STUDY OF THE INFLUENCE OF THE OPERATORS´ SKILLS ON THE CALIBRATION OF ROCKWELL INDENTERS

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Abstract: This work aims to study the influence of different hardness machine´s operators on the calibration of Rockwell indenters. The results allow the prediction of the indenters behavior based on direct calibration including the operator's influence. On this way it was concluded that the calibration of Rockwell indenters using the Gal-Indent system is dependent on the skill of each operator for performing hardness indenter calibrations.

Key words: Rockwell indenter, Rockwell hardness, operator's influence.

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-Vision") 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 relevant requirements for the measurement process that directly influences 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 both a direct calibration 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 system of direct calibration of Rockwell indenters called Gal-Indent requires specific operator´s skills when compared to the other two hardness standards, e.g., HSM and Gal-Vision ones.

Based on this observation studies have been conducted at the Inmetro´s Hardness Laboratory in order to determine to what extent the hardness machine´s operators influence on the final calibration of Rockwell indenters.

Two main parameters shall be considered in the calibration of Rockwell indenters: the tip radius and the included angle of the diamond cone. The radius and the angle of a good indenter shall have 200 ± 10 µm and 120 ± 0.1°, respectively [2].

2. MATERIALS AND METHODS

For this study, and consequently to determine the degree of influence of the operator on the result of a calibration, it was used the Primary System for Calibration of Vickers and Rockwell Diamond Indenters "Gal-Indent", located at the Inmetro´s hardness laboratory, shown in Figure 1.

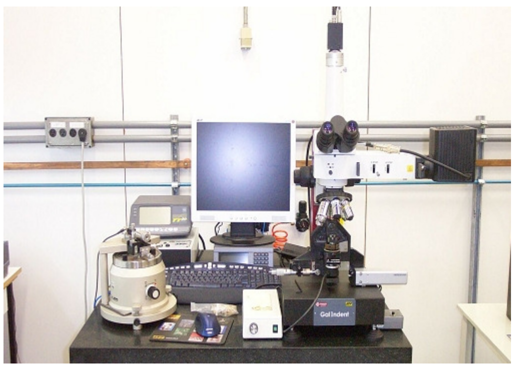

Fig. 1. Primary System of Rockwell and Vickers Diamond Indenters Calibration (Gal-Indent).

The direct verification of the Rockwell indenter was based on guidance provided by ISO 6508-2:2005 [2]. The statistical calculations and measurement uncertainty estimations are in agreement with the ISO-GUM [4].

The hardness comparisons were realized by four operators and the reference measures were established as those obtained from the indenter calibration certificate issued by the Italian National Metrology Institute INRiM (Istituto Nazionale di Ricerca Metrologica). These values are 120,03º for the angle and 196,3 µm for the radius of the indenter. As established by international standard [2] the angle measurements were obtained in four sections and the radius ones used eight sections. Estimation of normalized errors for all operators was made afterwards.

3. RESULTS AND DISCUSSION

To evaluate the comparisons among operators, measurements of the angle and the radius of the Rockwell indenter were performed during the calibration process. Table 1 shows the measurements for the angle while Table 2 presents the values obtained for the radius of the indenter.

Table 1. Calibration values related to the included angle of the diamond cone obtained for all operators

Sections	Operator 1 (º)	Operator 2 (º)	Operator 3 (º)	Operator 4 (º)
1	120.077	120.080	120.085	120.022
2	120.063	120.090	120.079	120.016
3	120.062	120.066	120.072	120.009
4	120.075	120.078	120.077	120.012

Table 2. Calibration values related to indenter tip radius for all operators

Sections	Operator 1 (µm)	Operator 2 (µm)	Operator 3 (µm)	Operator 4 (µm)
1	199	195.9	200.3	196.8
2	197.2	193.8	198.6	197.1
3	197.5	194.4	198.5	193.9
4	199.1	196.5	200	194.7
5	199.8	197.6	200.2	196.7
6	197.7	195.7	199.9	196.7
7	196.8	194.7	198.1	195.5
8	198.1	196.3	200.1	193.8

Analyzing Tables 1 and 2, it is possible to observe that there are less variations in the angle values than in the values of the radius of the indenter measured by different operators. In relation to the operators´ influence it can be said the Gal-Indent system has a higher sensitivity to the operator´s skill when the radius measuring process is considered. However, the variation of the angle is critical, because the tolerance of measurement is 0.08% (0.1º in 120º) while for measuring the radius the tolerance is 5% (10 µm in 200 µm) [2].

