV5, HV10, HV20, HV30, HV50 and HV100.
Indenters	:	Vickers square-based pyramid Diamond indenters (MPA s/n 900029)
Force application	:	Dead weight force application system
Measurement cycle	:	Laser interferometer optic system and force measurement sensor
Indentation Measurement Sys.	:	An optical microscope with a special software prepared for indentation measurements for Brinell and Vickers
Operation	:	PC Controlled, special software, automatic testing cycle and hardness measurement
Calibration procedure	:	The machines are able to carry out hardness reference block calibration in accordance with ISO 6507-1:2018 [1], ISO 6507-3:2018 [2] and ASTM E-92-17 [4] Standards for Vickers scales.

UME - National Metrology Institute of Turkey

A Brinell-Vickers hardness standard machine (was designed by UME, produced and installed by a Turkish company İdeal Makina), a Microvickers hardness standard machine (produced by Leica), and an indentation measurement system (produced by LTF S.p.A. as GALILEO® GalVision) are used as the national standards of Turkey to provide traceability in hardness measurements in the most important and the most widely used hardness scales of Brinell and Vickers. The machines' specifications are all in accordance with the relevant ISO and ASTM hardness standards, particularly in regard to this comparison with ISO 6507-1:2018 [1] and ISO 6507-3:2018 [2] standards. The specifications of the machines are mentioned below.

Scales realized	:	HV0.05, HV0.1, HV0.2, HV0.3, HV0.5, HV1, HV2, HV5, HV10, HV20, HV30, HV50 and HV100.
Indenters	:	Vickers square-based pyramid Diamond indenters (Microvickers: LEICA, s/n 9616; Vickers: LTF, s/n 6467)
Force application	:	Dead weight force application system
Measurement cycle	:	Force measurement sensor
Indentation Measurement Sys.	:	An optical microscope with a special software prepared for indentation measurements for Brinell and Vickers
Operation	:	PC Controlled, special software, automatic testing cycle and hardness measurement
Calibration procedure	:	The machines are able to carry out hardness reference block calibration in accordance with ISO 6507-1:2018 [1], ISO 6507-3:2018 [2] and ASTM E-92-17 [4] Standards for Vickers scales.

4. Transfer Standards Used in the Comparison

In the bilateral comparison one set of hardness reference blocks provided by UME, composed of three blocks, was used for both hardness scales of HV1 and HV30. Some information related to the hardness reference blocks used in the comparison is given below.

Table 1. Hardness blocks for HV1 and HV30 Scales.

No	Hardness Value	Serial Number	Producer
1	200	294-472	YAMAMOTO
2	500	294-481	YAMAMOTO
3	800	224-804	YAMAMOTO

The first measurements were carried out by UME as the provider of the blocks, then the transfer standards were sent to the PL (INRiM) and INRiM performed its measurements, furtherly, the hardness blocks were sent back to UME. Then UME performed its second measurements for checking the stability of the transfer standards. Below are some pictures of the transfer standards used in the comparison.

S/N: 294-472, 200 HV   S/N: 294-481, 500 HV   S/N: 224-804, 800 HV

Figure 3. Transfer Standards for HV1 and HV30 Scales.

5. Procedure

Each participant assured that the national standards to be used in the comparison at least were in accordance with ISO 6507-1:2018 [1] and ISO 6507-3:2018 [2] standards. Under these circumstances the components to be calibrated/verified are as follows;

- Force
- Testing cycle (in accordance with ISO 6507-1:2018 [1] and ISO 6507-3:2018 [2] standards).
- Indenter (in accordance with ISO 6507-3:2018 [2] standard).
- Indentation measurement system (in accordance with ISO 6507-3:2018 [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 performed are as follows;

- Before starting the measurements, it was assured that the standardizing machines were working properly in accordance with their design parameters and relevant ISO Hardness Standards requirements.
- Assured that the anvil where the blocks are seated on and both surfaces of the reference blocks were clean.
- Assured that the relevant scale and related indenter and other requirements were mounted/selected etc.
- The ambient temperature was recorded.
- One set of 5 measurements uniformly distributed on the surface of the block was made and recorded on the data form. Measurement values are the mean of the 5 individual measurements
- The ambient temperature was recorded.

