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PERFORMANCE TESTS FOR QUALIFYING METROLOGICAL ROCKWELL INDENTERS

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Abstract: Much work has been done on Rockwell diamond indenters to evaluate the relationship between geometry and hardness measurement results. However, it has been observed that the residual after geometrical correction is significant (within ±0,3 HRC). Some investigations on the non-geometric parameters of the Rockwell diamond indenters, as mechanical properties of the diamonds and the soldering of the diamond prism into the holder, were carried out in the past. Recently, using the INRiM primary machine, some experimental tests were carried out to investigate the possibility to correlate the differences on hardness measurements observed using different indenters to the non-geometric characteristics of indenters. The results show that this correlation exists and it can justify the discrepancies.

Keywords: hardness, indenters, performances.

1. INTRODUCION

Much work has been done on Rockwell diamond indenters to evaluate the relationship between geometry and hardness measurement results [1, 2]. However, it has been observed that the residual after geometrical correction is significant (within ±0,3 HRC) [3].

The reason for these residuals is not completely clear, but reasonable sources of discrepancies are the mechanical properties of the diamonds and the soldering of the diamond prism into the holder [4]. At the present level of knowledge, it seems that it is not possible to predict the performance of a diamond indenter using only direct measurement of the geometry.

In fact, international standards [5] prescribe that indenters, used in calibrations of hardness blocks, must be verified by comparison with so called “reference indenters” recognized at the national level (“metrological indenters”). Metrological indenters are not defined at all by the ISO standards or by any other international organization.

To select suitable metrological indenters, it is necessary to perform both geometrical measurements and performance tests.

Geometrical measurement can be done in different ways [6-8], but to assure compatibility in results, it is necessary to compare the definition of the measurand and the measurement capabilities. The compatibility assurance will probably be obtained by results of comparisons among some NMIs [9].

Performance tests require the use of hardness standardizing machines working with an agreed measurement cycle and knowing the machine’s performance with respect to internationally agreed hardness scales.

It is therefore important to develop a procedure for qualifying metrological indenters, so that any NMI maintaining hardness scales can procure his primary indenters.

INRiM has made hysteresis tests on indenters indicating that hysteresis is different among indenters.

2. DESCRIPTION OF THE TEST

Preliminary tests have been carried out with the INRiM primary machine [10]; they consists in fifty Rockwell C tests made on the same indentation, recording the indentation levels at the preload (loading and unloading) and at the full-load. These tests were repeated at three different hardness levels (low, medium and high hardness level), for five different indenters.

As result of a first evaluation of these tests, a procedure has been studied allowing the determination of the indenters performances in a possible faster way. So, a second set of tests have been carried out recording only the hardness value as results of a repetition of thirty tests in the same indentation.

Fitting measurement results with a simple mathematical model, it is possible to predict the real behaviors of the indenter, eliminating the influence of the hardness block under test and the elasticity of the machine.

3. RESULTS

3.1. Preliminary study

From the preliminary tests, different kinds of elaborations allow calculating the indenter hysteresis Δd: the most useful parameter is the difference from the displacement measured during the loading, d_l, and unloading, d_u, at the preload level (fig. 1), calculated as follows:

$$\Delta d = d_l - d_u \quad (1)$$

The results show that it is possible to calculate, for each indenter, a correlation between the above mentioned parameter and the differences observed on the hardness measurements (fig. 2 and 3).

The correlation is explained directly by the physical phenomenon of the hysteresis: if the indenter do not recover completely his deformation after the removal of the compression force, the residual deformation (hysteresis, Δd) is "measured" by the hardness machines like deformation of the material under test, so it is directly included in the measured hardness.

$$\Delta H / HRC = \frac{\Delta d / \mu m}{2} \quad (2)$$

Removing this effect from the hardness calculation, as is possible to see in the fig. 2 and 3, it is possible to justify about half of the discrepancies between the indenters under test.

