Measurement: Sensors 18 (2021) 100360

Contents lists available at ScienceDirect

Measurement: Sensors

journal homepage: www.sciencedirect.com/journal/measurement-sensors

Bilateral comparison in Rockwell C hardness scale between INRiM and GUM

ARTICLE INFO

Keywords
Rockwell
Hardness
HRC
Bilateral comparison

ABSTRACT

This bilateral comparison in HRC is conducted in order to confirm the accuracy claimed by National Institute of Metrological Research in Italy (INRiM) and Central Office of Measures in Poland (GUM). Also, this study compares the difference of measurement results between two modernized deadweight-type Rockwell's hardness standard machines (HSMs) from GUM and primary hardness standard machine (PHSM) from INRiM. The hardness blocks of about 20 HRC, 35 HRC, 45 HRC, 50 HRC, 60 HRC and 65 HRC, which all have uniformity less then ±0.4 HRC according to EN ISO 6508-3, were used in this comparison.

1. Introduction

Rockwell C hardness scale (HRC) is the most widely used mechanical testing method for metallic materials and their components. Due to the fact that many NMIs use different types of Rockwell hardness standard machines, the key point in this field is to establish a world-wide unified Rockwell hardness scale with metrological traceability [1]. The last word-wide unified scales Rockwell hardness test, HRC, in which GUM participated took place 20 years ago [2]. Current bilateral comparison has been carried out between primary hardness standard machine from INRiM (as a Pilot) and two modernized deadweight-type Rockwell's hardness standard machines from GUM.

2. Comparison method

2.1. Measurement method

The hardness standard blocks of 20 HRC, 30 HRC, 45 HRC 50 HRC, 60 HRC and 65 HRC with MPA-NRW/QNESS/ASTM certificates were used in this comparison. Two sets of measurements (2 by GUM, 1 by INRiM) on hardness standard blocks are performed with each laboratory's indenter in order to confirm their declared uncertainties of hardness scale. The quality of the hardness standard blocks used in the Rockwell hardness comparison is shown in Fig. 1. Standard testing cycle according to EN ISO 6508-3 [3] is used in all measurements.

2.2. Rockwell hardness standard machines

2.2.1. INRiM's Primary Rockwell Hardness Standard machines

The INRiM PHSM realize all Rockwell scales, Vikers scales from HV3 to HV100 and Brinell scales from HBW1/5 to HBW2,5/187,5 (Fig. 2).

It was design and realized the end of the '70 years of the last century [4]. It has been improved in electronic, electro-mechanics and software control in occasion of the second realization, at the beginning of '90 years, for NIST (USA) [5]. New improvement was done during the third realization for the LFT accredited calibration laboratory at the beginning of the new century. In the last years, many others PRHMs were realized for several other NMIs and Laboratories in Brazil, Bulgaria, India, Rep. of Korea, USA, China, Saudi Arabia, etc.

It consists in a dead weight machine for the generation of the test forces and a laser interferometric system for the indentation depth measurements. The main characteristics are also the high stiffness, isostatic design and a very flexible software control that permits to set and measure all the most important parameters involved in the test cycle (times and velocities). Its metrological characteristics allow to realize the definition of the hardness scales with the best accuracy of the state of the art.

2.2.2. GUM's Rockwell hardness standard machines

The GUM twin deadweight-type HSMs (HSM-S01, HSM-S02) realize A, B, C, D, E, F, G, H, K Rockwell scales. The HSM-01 was design and manufactured at the beginning of '90 years by COBRABID LTD (Poland) and then improved in electronic and a laser interferometric system (wavelength of 633 nm) for the indentation depth measurements by Warsaw University of Technology. On the other hand, the HSM-S02 was design and realized the end of the '70 years of the last century by ERNST LEITZ BMbH WETZLAR (Germany) and recently modernized by MERICORE (Poland). As part of the modernization process, a new control system for the station, a hydraulic pump, a displacement measuring system and an application enabling the operator to operate the measuring station were made. Modernized HSM-S02 (Fig. 3) is equipped with the Renishaw RESOLUTE system for depth measurement of indentation, which consists of an optical encoder (head) and a stainless steel belt scale with laser-engraved absolute code. The system used has a measurement resolution of 1 nm and an accuracy of 3.5 μm per metre of scale length [6]. All standard machines were directly verified according to EN ISO 6508-3.

