Analysis of possible distortions in Rockwell Hardness Values Due to changes in current ISO standards compared to obsolete ones

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Abstract. This work analyzes the possible changes in the determination of the Rockwell Hardness value by comparing the current Rockwell Hardness standard, ISO 6508-1:2016, in relation to the similar standard that expired, ISO 6508-1:2005. They are described in detail item by item, note by note and annex by annex, comparing the two standards. Both the number of pages and changes in technical requirements are compared - technical and scientific explanations are offered when relevant, since these technical-scientific issues apparently were not considered in the ISO sessions that defined the normative requirements of the standard in force.

1. Introduction

The mechanical property Hardness is defined as resistance to permanent plastic deformation, energy absorbed during impact, scratching or indentation of a harder material into a softer one. It is also the best-known and most widespread mechanical property given its essential importance both in the production and in-service performance of items produced in practically all industrial segments - especially in the metal-mechanic, steel, metallurgical, automotive, aerospace and machinery sectors and tools [1, 2].

The Rockwell hardness measurement is the most used in the production line in order to guarantee the quality of several items produced, through sampling in the middle of production processes and in the tests of receiving materials. Its use is related to the fact that to determine the Rockwell hardness of a material, apart the use of suitable constants, it is only necessary to know the depth of penetration and the force used during the procedure [3, 4].

Hardness measurement is one of the most evaluated in research and development (R&D) activities carried out in universities, R&D centers and industries. The hardness results are also used during the development of new materials, products, processes, methods and innovative technologies. Amongst the existing indentation hardness scales, the most used are Brinell, Vickers and Rockwell [3].

The quantity Hardness is also the target of standardization actions through international standards issued by ISO, Brazilian (ABNT NBR) and regional (Mercosul/NM) standards, other national standards (ASTM, etc.), as well as through the Rockwell hardness guideline of EURAMET [5]. EURAMET is an organization that brings together all the INMs (National Metrology Institutes) in Europe, which

establishes the recommended practices for obtaining measurement uncertainty in many quantities´ tests. Table 1 shows the main characteristics of current ISO 6508-1:2016 [6] and former ISO 6508-1:2005 [7] Rockwell hardness standards.

Table 1 – Basic characteristics of the ISO 6508-1:2005 [7] and ISO 6508-1:2016 [6] standards

Characteristics	6508-1:2005	6508-1:2016
No. of pages	35	39
No. of regulatory annexes	4	6
No. of informative attachments	3	2
No. of normative references	8	12

Table 1 shows some differences related to the characteristics of the ISO 6508-1:2005 and ISO 6508-1:2016 standards. These changes were analyzed for their negative and positive impacts in relation to the determination of the Rockwell hardness magnitude [6-7] and are the objective of this work.

2. Materials e Methods

The methodology of this work will be based on the detailed analysis of bibliographical references in the area of Rockwell hardness to provide comparability between ISO 6508-1:2005 and ISO 6508-1:2016 standards [8].

3. Results and discussion

3.1 General aspects of the comparison between ISO 6508-1:2005 and ISO 6508-1:2016

As the first step, the characteristics and differences between the ISO 6508-1:2005 and ISO 6508-1:2016 standards were compared. In an initial analysis, one can recognize that in the current version of ISO 6508-1:2016 [6]] there is an increase of 4 pages. In addition, two more annexes were incorporated, namely annex H – Working Group on Hardness and annex I – Traceability of Rockwell hardness measurement.

Annex H of the ISO 6508-1:2016 standard addresses the performance of the Working Group on Hardness of the International Committee for Weights and Measures (CIPM). In addition, it highlights the importance of hardness, as it is one of the most widespread mechanical properties in the world.

Annex I, which deals with the traceability of Rockwell hardness measurement, brings in addition to the definition of the concept of traceability, its importance for the existence of hardness measurements that are metrologically reliable. Traceability refers to an uninterrupted chain of calibrations of the magnitudes involved in determining the hardness magnitude. This chain of calibrations guarantees the validity of hardness results obtained in laboratories, factories and universities.

The comparison between both the published ISO 6508-1:2016 technical standard [6] and the withdrawn ISO 6508-1:2005 one [7] is shown in the following sub-items.

3.2 Scope of the current standard'

The current standard makes the insertion of stationary and portable hardness testing machines more comprehensively than the old version´s. In addition, note 2 of the obsolete standard was rewritten and places it as an item within the scope of the standard when dealing with hardness tests of specific

materials for ISO 3738-1:1982 standards (Hardmetals – Rockwell hardness test (scale A) – Part 1: Test method) [11] and ISO 4498:2010 (Sintered metal materials, excluding hardmetals – Determination of apparent hardness and microhardness) [12].

The scope of the current standard only has a single note, however this note mentions what was previously in the body of the old standard. Furthermore, in the current standard there is no warning that there is the possibility of different results for the hardness value when using the spherical steel indenter compared to the spherical indenter of WC (tungsten carbide).