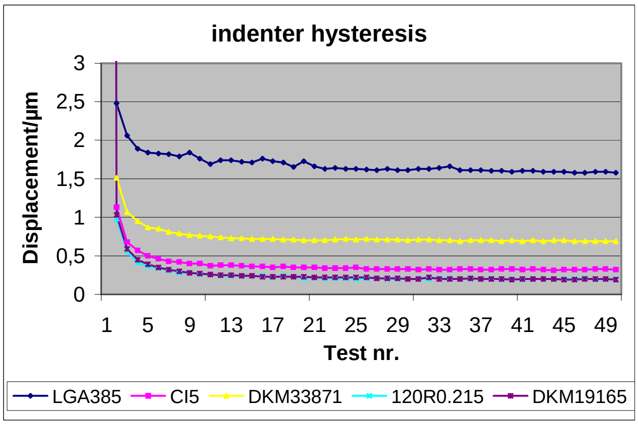

Fig. 1. Performance test of the indenters: evaluation of the indenter hysteresis calculated as difference between the displacement measured during the loading and unloading at the preload level.

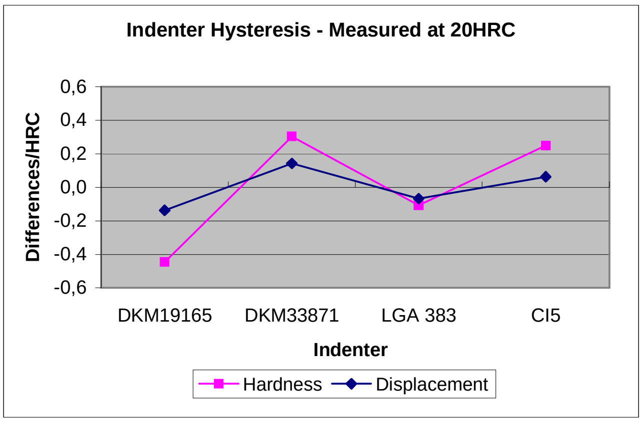

Fig. 2. Hysteresis calculated (and converted in hardness) using the 20HRC block compared with differences on hardness measurements (corrected for the geometry of the indenters).

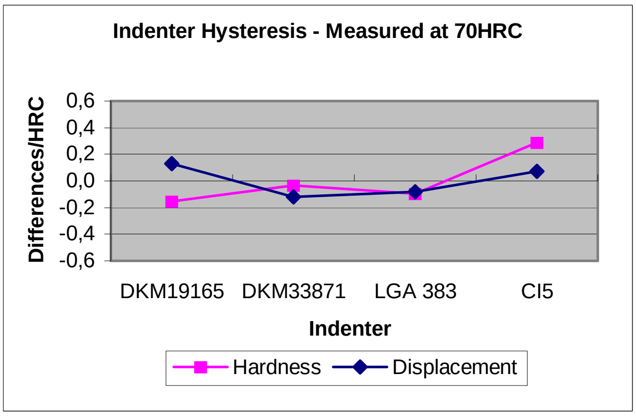

Fig. 2. Hysteresis calculated (and converted in hardness) using the 70HRC block compared with differences on hardness measurements (corrected for the geometry of the indenters).

3.2. Proposed procedure

As consequence of the first encouraging results, an experimental procedure has been studied to qualify the performance of Rockwell indenters. The proposed procedure has been tested with two different indenters on three different hardness levels (low, medium and high HRC).

As first step, the number of tests necessary to extract the information useful for the analysis has been determined. Analyzing a set of sixty measurements on the same indentation (fig. 4a) we can observe that the results, after sixty indentations are stable. Moreover, it has been noted that interpolating from the 15th to the 30th experimental result with a logarithmic curve (fig. 4b), the predicted 60th result calculated like extrapolation of this fitting curve coincides with the experimental one within 0,02 HRC.

