INTERLABORATORY COMPARISON IN ROCKWELL HARDNESS SCALES BETWEEN TÜBİTAK UME AND TSE

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Abstract:

An interlaboratory comparison between TÜBİTAK UME (National Metrology Institute of Türkiye) and TSE (Turkish Standards Institution) was organized in the field of Hardness Metrology to determine the consistency of the primary hardness standard machine of TÜBİTAK UME and hardness calibration machine of TSE realizing Rockwell Hardness measurements in accordance with ISO 6508-1:2016 [1] and ISO 6508-3:2015 [2] standards.

In this study the procedure and measurement results of the interlaboratory comparison between the two institutes are explained.

Keywords: Hardness; Rockwell; comparison; interlaboratory

1. INTRODUCTION

An interlaboratory comparison was carried out between TÜBİTAK UME and TSE in the field of Hardness Metrology to determine the consistency of both institutes that realize Rockwell Hardness measurements in accordance with ISO 6508-1:2016 [1] and ISO 6508-3:2015 [2], including the new definition of Rockwell Hardness scales accepted by the CIPM/CCM WGH [3]. The most important and the most widely used Rockwell Hardness scales such as HRA, HRBW and HRC constitute the scope of the comparison which was piloted by TÜBİTAK UME.

The blocks used in the comparison as transfer standards were provided by TÜBİTAK UME and TSE. Each laboratory measured five hardness levels for HRC and four hardness levels for HRA and HRBW scales on the same transfer standards, using both their own indenters and a common one which was provided by TSE. Measurements were carried out first by TÜBİTAK UME as the PL (Pilot Laboratory), then by TSE, then again by TÜBİTAK UME for checking the stability of the transfer standards during the measurements realized.

2. TRANSFER STANDARD USED IN THE COMPARISON

In this 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, see Table 1 to Table 3. The blocks are transferred between TUBİTAK UME and TSE by private car so all hardness blocks were placed in a cardboard case during transportation with their anti-rusting paper and original cover provided by their producer. Some information related to the hardness reference blocks used in the comparison and their pictures are given below:

Table 1: Hardness reference blocks for HRA scale

No.	Hardness Value	Serial Number	Provider
1	30 HRA	12S77377	WILSON
2	50 HRA	11N60592	WILSON
3	66 HRA	293-733	YAMAMOTO
4	87 HRA	284-385	YAMAMOTO

Table 2: Hardness reference blocks for HRBW scale

No.	Hardness Value	Serial Number	Provider
1	31 HRBW	687-247	YAMAMOTO
2	49 HRBW	T79610	WILSON
3	73 HRBW	687-991	YAMAMOTO
4	95 HRBW	686-218	YAMAMOTO

Table 3: Hardness reference blocks for HRC scale

No.	Hardness Value	Serial Number	Provider
1	20 HRC	355-221	YAMAMOTO
2	35 HRC	489-679	YAMAMOTO
3	45 HRC	356-390	YAMAMOTO
4	56 HRC	367-649	YAMAMOTO
5	65 HRC	353-419	YAMAMOTO

Surfaces of hardness reference blocks were cleaned with soft material before and after measurements when it is needed.

3. COMPARISON PROCEDURE

It was requested that each participant shall assure that the primary machine (of TÜBİTAK UME) and the calibration machine (of TSE) to be used in the comparison at least were 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 additional load).
- Testing cycle (in accordance with the ISO 6508-1:2016 [1] and the ISO 6508-3:2015 [2] standards).
- Geometrical parameters of indenter (in accordance with the ISO 6508-3:2015 [2] standard).
- Depth measuring system (in accordance with the ISO 6508-3:2015 [2] standard).

In addition to the management of calibration of the components given above, the blocks were placed in the laboratory one day before the measurements for ambient conditions equilibrium.

The measurement steps performed during the comparison measurement, as specified in the ISO 6500-3: 2015 [2] standard, are the preparation of the machines, the cleaning of the contact surfaces of the anvil and the blocks, recording the ambient temperature, and recording two sets of 7 measurements (with two indenters, one common and one own) uniformly distributed on the surface of the block were made.