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 ISO Vickers Hardness standards specifications [1] and [2]. Deviations from these values were taken into the uncertainty calculations. Below are the reference values and measurement cycle used in the HV1 and HV30 measurements.

Table 2. Reference Values for Vickers Hardness Scales HV1 and HV30.

Symbol	Test parameter	Reference value	Start measurement	Stop measurement
F	Total test force for HV1	9.807 N	-	-
	Total test force for HV30	294.2 N	-	-
α	Angle of the indenter	136°	Tip of the indenter	400 µm
V_{app}	Indenter approach speed	$\leq 200\ \mu m \cdot s^{-1}$	~0% F	~1% F
T_a	Application time of test force	7 s	~1% F	~99% F
T_d	Duration of the total force	14 s	~99% F on force application	~99% F on force removal
T	Temperature of test	23°C	Beginning of the test	End of the test

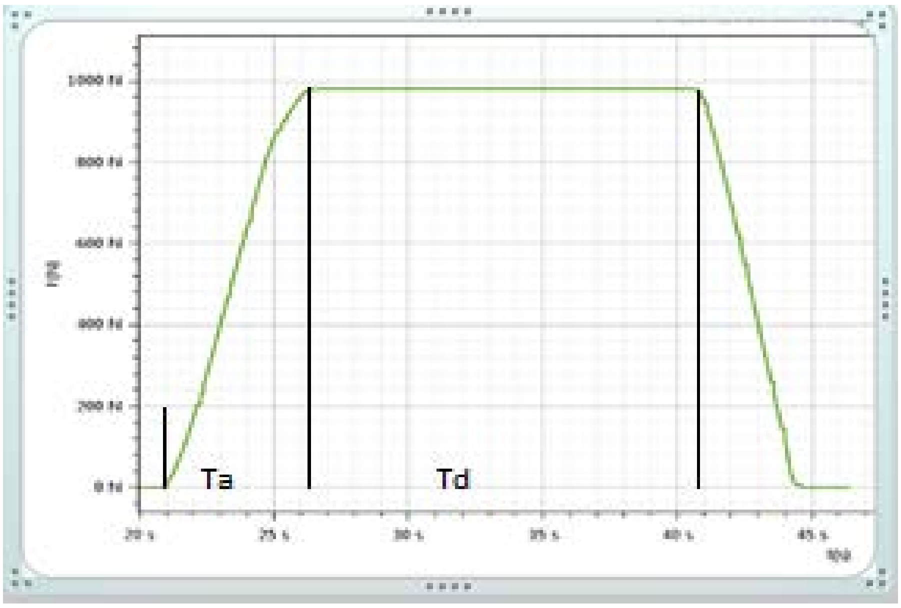

Figure 2. Measurement Cycle for HV1 and HV30 Hardness Scales.

7. Uncertainty Evaluation

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

- test force
- indentation measurement system
- tip angle of the indenter
- tip radius of the indenter
- length of line of junction of the indenter
- 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.

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 3. Schedule of Measurements.

Institute/Country	Lab	Date of measurements
UME, Turkey	Participant	May, 2019
INRiM, Italy	Pilot	November, 2019
UME, Turkey	Participant	December, 2019

9. Transportation

The travelling standards, hardness reference blocks, 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 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 of UME with the Key Comparison Reference Values of the CCM.H-K1.b.c by linking the measurement results through the Pilot Laboratory (PL) INRiM. At 840 HV1, where the linking is not possible to calculate, the degree of equivalence of UME and INRiM with the Comparison Reference Value (CRV) is computed. The E_{n} ratio is computed for all ranges.
The calculation is shown in following steps and made by making use of the relevant equations.