This way to operate allows to reduce the number of tests to thirty, having the possibility to predict the result after other thirty tests with an accuracy of 0,02 HRC that is reasonable with this kind of analysis. Several tests were made to evaluate the reproducibility that was found of 0,01 HRC.

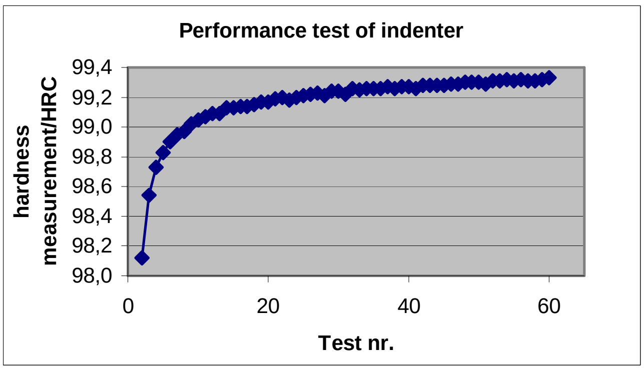

Fig. 4a. determination of number of tests necessary to extract the information useful for the analysis: results of hardness measurements during sixty consecutive tests.

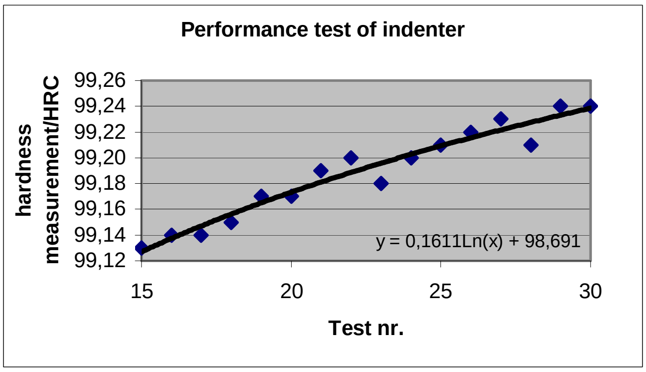

Fig. 4b. determination of number of tests necessary to extract the information useful for the analysis: interpolation from the 15th to the 30th experimental result with a logarithmic curve.

The second step was the determination of the rigidity of the INRiM primary hardness machine. A big tungsten carbide ball (25 mm diameter) has been used instead of the diamond indenter for similar tests performed at 25 HRC, 45 HRC and 65 HRC. Results are shown in fig. 5.

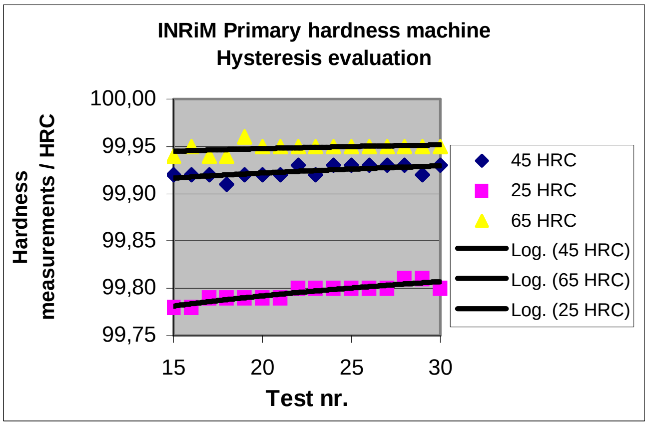

Fig. 5. Determination of INRiM primary hardness machine hysteresis.

Following the same analysis described before (logarithmic interpolation), the predicted values at the 60th test have been calculated for these three hardness levels. Observing that increasing the hardness value the measured hysteresis decreases, the expected result at 100 HRC level (after theoretical 60 indentations) has been calculated interpolating the relation between hardness-level and calculated hysteresis with a simple parabola (second degree polynomial curve). The result shows a residual of -0,0185 HRC from the theoretical value of 100 HRC. Considering the accuracy of the method of about 0,02 HRC, we can conclude that the hysteresis of the INRiM primary machine is negligible and it can be assumed as zero HRC.