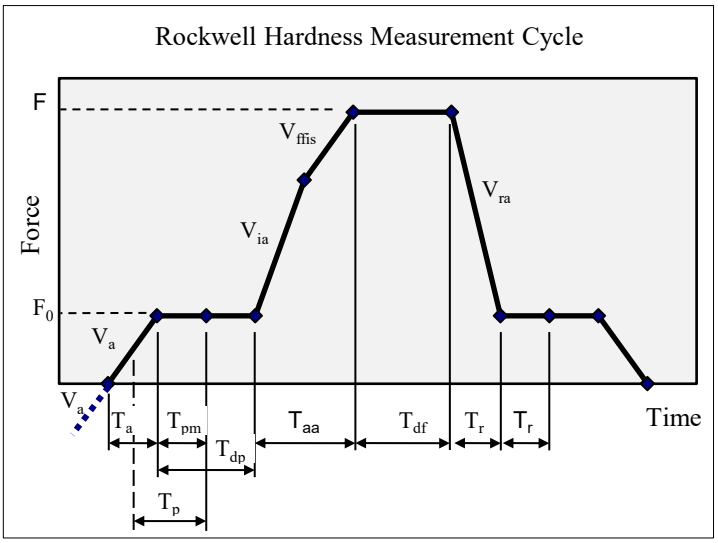
4. REFERENCE VALUES OF INFLUENCE PARAMETERS

In the calibration of hardness reference blocks the calibration laboratories realize this work in accordance with some internationally defined standards or accepted definitions. 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 to have more comparable reference systems. 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. Table 4 includes the reference values and measurement cycle used in the HRA, HRBW and HRC measurements and Figure 1 shows the measurement cycle for HRA, HRBW and HRC.

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

Reference values for HRA, HRB and HRC Scales					
Symbol	**Test parameters**		**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



Parameters
F_0 – Preliminary Force
F – Total Test Force
T_a – Application time of preliminary test force
T_{pm} – Duration time of preliminary test force
T_{dp} – Preload Dwell Time
T_p – Total time of preliminary test force
T_{aa} – Additional load Application Time
T_{df} – Duration of the total force
T_{ra} – Additional load Removal Time
T_{rf} – Final reading time
V_a – Approach Velocity
V_{ap} – Preload Application Velocity
V_{iaa} – Initial Velocity of Additional load Application
V_{fis} – Final indentation speed of additional load application
V_{ra} – additional load removal velocity

Figure 1: Identification of the HRA, HRBW and HRC Measurement Cycle [3]

5. ELABORATION OF THE RESULTS

The measurement procedure was applied in accordance with the technical protocol (TP). Seven measurements were carried out: the first two were discarded to eliminate the effects coming from adaptation of the machine and the blocks. The last five indents were considered in the calculations.

In the calibration of hardness reference blocks calibration laboratories carry out this work according to internationally accepted standards or definitions. As for the participants, to perform measurements under the same or very similar conditions, it has been significant to agree on reference values of the influence parameters and testing cycles and realize them as much as possible to have more comparable reference and calibration systems.

The pilot laboratory was responsible for bringing together the measurement data from the participants, compiling, elaboration and preparing the reports [4], [5]. The measurement results were used to compute the Comparison Reference Value (CRV), degrees of equivalence (DoE) with the CRV and E_n ratios. The calculation is shown in following steps and made by making use of the following equations.

- Calculation of the Comparison Reference Value (CRV)

The pilot laboratory determined CRV by calculating the weighted mean of measurements of the two participants (x_{ref}) using the following equation,

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

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

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

where
x_i : measured value of participating laboratory, i (i = 1, 2, …, n)
$u(x_i)$: standard uncertainty of x_i
$u(x_{\mathrm{ref}})$: standard uncertainty of x_{ref}

- The deviation from the CRV is calculated by,

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

- 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 as follows,

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

and $k = 2$.

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

$$E_{\mathrm{n}} = \frac{x_i - x_{\mathrm{ref}}}{\sqrt{U^2(x_i) + U^2(x_{\mathrm{ref}})}}, \quad (6)$$

where,

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

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

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

6. COMPARISON RESULTS

In this comparison, equivalence degree of each participant according to CRV was calculated. This calculation includes each participant's deviation from the CRV and the uncertainty associated with that deviation. In addition, E_{n} ratios were calculated for each hardness scale and level. Two participants declared consistent values of uncertainty, and the measurement results are in substantial consistency with each other. Measurement results and calculations are shown in the tables below.