11.1 Linking Measurement Results to the CCM.H-K1.b.c Key Comparison Reference Values (KCRVs)

The EURAMET.M.H-K1.b.c was organized to link the comparison results to the Key Comparison Reference Values (KCRVs) of the last CCM Key comparison (CCM KC) for Vickers hardness (CCM.H-K1), where HV1 and HV30 measurement results are linked to the CCM.H-K1.b and the CCM.H-K1.c values, respectively, except for the 840 HV1 scale comparison where the PL is not consistent with the KCRV of the CCM KC. For the linked scale comparisons, the PL had participated in the CCM KC and the link was made through this laboratory measurement and relevant uncertainty values. The link calculation is given below.

- Calculation of the Linked Comparison Reference Value ($\boldsymbol{KCRV}_{\mathbf{LINK}}$):
  The PL (INRiM) calculated the Comparison Reference Values ($KCRV_{\mathrm{LINK}}$) for this EURAMET bilateral Key Comparison which are linked to the CCM KCRV by making use of the PL's Degree of Equivalence (DoE) with the CCM KCRV. The DoE includes the deviations (d_{CCM}) of the PL's measurement values from the CCM KCRV and their associated uncertainties ($U_{d_{\mathrm{CCM}}}$). These values are reported in the CCM.H-K1 CCM Key Comparison Report.
- The PL's CCM KC measurement deviation values (d_{CCM}) provide the link between the results of this comparison and the CCM KCRV and were calculated as shown in Eq. 1.

$$d_{\mathrm{CCM}} = X_{\mathrm{INRiM}_{\mathrm{CCM}}} - KCRV_{\mathrm{CCM}} \tag{1}$$

where,

$X_{\mathrm{INRiM}_{\mathrm{CCM}}}$: INRiM's mean measurement value of the CCM KC

$KCRV_{\mathrm{CCM}}$: CCM Key Comparison Reference Value.

- The linked Key Comparison Reference Values ($KCRV_{\mathrm{LINK}}$) for this comparison are calculated from the PL's mean measurement value on the reference block and subtracting the associated d_{CCM} value as shown in Eq. 2.

$$KCRV_{\mathrm{LINK}} = X_{\mathrm{INRiM}} - d_{\mathrm{CCM}} \quad (2)$$

where,

X_{INRiM}: INRiM's mean measurement value of this comparison.

- The uncertainty of d_{CCM} (the deviation of the PL from the CCM KCRV) at a 95% level of confidence is calculated as in Eq. 3:

$$U_{d_{\mathrm{CCM}}}^2 = U_{\mathrm{INRiM_{CCM}}}^2 + U_{\mathrm{KCRV_{CCM}}}^2 \quad (3)$$

where,

$U_{\mathrm{INRiM_{CCM}}}$: uncertainty in INRiM's mean measurement value of the CCM KC

$U_{\mathrm{KCRV_{CCM}}}$: uncertainty in the associated CCM KCRV.

These values are reported in the CCM.H-K1 CCM Key Comparison Report.

- The uncertainty of the linked Key Comparison Reference Value ($KCRV_{\mathrm{LINK}}$) at a 95% level of confidence is calculated as in Eq. 4:

$$U_{KCRV_{\mathrm{LINK}}}^2 = U_{\mathrm{INRiM}}^2 + U_{d_{\mathrm{CCM}}}^2 \quad (4)$$

where,

U_{INRiM}: uncertainty in INRiM's mean measurement value of this comparison.

- The deviation of UME's measurement value ($\boldsymbol{d}$) from the associated $\boldsymbol{KCRV_{\mathrm{LINK}}}$ is calculated as in Eq. 5:

$$d = X_{\mathrm{UME}} - KCRV_{\mathrm{LINK}} \quad (5)$$

where,

X_{UME}: UME's mean measurement value of this comparison.

- The uncertainty of d at a 95% level of confidence is calculated as in Eq. 6:

$$U_d^2 = U_{\mathrm{UME}}^2 + U_{KCRV_{\mathrm{LINK}}}^2 \quad (6)$$

where,

U_{UME}: expanded uncertainty in UME's mean measurement.

