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COMPARISON BETWEEN CONVENTIONAL ROCKWELL HARDNESS TESTING AND INSTRUMENTED INDENTATION TESTING

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Abstract – With base in the precepts and technical procedures of ISO 6508-1 standard [1] and ISO/FDIS 14577-1 standard draft [2], Rockwell hardness testing and instrumented indentation testing (*IIT*) were carried out using a universal testing machine, through adaptation of a system developed for these ends [3]. The results pointed out a good relation between the two hardness tests, taking into account that *IIT* can provide other materials parameters besides being the simplest method, not requiring any preliminary force or operator influence. Nevertheless, it was observed the necessity of the improvement of the used system, regarding the monitoring of zero-point.

Keywords: Instrumented Indentation Testing

1. INTRODUCTION

In order to analyse the attendance and the contributions of the new metallic materials test for hardness and other parameters in macro range (2 N <F < 30 000 N), it was developed a system taking in advance a universal testing machine and its software to do the instrumented indentation testing (*IIT*) and the conventional Rockwell C hardness testing (*HRC*), in spite of the system resolution. Before the *IIT* performs a *HRC* test was carry out into a standard block using a certified indenter, to check the system developed by indirect verification, taking into account the procedure provided in the ISO 6508-1 standard [1]. After that the system was performed following the procedure of ISO/FDIS 14577-1 [2] standard draft. Force (F) as well as displacement/indentation depth (h) control were used in this test, besides the Conical and Vickers indenters. A dwell time was used in accordance to the one established in *HRC* standard.

This work had two different objectives, first it was to verify the quality of the system developed with based on the conventional Rockwell C scale, by means of the whole test cycle simulation. The second objective was to verify the system regarding the instrumented indentation testing in the macro range and its comparisons with *HRC* test method.

2. METHOD AND PROCEDURE

The instrumented indentation testing method turns on the continuous monitoring of the force and the indentation depth during the whole dwell time, providing not only application but also removal force curves. Residual indentation measurements are not required in this method, so that it eliminates the operator influence. The main parameter given through this test is the Martens Hardness (*HM*) results, that is obtained by the calculation of the test force (F) and the superficial area of contact ($A_s(h)$), considering the indentation depth and the indenter geometry (in this case a *Vickers* and a *Conical* indenters), see (1), (2) and (3). In this work, the *HM* values were calculated for maximum test force (F_{max}). Besides the determination of *HM*, this method allows the determination of another materials parameters, like indentation hardness (H_{IT}), indentation modulus (E_{IT}), indentation creep (C_{IT}), indentation relaxation (R_{IT}) and plastic and elastic indentation work (W_{plast}, W_{elast}).

$$HM = \frac{F}{A_s(h)} \tag{1}$$

where $A_s(h)$ for *Vickers* indenter is

$$A_s(h) = 26{,}43 \times h^2 \tag{2}$$

and for *Conical* indenter is

$$A_s(h) = 10{,}88 \times h^2 \tag{3}$$

In a near future, it will be a powerful document for the mechanical properties users, because it will allow the determination of the these parameters, quickly and with great versatility, comparing with traditional hardness and tension tests.

The system used, in this work, was a universal testing machine operating in compression mode, carring out a force transducer of 9806,65 N (1000 kgf) with 100 % of full scale. To monitor the test displacement a Linear Variable Differential Transducer (LVDT) was used with 10 mm of stroke.

Certified indenters (Conical and Vickers) were used to carry out *HRC* tests and *IIT* with force and displacement control. The tests were made using three Rockwell C hardness standard blocks with 29,1 HRC, 38,9 HRC and

65,0 HRC. The 65,0 HRC block was used only for *HRC* test and *IIT* (force control and Conical indenter).

The rate used for *HRC* test was 196 N/s (20 kgf/s) during the application and removal of the additional test force, with 5 s in additional test force. The whole test cycle was 19 s plus 10 s for final indentation depth measurement. To *IIT* with force control a rate of 98 N/s (10 kgf/s) was used as during the application as during the removal test force. The whole cycle was 30 s, without any time of maintenance of F_{max} = 1471 N (150 kgf). The rate used for *IIT* with displacement control was 0,01 mm/s during the application and the removal test force, also without any time of maintenance of F_{max}. In this case, the full cycle depended on the materials characteristics for each block, i.e., the bigger the hardness value the smaller the cycle time.