Table 5: DoE of TSE and UME (wrt. CRV) – HRA – common indenter

X_{UME}	U_{UME}	X_{TSE}	U_{TSE}	X_{ref}	U_{ref}	d_{UME}	$U_{\mathrm{d\text{-}UME}}$	$E_{\mathrm{n\text{-}UME}}$	d_{TSE}	$U_{\mathrm{d\text{-}TSE}}$	$E_{\mathrm{n\text{-}TSE}}$
29.70	0.29	30.03	0.51	29.78	0.25	-0.08	0.14	0.56	0.25	0.44	0.56
49.78	0.30	49.75	0.50	49.77	0.26	0.01	0.15	0.05	-0.02	0.43	0.05
65.90	0.30	65.90	0.50	65.90	0.26	0.00	0.15	0.00	0.00	0.43	0.00
87.38	0.30	87.34	0.50	87.37	0.26	0.01	0.15	0.07	-0.03	0.43	0.07

Table 6: DoE of TSE and UME (wrt. CRV) – HRBW – common indenter

X_{UME}	U_{UME}	X_{TSE}	U_{TSE}	X_{ref}	U_{ref}	d_{UME}	$U_{\mathrm{d\text{-}UME}}$	$E_{\mathrm{n\text{-}UME}}$	d_{TSE}	$U_{\mathrm{d\text{-}TSE}}$	$E_{\mathrm{n\text{-}TSE}}$
30.80	0.43	30.14	0.60	30.58	0.35	0.22	0.25	0.89	-0.44	0.49	0.89
48.37	0.41	48.75	0.62	48.49	0.34	-0.11	0.23	0.51	0.26	0.52	0.51
72.08	0.39	71.82	0.61	72.01	0.33	0.08	0.21	0.36	-0.19	0.51	0.36
94.82	0.40	94.70	0.60	94.79	0.33	0.04	0.22	0.17	-0.09	0.50	0.17

Table 7: DoE of TSE and UME (wrt. CRV) – HRC – common indenter

X_{UME}	U_{UME}	X_{TSE}	U_{TSE}	X_{ref}	U_{ref}	d_{UME}	$U_{\mathrm{d\text{-}UME}}$	$E_{\mathrm{n\text{-}UME}}$	d_{TSE}	$U_{\mathrm{d\text{-}TSE}}$	$E_{\mathrm{n\text{-}TSE}}$
19.94	0.31	19.93	0.51	19.94	0.26	0.00	0.16	0.02	-0.01	0.44	0.02
34.81	0.28	34.70	0.50	34.78	0.24	0.03	0.14	0.19	-0.08	0.44	0.19
45.64	0.34	45.62	0.51	45.63	0.28	0.01	0.19	0.03	-0.01	0.42	0.03
55.60	0.30	55.52	0.50	55.58	0.26	0.02	0.15	0.14	-0.06	0.43	0.14
65.14	0.32	64.92	0.50	65.08	0.27	0.06	0.17	0.37	-0.16	0.42	0.37

Table 8: DoE of TSE and UME (wrt. CRV) – HRA – own indenter

X_{UME}	U_{UME}	X_{TSE}	U_{TSE}	X_{ref}	U_{ref}	d_{UME}	$U_{\mathrm{d\text{-}UME}}$	$E_{\mathrm{n\text{-}UME}}$	d_{TSE}	$U_{\mathrm{d\text{-}TSE}}$	$E_{\mathrm{n\text{-}TSE}}$
29.73	0.29	30.03	0.51	29.80	0.25	-0.07	0.14	0.51	0.23	0.44	0.51
49.67	0.30	49.75	0.50	49.69	0.26	-0.02	0.15	0.14	0.06	0.43	0.14
65.89	0.30	65.90	0.50	65.89	0.26	0.00	0.15	0.02	0.01	0.43	0.02
87.34	0.30	87.34	0.50	87.34	0.26	0.00	0.15	0.00	0.00	0.43	0.00

Table 9: DoE of TSE and UME (wrt. CRV) – HRBW – own indenter

X_{UME}	U_{UME}	X_{TSE}	U_{TSE}	X_{ref}	U_{ref}	d_{UME}	$U_{\mathrm{d\text{-}UME}}$	$E_{\mathrm{n\text{-}UME}}$	d_{TSE}	$U_{\mathrm{d\text{-}TSE}}$	$E_{\mathrm{n\text{-}TSE}}$
30.41	0.43	30.14	0.60	30.32	0.35	0.09	0.25	0.37	-0.18	0.49	0.37
48.58	0.41	48.75	0.62	48.63	0.34	-0.05	0.23	0.23	0.12	0.52	0.23
71.76	0.39	71.82	0.61	71.78	0.33	-0.02	0.21	0.08	0.04	0.51	0.08
94.52	0.40	94.70	0.60	94.58	0.33	-0.06	0.22	0.25	0.12	0.50	0.25