- The coefficient E_n is the equivalence between UME's measurements and the $KCRV_{\mathrm{LINK}}$, and is calculated as in Eq. 7:

$$E_n = \frac{X_{\mathrm{UME}} - KCRV_{\mathrm{LINK}}}{\sqrt{U_{\mathrm{UME}}^2 + U_{KCRV_{\mathrm{LINK}}}^2}} \tag{7}$$

- The mean measurement value X_{UME} is considered equivalent to the $KCRV_{\mathrm{LINK}}$ at 95% confidence level, if $|E_n| \leq 1$.

11.2 Measurement Results Not Linked to the CCM.H-K1.b.c Key Comparison Reference Values (KCRVs)

The 840 HV1 comparison results cannot be linked to the CCM. H-K1 Key Comparison Reference Values due to the INRiM measurement values at the CCM KC having an E_n coefficient greater than 1. Consequently, it is not possible to have a CRV linked to the CCM KCRV for that hardness scale, and the Degree of Equivalence is calculated only between the two participants of the comparison.

- Calculation of Comparison Reference Value (CRV) for 840 HV1 Hardness:

  The pilot laboratory determined the CRV for this case by calculating the weighted mean of measurements of all participants as in Eq. 8:

$$CRV = \frac{X_{\mathrm{INRiM}}/u_{\mathrm{INRiM}}^2 + X_{\mathrm{UME}}/u_{\mathrm{UME}}^2}{1/u_{\mathrm{INRiM}}^2 + 1/u_{\mathrm{UME}}^2} \tag{8}$$

where,

X_{INRiM}	INRiM's mean measurement value of this comparison
X_{UME}	UME's mean measurement value of this comparison
u_{INRiM}	standard uncertainty in INRiM's mean measurement value of this comparison
u_{UME}	standard uncertainty in UME's mean measurement value of this comparison

- The uncertainty of the CRV is calculated by the following expression,

$$\frac{1}{u_{CRV}^2} = \frac{1}{u_{\mathrm{INRiM}}^2} + \frac{1}{u_{\mathrm{UME}}^2} \tag{9}$$

- The deviation of each participant from the CRV is calculated by,

$$d_{\mathrm{INRiM}} = X_{\mathrm{INRiM}} - CRV \tag{10}$$

$$d_{\mathrm{UME}} = X_{\mathrm{UME}} - CRV \quad (11)$$

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

$$U_{d_{\mathrm{INRiM}}} = k \times u_{d_{\mathrm{INRiM}}} \quad (12)$$

$$U_{d_{\mathrm{UME}}} = k \times u_{d_{\mathrm{UME}}} \quad (13)$$

where $k = 2$.

Taking into account the correlation existing between the measurements carried out by the participants and the CRV,

$$u^2_{d_{\mathrm{INRiM}}} = u^2_{\mathrm{INRiM}} + u^2_{\mathrm{CRV}} - 2r(u_{\mathrm{INRiM}}, u_{\mathrm{CRV}})u_{\mathrm{INRiM}}u_{\mathrm{CRV}} \quad (14)$$

$$u^2_{d_{\mathrm{UME}}} = u^2_{\mathrm{UME}} + u^2_{\mathrm{CRV}} - 2r(u_{\mathrm{UME}}, u_{\mathrm{CRV}})u_{\mathrm{UME}}u_{\mathrm{CRV}} \quad (15)$$

The correlation coefficients $r(u_{\mathrm{INRiM}}, u_{\mathrm{CRV}})$ and $r(u_{\mathrm{UME}}, u_{\mathrm{CRV}})$ are not zero because CRV has been evaluated with the same INRiM and UME machines. The CRV uncertainty is based on all possible contributions of uncertainty, being random or systematic ones. Specifically, the systematic contributions (ie. the influence of the indenter, the timing and velocities, as well the intrinsic contribution due to the type of machines) cannot be considered two times in the difference between the CRV and the measurements performed by INRiM and UME. The correlation coefficients, at the same hardness measurements, can be estimated approximately by

$$r(u_{\mathrm{INRiM}}, u_{\mathrm{CRV}}) \cong \frac{u_{\mathrm{CRV}}}{u_{\mathrm{INRiM}}} \quad (16)$$

$$r(u_{\mathrm{UME}}, u_{\mathrm{CRV}}) \cong \frac{u_{\mathrm{CRV}}}{u_{\mathrm{UME}}} \quad (17)$$

