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ESTIMATION OF UNCERTAINTY IN ROCKWELL HARDNESS DIAMOND CONE INDENTERS

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Abstract – This work aims to validate the creation of a relationship between the direct and indirect calibrations of Rockwell C hardness diamond cone indenters. The resulting modelling allows the prediction of the indenters behaviour based on direct calibration. The uncertainty of indenters was obtained from the graph of uncertainty related to the Primary Hardness Standard Machine as a function of the uncertainty related to the Primary System for Calibration of Indenters. For mounting the experimental set-up it was necessary to use a lot of indenters, and their characteristics helped to model the behaviour of any other indenters. The majority of the results showed a good agreement between the uncertainty obtained from the indirect calibration and the uncertainty from the graphs used to create the mentioned model.

Keywords: Rockwell indenter, Rockwell hardness, measurement uncertainty.

1. INTRODUCTION

The Hardness Laboratory of the Brazilian NMI “INMETRO” has standardized the Rockwell, Superficial Rockwell, Brinell and Vickers hardness scales in Brazil recently. This standardizing task was supported by the actual INMETRO´s Hardness Primary Standardizing System, composed by the Primary Hardness Standard Machine (“HSM”), the Reference System for Measurement of Brinell and Vickers Indentations (“Gal-Vison”), and the Primary System for Calibration of Vickers and Rockwell Diamond Indenters (“Gal-Indent”).

ISO 6508-1:2005 [1], ISO 6508-2:2005 [2] and ISO 6508-3:2005 [3] standards relates to hardness testing, testing machines calibration and hardness reference blocks calibration, respectively. In a broad sense these standards provide the most important parameters for the measurement process that directly influence the determination of hardness in metallic materials.

Hardness indenters for scales A, C, D and N are the diamond cone ones. In order to verify the reliable performance of these indenters a direct and an indirect verification must be carried out, as described in the ISO 6508-2:2005 standard [2]. Although the direct calibration is based on a series of geometrical characteristics the indenters have to satisfy, the indirect calibration uses four hardness reference blocks pertaining to the hardness ranges 20 to 26 HRC, 52 to 58 HRC, 40 to 46 HR45N and 88 to 94 HR15N that have to be tested in a hardness testing machine that uses a reference indenter calibrated in a more strict sense in accordance to ISO 6508-3:2005 standard [3].

The uncertainty of an indenter calibration is a function of several factors: the manufacturing process, the raw material used, the conditions and the frequency of use. However, the uncertainty related to the calibration of the indenters themselves used in testing machines is a matter that has not been addressed in the hardness standards [2,3] so far.

This paper aims of drawing a correlation between the direct and indirect calibrations to determine the inherent uncertainty of Rockwell hardness diamond cone indenters, using the prescribed hardness levels for different scales listed in Table 1 of ISO 6508-2:2005 standard [2]. Thus, one could estimate the value of the uncertainty of an indenter using a model proposed here by combining the uncertainties in units of observed hardness that was obtained in direct verification and indirect verification procedures in different indenters used in Rockwell C calibration.

The determination of the uncertainty of indenters will bring an important contribution to the metrology related to testing and calibration of reference blocks and hardness testing machines. Furthermore, the estimation of the uncertainties of indenters could also provide criteria for comparing them in terms of the forecasted performance of them in service taking into account only the direct calibration in an independent way from the indirect calibration. This could mean only the direct calibration would be enough to ascertain a new way of distinguishing in

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advance a better or a not so better indenter. E.g., this is a proposition for classifying indenters in terms of expected performance prior to their use in service.

2. MATERIALS AND METHODS

For best results in measurements of the uncertainty of indenters on Rockwell hardness scale, data obtained from indenters of different manufacturers and with different histories of use were used. The Rockwell hardness reference blocks selected to carry out the work had nominal hardness values of 23HRC, 55HRC, 43HR45N and 91HR15N, respectively. This choice was based in the requirements of relevant international standards [2] in such a way be possible the examination of hardness scales in their low, medium and high ranges as a function of the indentation depth.

The results of measuring the hardness were submitted to a widespread analysing criteria for acceptance or rejection of the measured values [4], while the calculation of uncertainty of measurement used the methodology recommended by ISO-GUM [5].

Figure 1 shows the INMETRO´s Primary Hardness Standardization Machine. The indirect verification was carried out in this standard.

Figure 1 – Primary Hardness Standard Machine (HSM).