Table 10: DoE of TSE and UME (wrt. CRV) – HRC – own indenter

X_{UME}	U_{UME}	X_{TSE}	U_{TSE}	X_{ref}	U_{ref}	d_{UME}	$U_{\mathrm{d\text{-}UME}}$	$E_{\mathrm{n\text{-}UME}}$	d_{TSE}	$U_{\mathrm{d\text{-}TSE}}$	$E_{\mathrm{n\text{-}TSE}}$
20.22	0.31	19.93	0.51	20.14	0.26	0.08	0.16	0.49	-0.21	0.44	0.49
35.00	0.28	34.70	0.50	34.93	0.24	0.07	0.14	0.52	-0.23	0.44	0.52
45.59	0.34	45.62	0.51	45.60	0.28	-0.01	0.19	0.05	0.02	0.42	0.05
55.60	0.30	55.52	0.50	55.58	0.26	0.02	0.15	0.14	-0.06	0.43	0.14
65.17	0.32	64.92	0.50	65.10	0.27	0.07	0.17	0.42	-0.18	0.42	0.42

The graphical representations of the measurement results given in the tables are given below.

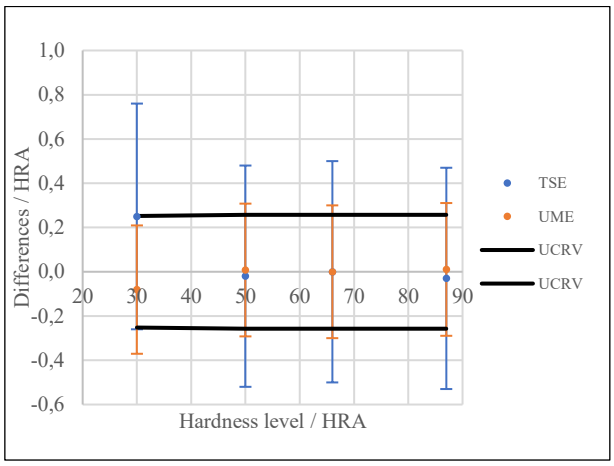


Figure 2: Deviations of TSE and TÜBİTAK UME values from the CRV with the associated expanded uncertainty – HRA – common indenter (Table 5)

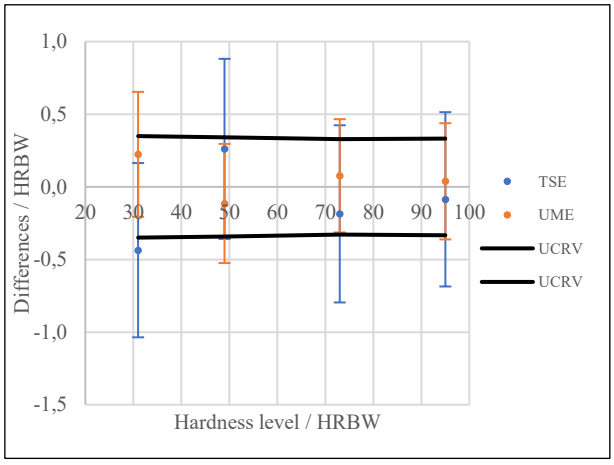


Figure 3: Deviations of TSE and TÜBİTAK UME values from the CRV with the associated expanded uncertainty – HRBW – common indenter (Table 6)

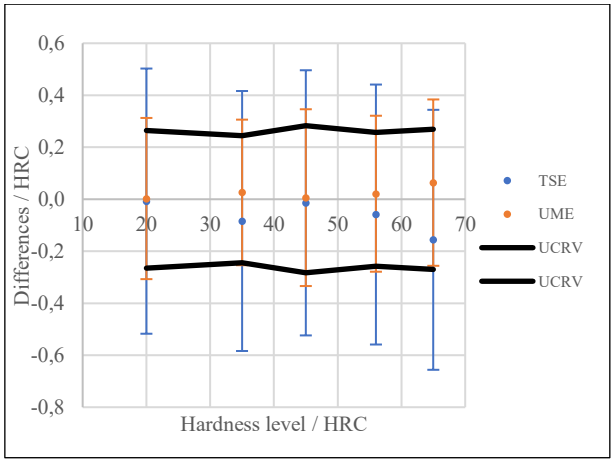


Figure 4: Deviations of TSE and TÜBİTAK UME values from the CRV with the associated expanded uncertainty – HRC – common indenter (Table 7)