Therefore, the eq. (14) and (15) became:

$$u^2_{d_{\mathrm{INRiM}}} = u^2_{\mathrm{INRiM}} + u^2_{\mathrm{CRV}} - 2u^2_{\mathrm{CRV}} = u^2_{\mathrm{INRiM}} - u^2_{\mathrm{CRV}} \quad (18)$$

$$u^2_{d_{\mathrm{UME}}} = u^2_{\mathrm{UME}} + u^2_{\mathrm{CRV}} - 2u^2_{\mathrm{CRV}} = u^2_{\mathrm{UME}} - u^2_{\mathrm{CRV}} \quad (19)$$

- The coefficient E_{n} is the equivalence between the measurements of the participating institutes and the CRV, and is calculated as follows,

$$E_{\mathrm{n-INRiM}} = \frac{X_{\mathrm{INRiM}} - CRV}{\sqrt{U^2_{\mathrm{INRiM}} - U^2_{\mathrm{CRV}}}} \quad (20)$$

$$E_{\mathrm{n-UME}} = \frac{X_{\mathrm{UME}} - CRV}{\sqrt{U^2_{\mathrm{UME}} - U^2_{\mathrm{CRV}}}} \quad (21)$$

where,

$$U_{\mathrm{INRiM}} = k \times u_{\mathrm{INRiM}} \tag{22}$$

$$U_{\mathrm{UME}} = k \times u_{\mathrm{UME}} \tag{23}$$

$$U_{\mathrm{CRV}} = k \times u_{\mathrm{CRV}} \tag{24}$$

and $k = 2$.

- The mean measurement value, X, for each participant is considered equivalent to the CRV at 95% confidence level, if the respective $|E_{\mathrm{n}}| \leq 1$.

11.3 List of symbols

X_{INRiM}	is the mean INRiM measurement value,
U_{INRiM}	is the expanded uncertainty value declared by INRiM,
X_{UME}	is the mean UME measurement value,
U_{UME}	is the expanded uncertainty value declared by UME,
$X_{\mathrm{INRiM_{CCM}}}$	is the INRiM mean measurement value of the CCM KC,
$U_{\mathrm{INRiM_{CCM}}}$	is the uncertainty of INRiM's mean measurement value of the CCM KC,
$KCRV_{\mathrm{CCM}}$	is the CCM Key Comparison Reference Value,
$U_{\mathrm{KCRV_{CCM}}}$	is the uncertainty of the CCM KCRV ($KCRV_{\mathrm{CCM}}$),
$KCRV_{\mathrm{LINK}}$	is the CRV linked to the KCRV of the CCM KC,
$U_{\mathrm{KCRV_{LINK}}}$	is the uncertainty of the CRV ($KCRV_{\mathrm{LINK}}$) linked to the KCRV of the CCM KC ($KCRV_{\mathrm{CCM}}$),
d_{CCM}	is the deviation of the INRiM value ($X_{\mathrm{INRiM_{CCM}}}$) from the CCM KCRV ($KCRV_{\mathrm{CCM}}$),
$U_{d_{\mathrm{CCM}}}$	is the uncertainty of the deviation (d_{CCM}) of the INRiM value ($X_{\mathrm{INRiM_{CCM}}}$) from the CCM KCRV ($KCRV_{\mathrm{CCM}}$)
E_{n}	is the degree of equivalence between the UME measurements and the CCM KCRV ($KCRV_{\mathrm{CCM}}$) expressed in E_{n} ratio,
d	is the deviation of the UME value (X_{UME}) from the CRV ($KCRV_{\mathrm{LINK}}$) linked to the KCRV of the CCM KC,
U_{d}	is the uncertainty of the deviation (d) of the UME value (X_{UME}) from the CRV ($KCRV_{\mathrm{LINK}}$) linked to the KCRV of the CCM KC,
CRV	is the Comparison Reference Value for the 840 HV1 comparison,
U_{CRV}	is the uncertainty of the CRV for the 840 HV1 comparison,
d_{INRiM}	is the deviation of the INRiM value (X_{INRiM}) from the CRV for the 840 HV1 comparison,
$r(u_{\mathrm{INRiM}}, u_{\mathrm{CRV}})$	correlation coefficient reported values of INRiM and the CRV