Therefore, it is necessary to be very careful on the calibration of the angle of the indenter since the changes among operators may provide different results regarding the approval or disapproval of the Rockwell indenter according to the tolerances given by ISO 6508-2:2005 [2].

It should be emphasized that this work was carried out among operators who have different degrees of knowledge and experience level in relation to the measurement of both the angle and the radius of the Rockwell indenter. Since the Operator 4 is the most experienced in the indenter calibration process he´s actually responsible for realizing the Inmetro's indenter calibration measurements. All the obtained results were compared to reference measures of both the angle and radius of the indenter.

Figure 2 shows the behavior of angle measurements for the various operators according to Table 1. The value for each operator is an average of a total of five measurements in repeatability conditions.

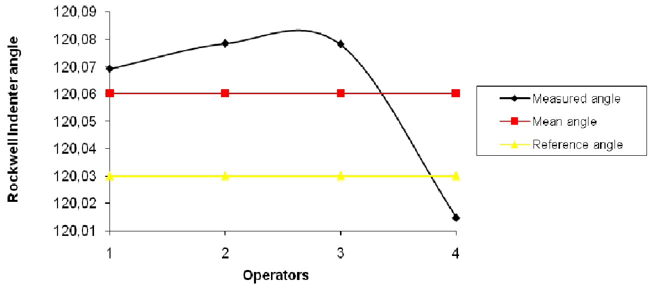

Fig. 2. The behavior of the measurement of the angle of the indenter as a function of the operators

In a more detailed way Figure 2 shows the behavior of measured angle by operators (black line), the mean angle that is the average of the four operators means from the indenter measurements (red line) and the reference angle value from the calibration certificate (yellow line). It can be seen that the operators 1, 2 and 3 presented a similar behavior. However, as expected only the value for the operator 4 was relatively closer to the reference value of the angle of the indenter.

According to Table 2 the Figure 3 shows the values found for the radius of the Rockwell indenter for each operator. Unlike the angle, the radius showed a greater variability amongst the obtained values.

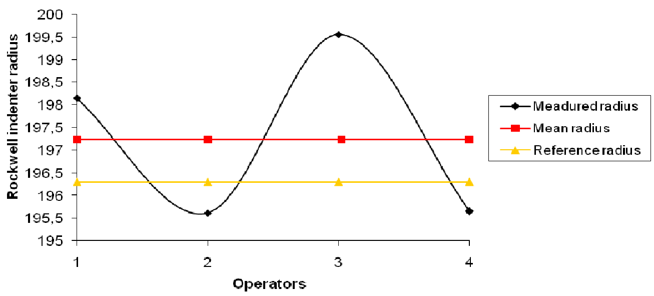

Fig. 3. The measurement behavior of the radius of the indenter as a function of the four operators.

Figure 3 shows that the values for the radius of the indenter found by operators 1 and 3 were quite different from the other two and relatively distant from the reference value. This described behavior was not the same for operators 2 and 4, which presented values for the radius very close to each other and to the reference value.

To assess the compatibility of measurement results for the measured values of not only the angle but also the radius of the indenter they were compared with the reference values of 120.03° and 196.3 µm, respectively. In order to compare the results with the reference values it was used the tool called "normalized error" which is defined according to equation (1) described below:

$$E_n = \frac{X_i - X_{ref}}{\sqrt{U_i^2 + U_{ref}^2}} \qquad (1)$$

where:
E_n - normalized error
X_i - values of average determined for the measurements of both the angle or radius of the indenter performed by a specific operator
X_{ref} - reference value of both the angle or the radius of the indenter
U_i - measurement uncertainties of both the angle or the radius of the indenter performed by a specific operator
U_{ref} - uncertainty of reference value of both the angle or the radius of the indenter.