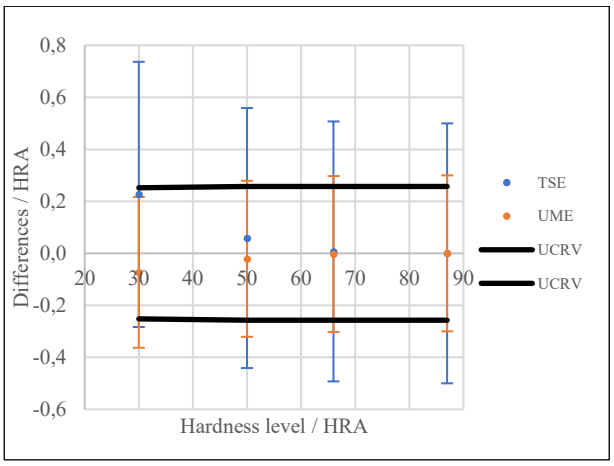


Figure 5: Deviations of TSE and TÜBİTAK UME values from the CRV with the associated expanded uncertainty – HRA – own indenter (Table 8)

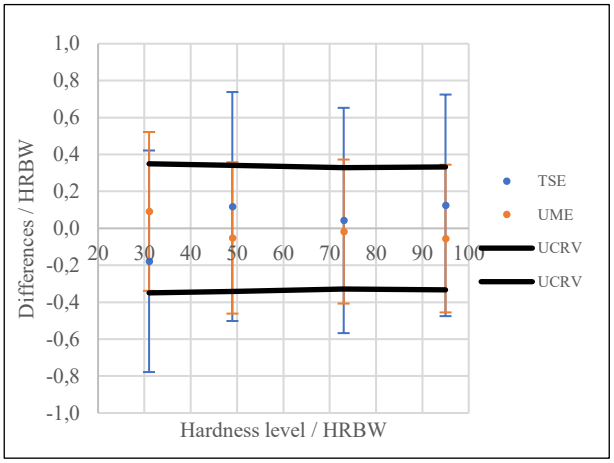


Figure 6: Deviations of TSE and TÜBİTAK UME values from the CRV with the associated expanded uncertainty – HRBW – own indenter (Table 9)

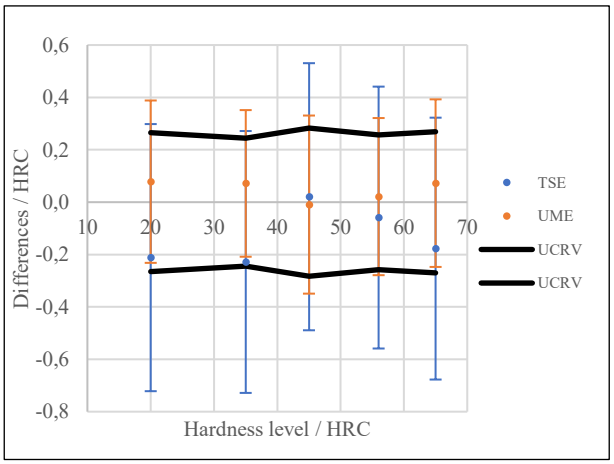


Figure 7: Deviations of TSE and TÜBİTAK UME values from the CRV with the associated expanded uncertainty – HRC – own indenter (Table 10)

7. SUMMARY

At the end of the bilateral comparison between TSE and TÜBİTAK 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 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 TSE and TÜBİTAK UME from the CRV and their uncertainties, d_{TSE}, d_{UME}, $U_{d\text{-}TSE}$, $U_{d\text{-}UME}$, and E_n ratios were calculated and shown in Table 5 to Table 10 and Figure 2 to Figure 7 in the Comparison Results. The degrees of equivalence show a significant consistency between TSE and TÜBİTAK UME hardness standards in HRA, HRBW and HRC Rockwell hardness scales and this comparison is supporting the present and possible new CMC submissions.

8. REFERENCES

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