$U_{d_{\mathrm{INRiM}}}$	is the uncertainty of the deviation of the INRiM value (X_{INRiM}) from the CRV for the 840 HV1 comparison,
$E_{\mathrm{n-INRiM}}$	is the degree of equivalence between the INRiM measurements and the CRV expressed in E_{n} ratio for the 840 HV1 comparison,
d_{UME}	is the deviation of the UME value (X_{UME}) from the CRV for the 840 HV1 comparison,
$r(u_{\mathrm{UME}}, u_{\mathrm{CRV}})$	correlation coefficient reported values of UME and the CRV
$U_{d_{\mathrm{UME}}}$	is the uncertainty of the deviation of the UME value (X_{UME}) from the CRV for the 840 HV1 comparison,
$E_{\mathrm{n-UME}}$	is the degree of equivalence between the UME measurements and the CRV expressed in E_{n} ratio for the 840 HV1 comparison.

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 4. Stability of the Transfer Standards / HV1 Scale

Scale	Block S. N.	Measurement Values		Non Uniformity		Deviation	Mean Value	Uncert.
		1st Meas.	2nd Meas.	1st Meas.	2nd Meas.			
HV1	294-472	200.95	202.78	2.47	0.50	1.83	201.87	3.45
	294-481	509.15	510.05	1.28	1.80	0.90	509.60	8.83
	224-804	845.23	851.59	1.52	1.78	6.36	848.41	18.28

Table 5. Stability of the Transfer Standards / HV30 Scale

Scale	Block S. N.	Measurement Values		Non Uniformity		Deviation	Mean Value	Uncert.
		1st Meas.	2nd Meas.	1st Meas.	2nd Meas.			
HV30	294-472	201.76	202.10	0.44	0.37	0.33	201.93	1.98
	294-481	506.72	506.20	0.51	0.22	-0.52	506.46	6.54
	224-804	811.47	813.11	0.59	0.76	1.64	812.29	12.49

13. Comparison Results

The EURAMET Key Comparison between INRiM and UME in the most widely used Vickers hardness scales HV1 and HV30 was completed successfully 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. UME measurement results were linked to the CCM.H-K1.b.c for HV1 and HV30 scales for 240 HV, 540 HV and 840 HV values through the PL (INRiM), except for the 840 HV1.

For the measurements that could be linked to the CCM KC, the Comparison Reference Values ($KCRV_{\mathrm{LINK}}$), the UME Degrees of Equivalence (d, U_{d}) and E_{n} ratios were calculated and are shown in Tables 6 and 8 and Figures 3 and 4 in the Annex.

For the 840 HV1 measurements that could not be linked to the CCM KC, the CRV value was calculated using the weighted mean of the participant's measurements. The deviation values of INRiM and UME from the CRV for 840 HV1 and their uncertainties (d_{INRiM}, d_{UME}, $U_{d_{\mathrm{INRiM}}}$, $U_{d_{\mathrm{UME}}}$), and their E_{n} ratios were calculated and are shown in Table 7 and Figure 3.

As a result of this comparison, DoE show a significant consistency between the UME and INRiM hardness standards, and UME with the CCM KCRV in HV1 (240 HV and 540 HV) and HV30 Vickers hardness scales and this report is supporting the present and possible new CMC submissions.