After the modernization, the stability and repeatability of GUM's deadweight-type Rockwell hardness standard machine were determined and the developed algorithm to compensate for measurement deviations was tested. The obtained measurements were confirmed that the station's mechanisms work properly and the compensating algorithm

https://doi.org/10.1016/j.measen.2021.100360

Available online 24 November 2021

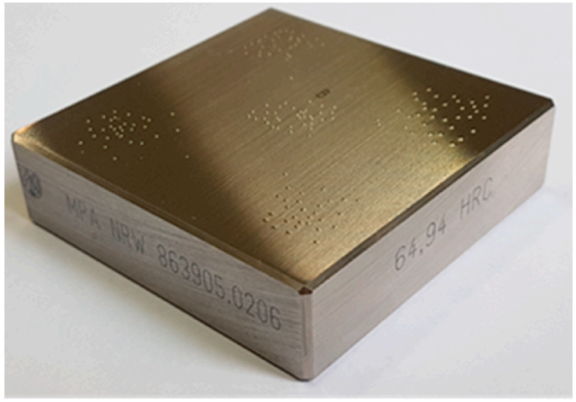

Fig. 1. The hardness standard block of 65 HRC used in HRC comparison between INRiM and GUM.

Fig. 2. INRiM's Rockwell preliminary hardness standard machine.

Fig. 3. GUM's Rockwell hardness standard machine (HSM-S02) equipped with the Renishaw RESOLUTE system, which consists of an optical encoder (head) and a stainless steel belt scale with laser-engraved absolute code and a computer with dedicated software (control and device diagnostics application written in LabVIEW) for data analysis and archiving.

allows correction of any deviations to the level of 0.05 HRC for the entire scale range [6].

This way of the adjustment HSM-S02 with the introduction of automatic compensation (correction) allows to improve the measured result (hardness) in real time.

On this basis, an uncertainty budget was developed. The compensation algorithm can be used to adjust the characteristics of the indenter or the system for measuring the displacement of the indenter if bilateral comparison made with the laser interferometer showed its non-linearity or offset.

Table 1
Measurement data of GUM Laboratory.

Nominal Hardness		GUM measurements [HRC]			
		Value	Uniformity	st.dev.	U
22,73	HRC	22,69	**0,28**	**0,05**	0,42
35,80	**HRC**	**35,84**	0,22	0,04	**0,42**
45,91	**HRC**	**45,57**	0,18	0,03	**0,42**
50,50	**HRC**	**50,87**	0,27	0,05	**0,42**
61,00	**HRC**	**60,73**	0,31	0,05	**0,43**
65,86	**HRC**	**65,55**	0,17	0,03	**0,41**

Table 2
Measurement data of INRiM Laboratory.

Nominal Hardness		INRiM measurements [HRC]			
		Value	Uniformity	st.dev.	U
22,73	HRC	22,24	**0,28**	**0,05**	0,31
35,80	**HRC**	**35,95**	0,15	0,03	**0,31**
45,91	**HRC**	**45,28**	0,19	0,03	**0,31**
50,50	**HRC**	**50,74**	0,35	0,06	**0,32**
61,00	**HRC**	**60,67**	0,24	0,05	**0,31**
65,86	**HRC**	**65,41**	0,13	0,02	**0,30**

Table 3
Comparison results of INRiM's and GUM's bilateral comparison in HRC.

Nominal Hardness		Comparison results		
		difference [HRC]	U_{diff} [HRC]	E_n
22,73	HRC	0,45	0,52	0,85
35,80	**HRC**	**−0,11**	**0,52**	**−0,20**
45,91	**HRC**	**0,28**	**0,52**	**0,54**
50,50	**HRC**	**0,13**	**0,53**	**0,24**
61,00	**HRC**	**0,05**	**0,53**	**0,10**
65,86	**HRC**	**0,14**	**0,51**	**0,27**

2.3. Standard testing cycle

A testing cycle according to EN ISO 6508-3 and to the HRC definition established by CCM-WGH [7] is used in this bilateral INRiM-GUM comparison.

2.4. Uncertainty of hardness measurement

The uncertainty budget evaluations were made following the EURAMET/cg-16/v.02 [8] and the JCGM 100 [9] guidelines. Each laboratory had the responsibility for determining their own uncertainty budget and uncertainty value for each measurement.