3. RESULTS AND DISCUSSIONS

3.1. Conventional HRC test

In order to analyse the system developed, *HRC* test was performed on the standard blocks using a universal testing machine. Table I shows the reference values of three Rockwell C standard blocks and the results obtained in the conventional testing into these blocks. The mean value and the standard deviation results, obtained for 10 measures in each block are also presented showing the compatibility of results between the *HRC* reference value and those made by the tests.

TABLE I. Rockwell C reference values and test results.

HRC reference values	Results (*HRC*)	
	Mean value	Standard deviation
29,1	29,0	0,5
38,9	39,0	0,2
65,0	65,0	0,5

As an example, Fig. 1 shows the curves Fxt and hxt obtained in the conventional Rockwell C testing. It is possible to observe in this graphic, first the repeatability of the test force cycle applied by the machine and second the differences between the permanent indentation depths and its test cycle that is used to provide the *HRC* results.

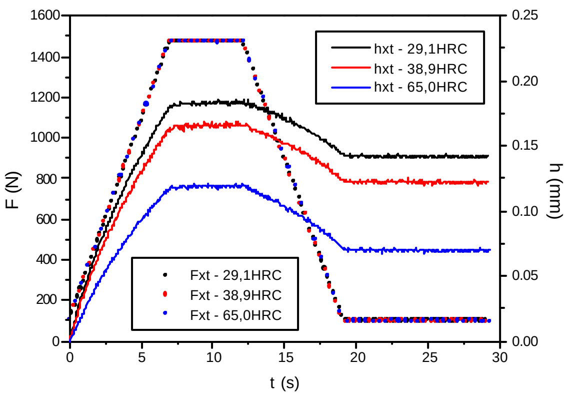

Fig. 1. F x t and h x t for *HRC* test.

Fig. 2 shows the curves Fxh for the conventional *HRC* test. The preliminary test force 98 N (10 kgf) is noted in the beginning and in the end curves.

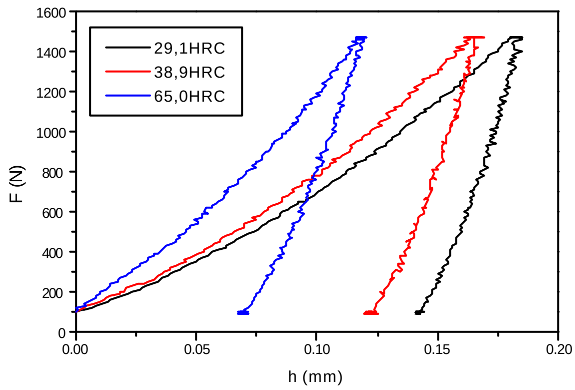

Fig. 2. F x h for *HRC* test.

3.2. Instrumented indentation test

IIT were performed with a diamond Conical indenter, using a dwell time established in *HRC* standard into three *HRC* standard blocks. Fig. 3 shows these curves obtained by force control. The similarity between these curves with those from Fig. 2 can observed, ignoring the preliminary test force.

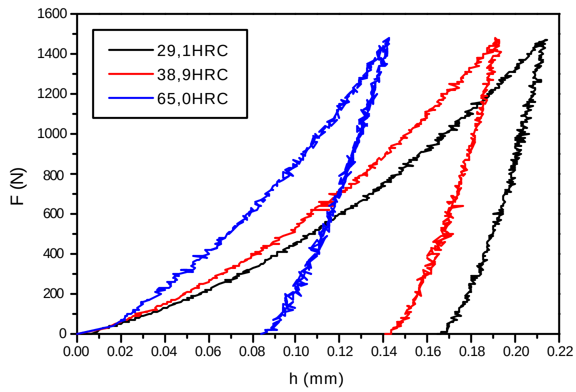

Fig. 3. F x h for *IIT* with Conical indenter by force controlled.

3.3. HRC test and IIT comparison

With the objective of comparing the *HRC* test and *IIT*, hardness standard blocks were used for this end. This item was divided in the test method for *HRC* and *HM*, and the hardness values comparison.