14. References

[1] EN ISO 6507-1: 2005, Metallic Materials – Vickers Hardness Test - Part1: Test Method

[2] EN ISO 6507-3: 2005, Metallic Materials - Vickers Hardness Test - Part3: Calibration of Reference Blocks

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

[4] ASTM E92-17, Standard Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials, ASTM International, West Conshohocken, PA, 2017, www.astm.org

[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 6. Degree of Equivalence of UME and the KCRV of the CCM.H-K1.b.c through INRIM as a Link Laboratory in HV1 Hardness Scale

HV1 Hardness Scale (measurement unit HV1)										
X_{UME}	U_{UME}	X_{INRiM}	U_{INRiM}	d_{CCM}	$U_{d_{\text{CCM}}}$	$KCRV_{\text{LINK}}$	$U_{\text{KCRV}_{\text{LINK}}}$	d	U_d	E_{n}
201.87	3.45	201.25	2.91	1.30	9.11	199.95	9.56	1.91	10.17	0.19
509.60	8.83	516.33	8.87	10.49	25.50	505.84	27.00	3.76	28.41	0.13

Table 7. Degree of Equivalence of INRiM and UME (wrt. the CRV) for 840 HV1 Hardness Value

HV1 Hardness Scale (measurement unit HV1)											
X_{UME}	U_{UME}	X_{INRiM}	U_{INRiM}	CRV	U_{CRV}	d_{UME}	$U_{d_{\text{UME}}}$	$E_{n-\text{UME}}$	d_{INRiM}	$U_{d_{\text{INRiM}}}$	$E_{n-\text{INRiM}}$
848.41	18.28	833.79	15.94	840.10	12.01	8.31	13.78	0.60	-6.32	10.48	-0.60

Table 8. Degree of Equivalence of UME and the KCRV of the CCM.H-K1.b.c through INRIM as a Link Laboratory in HV30 Hardness Scale

	HV30 Hardness Scale (measurement unit HV30)									
X_{UME}	U_{UME}	X_{INRiM}	U_{INRiM}	d_{CCM}	$U_{d_{\text{CCM}}}$	$KCRV_{\text{LINK}}$	$U_{\text{KCRV}_{\text{LINK}}}$	d	U_d	E_{n}
201.93	1.98	201.62	2.18	-1.32	2.45	202.94	3.28	-1.01	3.83	-0.26
506.46	6.54	507.91	5.74	-0.06	10.39	507.97	11.87	-1.51	13.55	-0.11
812.29	12.49	817.54	9.52	1.50	18.35	816.04	20.67	-3.75	24.15	-0.16