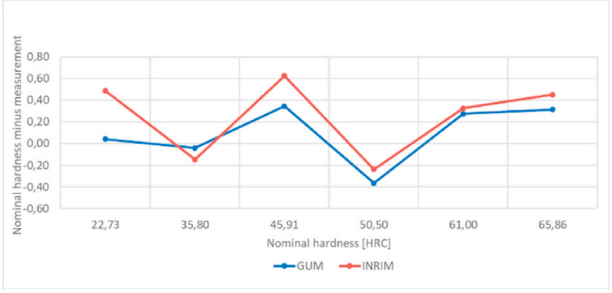

Fig. 4. Rockwell C Comparison INRiM – GUM - differences of nominal hardness and measurement between GUM and INRiM.

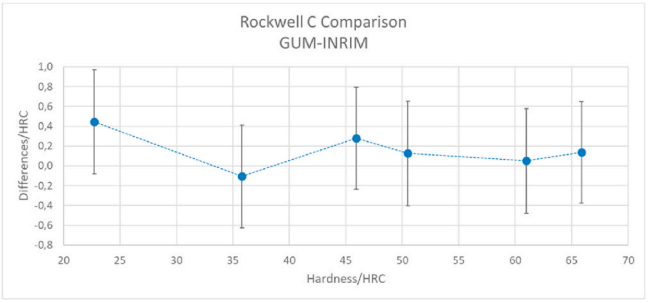

Fig. 5. Rockwell C Comparison INRiM – GUM - difference HRC with their uncertainty.

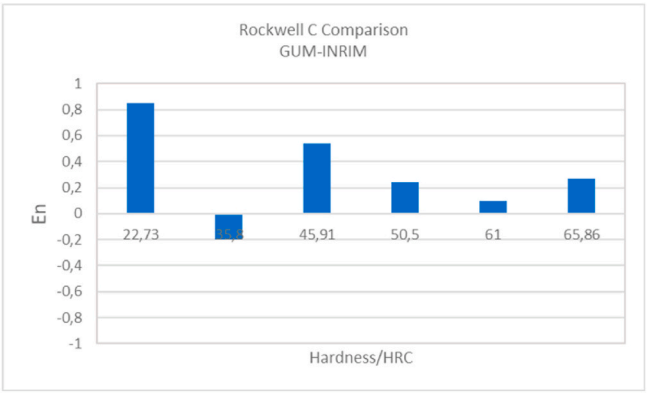

Fig. 6. The calculated En values – Rockwell C Comparison INRiM – GUM.

The measurement uncertainties of INRiM and GUM are shown in Table 1 and in Table 2 respectively.

3. Measurement results

In this work the measurement data from GUM's Rockwell hardness standard machine (HSM-S02) versus INRiM's Primary Rockwell Hardness Standard machine (PHSM) are reported. The distribution of traceability from HSM-S02 to HSM-S01 is the next action. The results, based on measurement data reported in Tables 1 and 2, have been analysed and reported in Table 3.

As shown in Fig. 4, the characteristics of differences of nominal hardness and measurement between GUM and INRiM are very similar.

It can be seen that the result for the standard block with the lowest hardness show the biggest difference between GUM and INRiM.

Nevertheless, the difference between the two laboratories does not exceed the limit values. From the comparisons of the PHSM (INRiM) and HSM-S02 (GUM), in relation to nominal values, the differences in measurements with uncertainty do not exceed the permissible value (see Fig. 5). The condition for a successful comparison is $|En| \leq 1$. The results of the calculated En values for Rockwell C Comparison between INRiM and GUM are shown in Fig. 6. One can claim that there is equivalence between both Institutes - the calculating En values are within En limits.

4. Summary

The bilateral comparison in HRC between National Institute of Metrological Research in Italy (INRiM) and Central Office of Measures in Poland (GUM) were performed. The study also compares the difference of measurement results between two modernized deadweight-type Rockwell's hardness standard machines (HSMs) modernized in accordance with Industry 4.0 requirements from GUM and primary hardness standard machine (PHSM) from INRiM. This bilateral comparison was successful. GUM is capable of in distributing the HRC traceability to the secondary laboratories and industrial sector in Poland by conducting interlaboratory comparisons and calibrations.

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