3.3.1 Test Method

Figs. 4, 5 and 6, provide the comparisons of two hardness methods of measurements, made into 38,9 *HRC* standard block, showing the slopes of Fxt, hxt and Fxh for the *HRC* test and *IIT* (force control and Conical indenter). It can be seen in Fig. 4 the dwell time and force rate differences. However, for both tests the dwell time used was in accordance with the procedure estabilished in the

ISO 6508-1 standard [1]. This figure also shows, in the very beginning cycle, the difficulties met by the system used regarding the zero-point control for *IIT*.

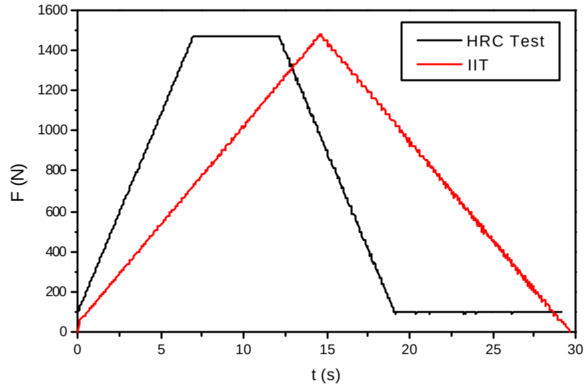

Fig. 4. F x t for *IIT* and *HRC* test.

Fig. 5 shows that the displacement rate is not constant in the test cycle, besides the constant force rate, see Fig. 4. In the Figs. 5 and 6 the smaller indentation depth for *HRC* test compared with *IIT* can be verified, mainly due to the preliminary test force in the *HRC* test.

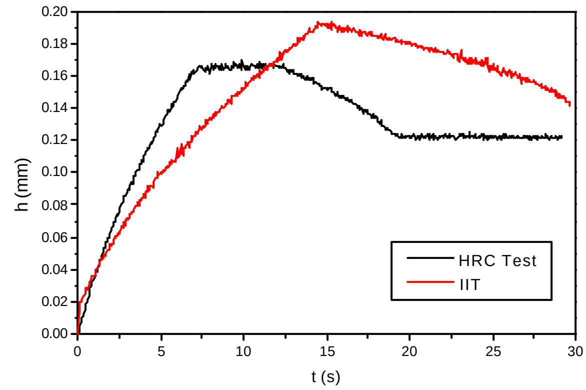

Fig. 5. h x t for *IIT* and *HRC* test.

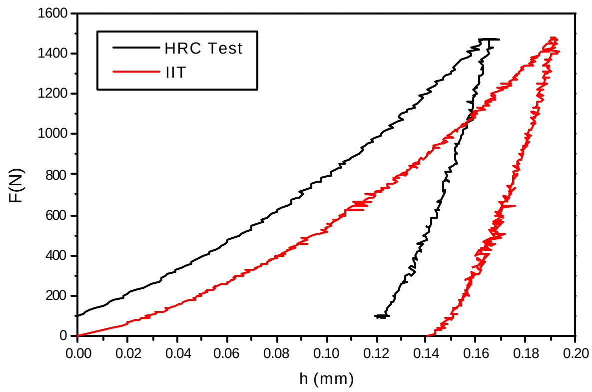

Fig. 6. F x h for IIT and HRC test.

3.3.2 HRC versus HM

Table II shows the results of *HM* test carried out by force controlled using either Conical or either Vickers indenters and Table III shows the results for displacement control.

It can observed in these tables that the values were in agreement in both scales (29,1 and 38,9 HRC). The major standard deviation (SD) during the force control, occured probably due to the zero-point definition. Comparing the mode controls the dispersion between the *HM* values was around 5,0 % more to displacement control, and this can be explained by the zero-point definition and the difficulties to maintain the same force rate for both mode controls.

TABLE II. *HRC* reference values and *HM* test with force controlled.

HRC reference values	*HM* results (N/mm2)			
	Conical indenter		Vickers indenter	
	Mean Value	SD (% of mean value)	Mean Value	SD (% of mean value)
29,1	2838,80	160,14 (5,64%)	1847,12	101,75 (5,51%)
38,9	3633,21	233,78 (6,43%)	2103,67	134,13 (6,38%)

TABLE III. *HRC* reference values and *HM* test with displacement controlled.