The last step was the evaluation of the hysteresis of the indenters in comparison with differences in hardness measurements. Two indenters have been chosen: one is the reference indenter recognized at the national level (DKM33871), and the other, supplied from another producer (LGA683), is a good indenter from the geometrical point of view (it fulfill ISO 6508-3 specifications).

Le prime prove saranno dedicate per misurare lo stesso HRC dei blocchetti di durezza alto (livello basso, medio e) con i due penetratori differenti per calcolare le differenze nella misura di durezza. Le differenze sono state corretto dovuto le caratteristiche geometriche dei penetratori (angolo e raggio). I risultati sono segnalati in tabella 1. Una seguente serie di prove con la procedura proposta (trenta prove sulla stessa rientranza, l'interpolazione logaritmica fra i quindicesimi e trentesimi valori ed estrapolazione al sessantesimo valore) è stata effettuata sui tre blocchetti differenti di durezza con i due penetratori. I risultati delle prove sono indicati nella figura 6.

Table 1. Hardness measurements of two indenters (corrected for the geometry).

Indenter	Low/HRC	Medium/HRC	High/HRC
DKM33871	24,86	45,94	64,26
LGA683	24,91	46,08	64,37
Differences	*+0,05*	*+0,14*	*+0,11*

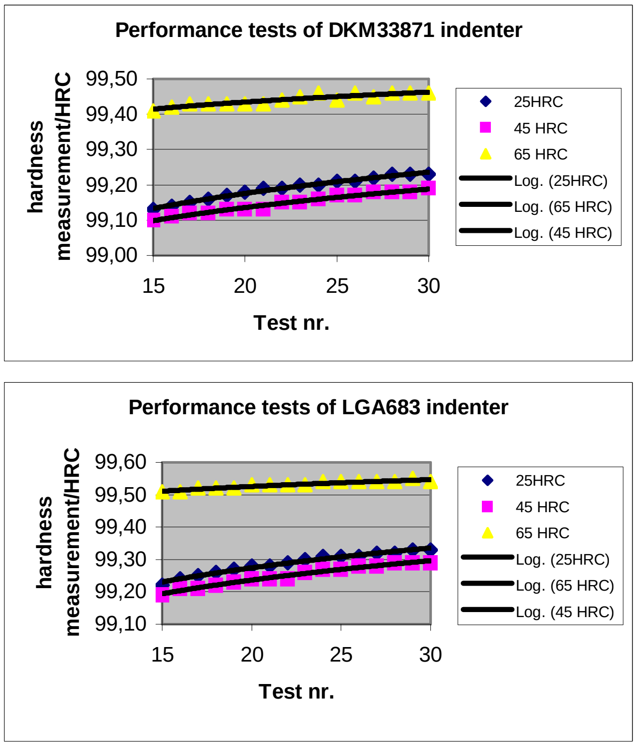

Fig. 6. Performance tests. Results of DKM33871 and LGA683 indenters at three different hardness levels (low, medium and high HRC).

From these results the six logarithmic equations that interpolate experimental results are the following:

$$Y_{DKM33871/25HRC} = 0,1479\ Ln(x) + 98,733$$

$$Y_{DKM33871/45HRC} = 0,1292\ Ln(x) + 98,749$$

$$Y_{DKM33871/65HRC} = 0,0689\ Ln(x) + 99,228$$

$$Y_{LGA683/25HRC} = 0,1517\ Ln(x) + 98,820$$

$$Y_{LGA683/45HRC} = 0,1476\ Ln(x) + 98,794$$

$$Y_{LGA683/65HRC} = 0,0518\ Ln(x) + 99,370$$

Differences evaluated through the interpolation with a logarithmic curve followed by the extrapolation to the 60th expected values are reported in table 2.