The calculation of the uncertainty of the indenter through indirect calibration was done taking into account the uncertainties related to the measurement repeatability and the type-B uncertainty calculation that resulted from the Primary Hardness Standard Machine´s calibration documentation.

The determination of the uncertainty of Rockwell indenters into units of length was calculated from the results obtained by direct calibration. For that, it was used the Gal-Indent system for the calibration of the indenters.

Figure 2 shows the Primary System for Calibration of Vickers and Rockwell Diamond Indenters "Gal-Indent".

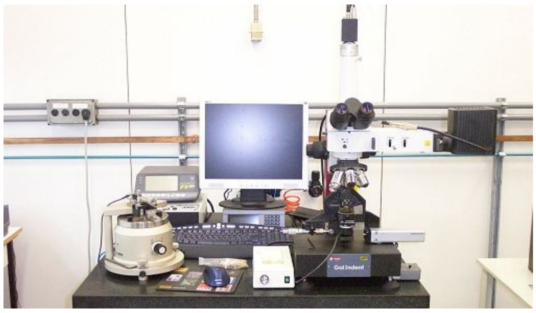

Figure 2 – Primary System of Rockwell and Vickers Diamond Indenters Calibration (Gal-Indent).

The determination of the combined uncertainty of Rockwell diamond cone indenters comprised the estimation of uncertainties related to the angle, radius and generating angle of inclination of the indenter that resulted from the direct verification of indenters. At the same time, there was a combination of the values of uncertainty into the unit of length, as the uncertainties related to the angle between the indenter sides and the angle of inclination of the indenter are given in degrees by the Gal-Indent system. After the equalization of the units it was possible associating the squared standard uncertainties and combining them afterwards.

In the equation 1 below, the considered uncertainty sources used for calculating the uncertainty of the indenter in millimetres are shown.

$$\mu_{Gal} = \sqrt{\mu_{angle}^{2} + \mu_{raddi}^{2} + \mu_{generatrix}^{2} + \mu_{inclination}^{2}} \qquad (1)$$

where μ_{Gal} is the uncertainty of the indenter from direct calibration, μ_{angle} is the uncertainty related to the included angle of the diamond cone of the indenter, μ_{raddi} is the uncertainty from the radii calibration, $\mu_{generatrix}$ is the uncertainty related to deviations from straightness of the generatrix of the diamond cone adjacent to the blend and $\mu_{inclination}$ is the uncertainty of the angle between the axis of the diamond cone and the axis of the indenter-holder. All uncertainties are provided in units of length.

For indirect calibration the considered uncertainty sources were the HSM calibration itself and the repeatability concerning the tests, as shown in the equation 2 below.

$$\mu_{I} = \sqrt{\mu_{HSM}^{2} - \mu_{\mathrm{Re}\,p}^{2} - \mu_{Block}^{2}} \qquad (2)$$

where μ_{I} is the uncertainty of the indenter, μ_{HSM} is the uncertainty of the Primary Hardness Standardization Machine, μ_{Block} is the uncertainty related to standards blocks and μ_{Rep} is the uncertainty related to the repeatability of the tests. All uncertainties are provided in units of hardness.

3. RESULTS AND DISCUSSION

As a consequence of the analysis of results for the uncertainty of the indenters using both direct and indirect verifications it was possible to determine the compatibility between the two results regarding the verifications. Moreover, it was possible to show there was an agreement between the calculated and modelled uncertainties taking into account the same scale of hardness in which data were obtained.

The amount of results were used to create and validate a mathematical model developed in this paper. This model has proved its ability to use the uncertainty using only the dimensional and geometric properties of the tested indenters that were obtained from direct calibrations.

This study succeed in determining graphically the uncertainty of the indenter in units of hardness through its uncertainty in units of length, obtained by direct calibration. Since the uncertainty values, due to indirect calibration and the values estimated by graphical representation, were determined in hardness units it was possible to assess the correlation between values presented in “x” and “y” coordinates.

This above discussion arised from the plotting in a x-y graph many points whose coordinates were the uncertainties obtained in both direct and indirect indenters verification. The adjustment of the best curve to these experimental points (the so-called “calculated” ones) allowed the estimation of the respective uncertainties related to the indirect verification (the “modelled” values).