HRC reference values	*HM* results (N/mm2)			
	Conical indenter		Vickers indenter	
	Mean Value	SD (% of mean value)	Mean Value	SD (% of mean value)
29,1	3052,22	86,11 (2,82%)	1962,71	46,71 (2,38%)
38,9	3809,26	54,92 (1,44%)	2298,01	86,53 (3,77%)

Fig. 7 shows the curves F x h obtained for *IIT* using as Conical as Vickers indenter by displacement control into 38,9 HRC standard block. Analysing the whole cycle of both tests, it can be observed that during the force application the indentation depth (h) with Vickers indenter was smaller than Conical indenter. Nevertheless, the Martens hardness results using a Vickers indenter was smaller, due to the largest superficial area of contact ($A_s(h)$), taking into account the same force test. It can be seen in Tables III and IV.

TABLE IV. Conical and Vickers indenters, the corresponding indentation depth, the superficial area and it HM values calculated for F_{max} into 38,9 HRC standard block.

Indenters	h (mm)	$A_s(h)$ (mm^2)	HM (N/mm^2)
Conical	0,188	0,385	3809,26
Vickers	0,156	0,641	2298,01

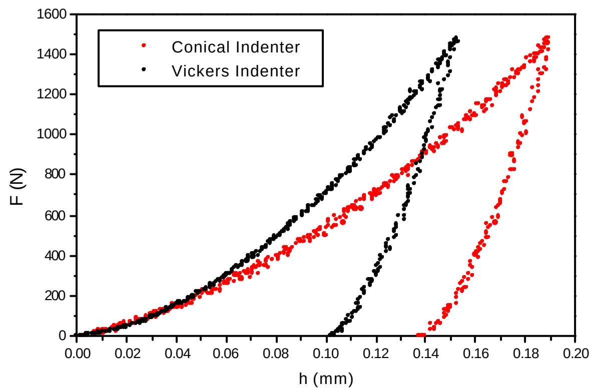

Fig. 7. F x h for *IIT* with Conical and *Vickers* indenters by displacement controlled.

The last analysis was made considering Table V that shows the Martens Hardness (*HM*) results obtained for *IIT* and the *HRC* reference values. The *HM* values were calculated taking into account the force control and diamond Conical indenter, in accordance with (3). Fig. 8 shows the data for three standard blocks from Table V showing a linear fit slope between *HRC* and *HM* values.

TABLE V. *HRC* reference values and *HM* test results with Conical indenter by force controlled.

HRC reference values	*HM* results (N/mm^2)	
	Mean value	Standard deviation
29,1	2838,80	160,14
38,9	3633,21	233,78
65,0	6616,63	493,83

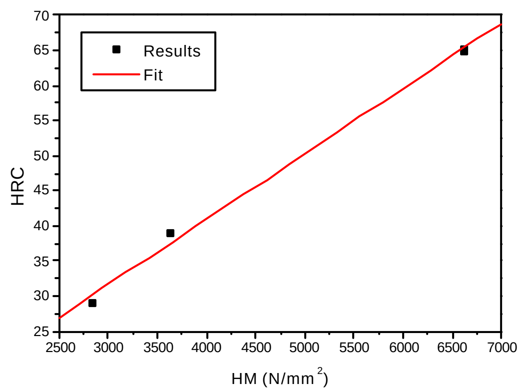

Fig. 8. *HRC* x *HM*.

4. CONCLUSION

In regards to the system developed, the results shown satisfactory, mainly in respect to the measures of conventional Rockwell C hardness scales. The measures of instrumented indentation as well as using force as displacement control showed an agreement between them for both indenters. Although for Conical and Vickers indenters the results had differences between them due to the stress field generated by the indenter geometries. Besides that we should consider the difficulties of zero-point definition causing dispersed results.

In regards the comparison between *HRC* and *IIT* test method, the results shows that the use of the new test method provided hardness values that could be co-related with the conventional Rockwell C test. This preliminary study showed the linear fit agreement between them.

In order the get better results, it is necessary for one hand to improve the system, increasing the LDVT and the force transducer resolutions, and in the other hand, increasing the test numbers for each condition.

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