Table 2. Hysteresis tests of two indenters. Results of the predicted values to the 60th test and their differences.

Indenter	Predicted value to the 60th test		
	Low/HRC	Medium/HRC	High/HRC
DKM33871	99,34	99,28	99,51
LGA683	99,44	99,40	99,58
Differences	*+0,10*	*+0,12*	*+0,07*

From this analysis is clearly demonstrated that differences in hardness measurement performed by indenters (corrected for the geometry) are due to different hysteresis of indenters and that the method used to measure this hysteresis is appropriate. If we apply the calculated correction due to the hysteresis, the differences between the indenters are reduced to –0,05 HRC at low, +0,02 HRC at medium and +0,04 HRC at high hardness level (fig. 7). Considering the accuracy of the method of about 0,02 HRC, we can be very satisfied of the result.

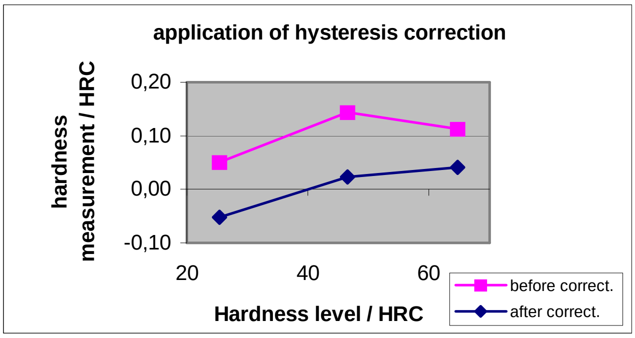

Fig. 7. Residual differences of the indenters before and after hysteresis correction (corrected for the geometry)

Another very important and interesting point to underline is the big difference obtained with these performance tests when a big ball or diamond indenters are used. In fact, when a big tungsten carbide ball (25 mm diameter) is used, a residual of -0,02 HRC of deformation is observed (with an accuracy of 0,02 HRC) at the theoretical level of 100 HRC. Analyzing the results of indenters in the same way made with the results of the tungsten carbide ball, at the same theoretical hardness level of 100 HRC, indenters shown -0,44 HRC and -0,38 HRC respectively. It is clear that about 0,4 HRC point less than the theoretical value (zero HRC) is measured by each indenter. This result is justified by the hysteresis of the indenters because other factors like the friction between indenter and material under test are probably eliminated with this kind of elaboration of results (extrapolation to the theoretical 100 HRC hardness level that means no penetration).

3. CONCLUSION

A method to characterize the performance of Rockwell diamond indenters has been proposed. The residuals after the correction calculated with this method are inside ±0,05 HRC that is very low compared with the normal uncertainty declared by the NMIs (between 0,15 HRC and 0,3 HRC). Results are also very interesting compared to residual after geometrical correction obtained in the international comparisons (within ±0,3 HRC) [3].

The obtained results encourage a deep investigation of this effect not only on the INRiM primary machine but also on other primary machines.

Under the CCM-WGH of the CIPM, a pilot study on this matter has been proposed recently. With a circulation of three HRC blocks (at different hardness levels) and two common indenters among the NMIs, it will be possible to investigate better the method for its validation at international level.

The average measure of about –0,4HRC less than the theoretical 100 HRC value is very big compared to the normal declared uncertainty by the NMIs. If it will be confirmed, it demonstrate that all the Rockwell measurements in the world are affected by a systematic error of about –0,4 HRC that it is not possible to detect during international comparisons.

Since this systematic error is probably of the same amount also in the industrial measurements, its evaluation is not more than a theoretical exercise. Being hardness a conventional quantity, if this error is really systematic, no problem occur for the definition and during the dissemination of this quantity. However, the authors denote that this is the first time that this error is evidenced with its estimation.

The proposed method will be suitable for the characterization of the non-geometric effects of the indenters and it could be used for selecting metrological indenters or to calculate possible corrections in hardness measurements.

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