Figure 3 establishes the relationship between the uncertainties as calculated from the calibration obtained through indirect and direct calibration as shown in figures 3A, 3B, 3C and 3D that refers to tests carried out in high, medium and low depths of penetration, e.g. by the use of the hardness reference blocks 23HRC, 55HRC, 43HR45N and 91HR15N, respectively. In this graph the uncertainty related to the PHSM (in HRC units) is depicted in the y-axis; the uncertainty linked to the Gal-Indent System (in mm values) is located in x-axis.

Figure 3 compares the uncertainty values calculated by the indirect and the direct calibrations, and it was drawn from a number of data originated in measuring Rockwell indenters calibrated at INMETRO´s Hardness Laboratory.

The small difference between the calculated and estimated graphical values of uncertainty is shown in Table 1 below.

In Table 1, “Hardness” is the hardness blocks used in the indirect verification, “Unc. Calc.” is the uncertainty resulted from the indirect verification whereas the “Unc. Est.” is the estimated graphical value of uncertainty. “Difference” is the difference between the calculated uncertainty and the estimated uncertainty.

It is important to mention that the indenters which showed satisfactory performance in indirect calibration are the more prone to agree with model created to estimate the indenter uncertainty.

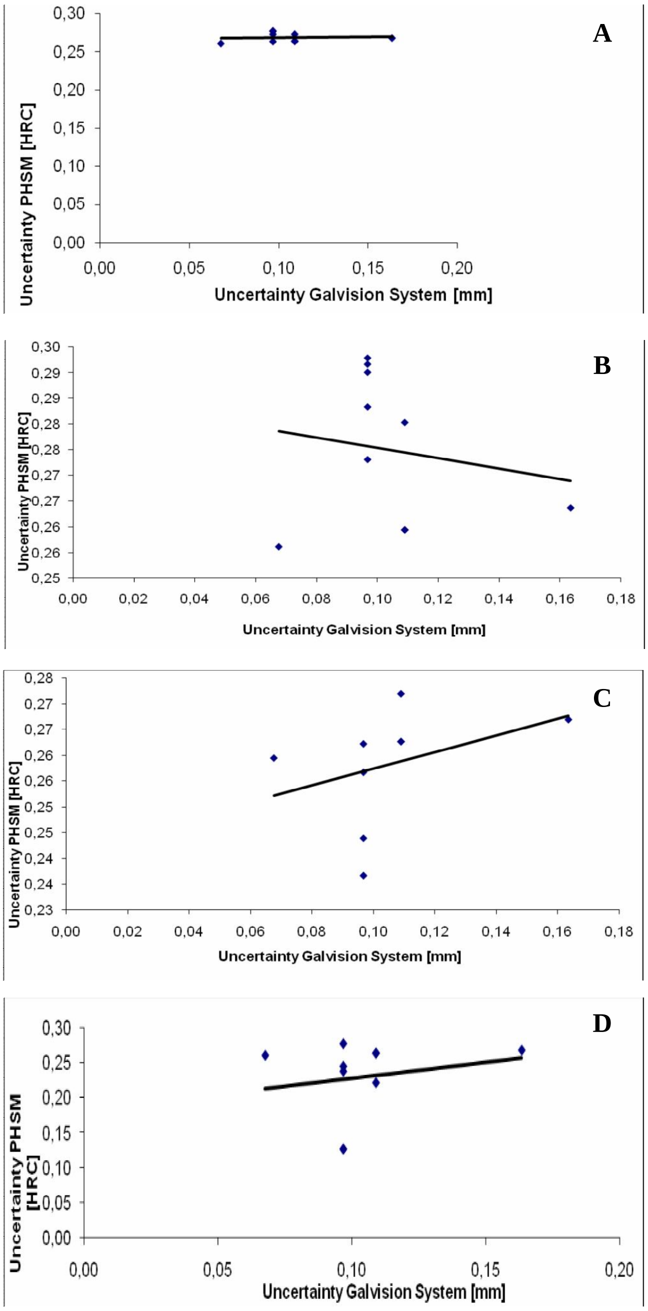

Figure 3 – Graphs on the behaviour of the uncertainties of direct and indirect calibration of Rockwell diamond cone indenters, where figures 3A, 3B, 3C and 3D refer to the hardness reference blocks 23HRC, 55HRC, 43HR45N and 91HR15N, respectively.