The results of each operator will be compatible with the reference values of the angle and radius of the indenter E_n value if its maximum value is not higher than 1. Yet, the measured values will be considered incompatible if E_n has a value above 1. In Figure 4 it is possible to observe the behavior of E_n as a function of both measured the angle and the radius of the indenter for all operators. Two curves, one of them in blue and the other in red, relative to E_n values obtained from the angle and radius measurements, respectively, and another curve in green linked to the compatibility limit for accepted values of E_n as well, can be seen in Figure 4.

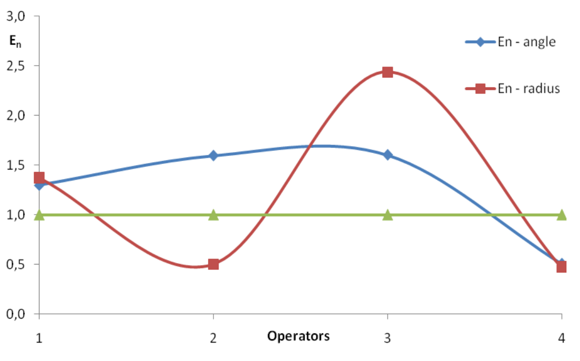

Fig. 4. The normalized error for measurements of the angle (blue curve) and the radius (red curve) of the indenter as a function of each operator, as well as the compatibility limit for E_n (green curve).

As a consequence of the above discussion it can be realized that according to the measurement of the angle of the indenter (Figures 2 and 4) there is a close relation among operators 1, 2 and 3 since they are relatively close to each other, although they are not compatible with the reference value. On the other hand, operator 4 presented the closest value to the reference value achieving compatibility in terms of E_n which presented a value of about 0.4.

In last, the measured values found by the operators had a higher variability relative to the radius of the indenter (Figure 2). However, regarding the compatibility of the results with the reference, it was observed that the operators 2 and 4 are compatible (with E_n values of about 0.5 and 0.4, respectively) with the reference values.

It is possible to extract from Figure 4 some facts: a) operator 4, the best of all of them, needs no further training action at all; b) operator 2 only needs a new angle training activity since its skills to the radius calibration is compatible with operator 4; c) operator 1 needs some training with same intensity in both the angle and the radius; d) operator 3 has the relative same behavior as operator 1 although the intensity of training for the radius have to be higher than for the angle.

Considering the results presented above it can be said that in the indenter's calibration the contribution of the operator is a factor that cannot be disregarded. In addition, it was found in the calibration of the angle of the indenter that there operators 1, 2 and 3 needs some re-training in the calibration process in order to achieve compatibility with the reference values.

4. CONCLUSION

This work deals with the calculation of the influence of operators´ skills in executing the calibration of Rockwell hardness indenters in the Primary System for Calibration of Vickers and Rockwell Diamond Indenters ("Gal-Indent"). For this four operators run some measurements at the Inmetro´s Hardness Laboratory. Along this work his measurement results were compared with reference values for the angles and radius of the indenter issued by the Italian National Metrology Institute INRiM. The normalized error was calculated as well for all operators afterwards.

It was found that the operator 4 is the only that meets qualified skills for calibrating hardness indenters in a closer condition near to the ideal one to perform the calibration process. At the same time operators 1, 2 and 3 need to improve their knowledge and skills in the calibration of the indenter so that they have their results as close as possible to given reference values.

All four operators presented good results in terms of repeatability and reproducibility but these ones proved not to be enough to assure a qualified measurement since three of them had his results not totally compatible with particular reference values for angle and radius of indenters.

It was found that in order to obtain the best possible results in the calibration of indenters three of the operators must be re-trained and qualified in different levels.

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