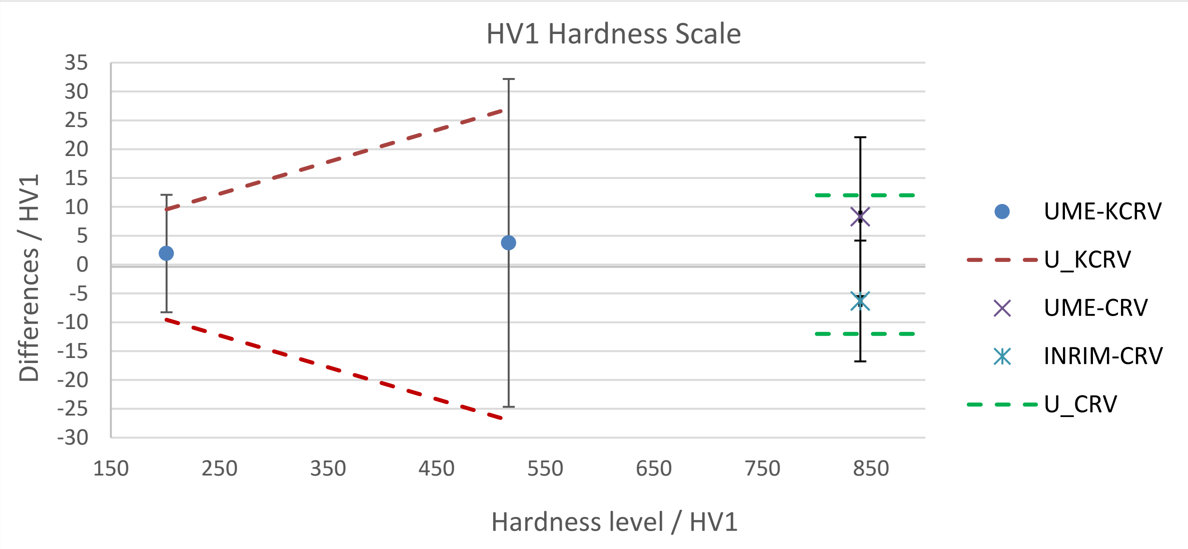

Figure 3. Deviation (d) of UME from the KCRV (X_{UME} minus $KCRV_{\mathrm{LINK}}$) for 240 HV1 and 540 HV1 with the associated expanded uncertainties (95% confidence level) (U_d and $U_{\mathrm{KCRV_{LINK}}}$), and deviations of INRiM (d_{INRiM}) and UME (d_{UME}) values from the CRV for 840 HV1 with the associated expanded uncertainties (95% confidence level) ($U_{d_{\mathrm{INRiM}}}$, $U_{d_{\mathrm{UME}}}$ and U_{CRV}) in HV1 Hardness Scale.

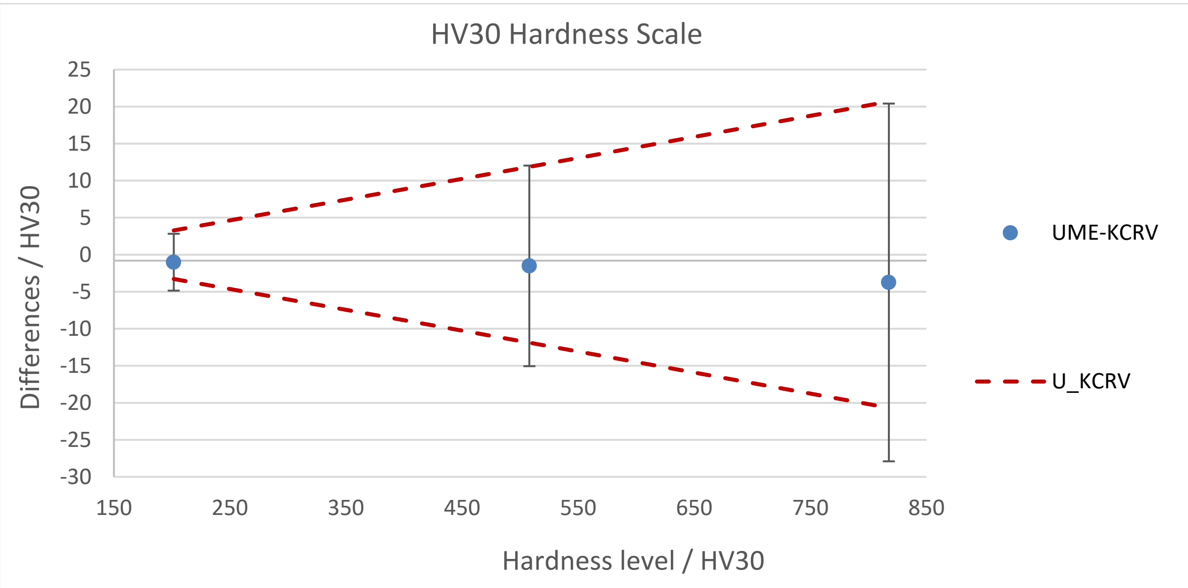

Figure 4. Deviation (d) of UME from the KCRV (X_{UME} minus $KCRV_{\mathrm{LINK}}$) in the HV30 Hardness Scale with the associated expanded uncertainties (95% confidence level) (U_d and $U_{\mathrm{KCRV_{LINK}}}$) in HV30 Hardness Scale.