One can infer from Table 1, indenters P1 and P2 are the best candidates for being considered high-level indenters, e.g. reference indenters, since there appeared a “zero” difference in the calculations referred to these indenters. On the other hand indenter P4 seems to be able to be at most a working indenter, eventually even a non-approved indenter, due to a 0.11 difference (and a 0.05 value as well) that appeared for one of the hardness blocks used. As expected the indenter P3 had an intermediate behaviour when compared to the other three indenters shown in Table 1.

Table 1 - Comparison between the calculated values of the uncertainty of the indenters through indirect calibration and the values observed by graphical simulation.

Indenter	Hardness	Unc. Calc.	Unc. Est.	Difference
P1	23HRC	0.26	0.26	0
P1	55HRC	0.26	0.30	-0.04
P1	43HR45N	0.26	0.29	-0.03
P1	91HR15N	0.27	0.31	-0.04
P2	23HRC	0.26	0.26	0
P2	55HRC	0.27	0.3	-0.03
P2	43HR45N	0.26	0.26	0
P2	91HR15N	0.26	0.23	0.03
P3	23HRC	0.25	0.26	-0.01
P3	55HRC	0.27	0.30	-0.03
P3	43HR45N	0.23	0.26	-0.03
P3	91HR15N	0.28	0.23	0.05
P4	23HRC	0.15	0.26	-0.11
P4	55HRC	0.29	0.30	-0.01
P4	43HR45N	0.24	0.26	-0.02
P4	91HR15N	0.28	0.23	0.05

Table 2 shows the performance testing for indenters P1 through P4 when subjected to indirect verification. There, according to the requirements of the hardness standards, “W” means that indenter was classified as a working one, “R” if the indenter is to be classified as a reference one, and “NA” in case the indenter was considered as a non-approved one.

Table 2 – Indenters performance for indirect calibration

Indenters	Hardness ranges			
	23HRC	55HRC	43HR45N	91HR15N
P1	W	W	W	W
P2	R	W	W	R
P3	W	W	NA	R
P4	NA	NA	NA	NA

Regarding Table 2, none of the indenters would be a “pure” reference indenter, since for each indenter not all hardness blocks had an “R”. Indenters P2 (with two “Rs”) and P3 (with one “R”) could in theory be reference indenters for not all hardness blocks. From this point of view indenter P2 seems to be the better than P3 because it doesn´t have any “NA” as P3 has. So, P4 is the worst amongst all indenters.

Crossing the information of both Table 1 and Table 2 it is possible to infer the behaviour of an indenter in service depending only on the direct verification of it. In doing so, for the cases presented in this paper, P2 is the best indenter, P1 is the next, P3 is the third one. Thus, it appears that indenter P4 will provide not good compliance between the model and the value found by the indirect calibration. It is strongly related to the fact it was “not-approved” in a performance test related to indirect calibration.

In last, Tables 1 and 2 provide a classification for each indenter covering low, medium and high depth of penetration in hardness tests.

The results demonstrated the simulation of the uncertainty values of the indenters in hardness units without carrying out actual indirect verifications is viable. This graphical modelling is only a sole function of the uncertainties obtained with the Gal-Indent system for direct calibration of Rockwell diamond cone indenters. Moreover, it was possible to detect that when the indenters display geometrical characteristics different from those established by ISO, as expected one cannot attain an agreement between the calculated uncertainty and that one obtained graphically by the method presented in this research.

CONCLUSIONS

- This work makes the proposition of the possibility of using a new model in order to tackle with the dimensional and geometrical characteristics of diamond cone indenters. This model is directly related to the uncertainty of the indenter extracted from the indirect calibration. Thus, it is possible to qualify and at the same time model the behaviour of a particular indenter in its lifetime.

- As the Rockwell hardness is directly related to the depth of penetration, the indenter does present different characteristics depending on the hardness range that is linked to a low, medium and high depth of indentation.

This work proposes a new methodology for classifying indenters as a function only of the direct calibration of them. That is, according to the their dimensional characteristics, e.g. their inherent geometrical state, it would be possible to estimate with a high probability if any indenter is going to present the behaviour of a reference indenter, a working indenter or even if it has to be considered a non-approved indenter for testing and calibration of hardness machines. The model proposed here is as of a model for estimating the in-service behaviour of any indenter.

- Initial results showed a good correlation between the calculated uncertainty values and the value obtained through modelling. In order to increase the statistical reliability of results, the same test procedure has been done with other Rockwell indenters from several manufacturers. This way, the result will be statistically more robust, which will also validate the extension of this methodology for not only Rockwell indenters but also for Vickers and Brinell indenters as future research works.

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