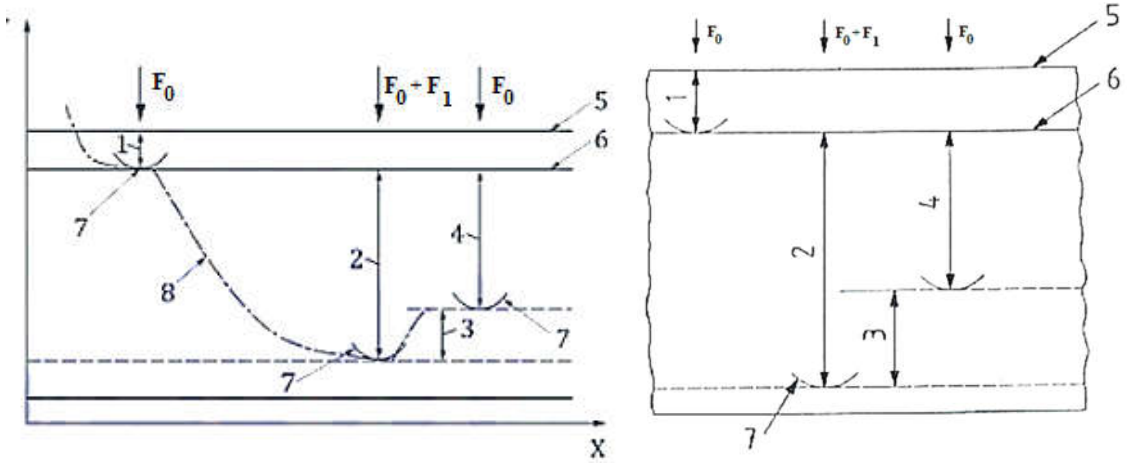
3.3 Principle of the Rockwell hardness method

The principle of hardness, which is directly related to the definition of the hardness quantity, underwent some nomenclature changes, as can be seen in Table 2.

Table 2 – Changes in terminology for the Rockwell hardness realization principle

#	ISO 6508-1:2005	ISO 6508-1:2016
1	Two force levels	Two force steps
2	Initial test force	Preliminary force
3	Additional test force	Additional force
4	Permanent depth, *h*	Difference between final and initial depth, *h*

There are significant changes in terminology, among them, the change in the term related to the length measurement used to determine the Rockwell hardness value, that is, h. The obsolete version of the standard called this length as “permanent depth” and the current version of the standard defines it as “the difference between the final and initial depth”. The definition of the current standard is physically more suitable, as the measured depth is not in fact a permanent depth, but a permanent depth maintained by the application of the preliminary force during the performance of the Rockwell hardness test. Figure 1A below shows that there has been an update to the current standard [6] in order to make understanding the principle of the Rockwell hardness method easier. Figure 1B shows the implementation of the Rockwell method according to ISO 6508-1:2005 [7].



A **B**

Figure 1 – Rockwell principle diagram: A – in force [6] and B – obsolete [7]

Where:
1 – Indentation depth due to preliminary force, F_0;
2 – Depth of penetration due to additional test force, F_1;
3 – Elastic recovery right after removing the additional test force, F_1;
4 – Permanent indentation depth, h;
5 – Sample surface;
6 – Reference plane for measurement;
7 – Indenter Position;
8 – Indentation depth x time.

The difference between Figures 1A and 1B of the two standards is mainly in the indication of the position of the indenter at different points during the performance of the Rockwell hardness method. In addition, item 8 is a novelty of the current standard in which the behavior of the penetration depth in relation to the time of the Rockwell hardness test is evidenced.

3.4 Symbol, abbreviated terms and designations

Table 1 present in the obsolete standard and entitled "Rockwell Scales" differs in its presentation from the current standard. The current standard divided Table 1 of the obsolete standard into two Tables, Table 1 deals with Regular Rockwell Scales and Table 2 with Superficial Rockwell Scales. Furthermore, there is a translation error in the denomination in the seventh column of Tables 1 and 2. In this item it is written "Constant Complete Range N" and the correct one should be "Constant of Complete Range N". The first one is related to the removal of the additional force column (F_1) in the current standard, which simplified the presentation of Table 4.

3.5 Testing Machine

The main changes in this item in the current standard would be are listed below.

- There is a flexibility for the hardness testing machine in relation to the realization of the scales. Thus, in the new version of the standard, the hardness testing machine can perform only some hardness scales, whereas in the obsolete standard it was required to perform all hardness scales.
- In the current version there are details of the information regarding the indenter, which can be diamond spheroconical. Furthermore, there is the possibility of using the indenter in three situations: the first to carry out regular scales, the second to carry out only superficial scales and the third to carry out superficial and regular scales of Rockwell hardness.
- In the case of the spherical WC indenter, an explanatory note was inserted in the current standard detailing various information regarding the use of this type of indenter.

3.6 Test piece

In this item there were no major changes in relation to the current standard, there was only a simplification for the determination of Rockwell hardness in curved surfaces, making reference to another item of the standard.

3.7 Procedure

The new version of the standard also mentions the discarding of two hardness measurements due to the need to seat the block and the indenter in the hardness testing machine. In this sense, it is considered

that such measurements, when discarded, do not interfere with the result, given that these measurements do not represent the hardness of the material being tested.

The hardness test can only be carried out with the indenter used in the indirect verification of the machine, that is, it is the methodology that certifies the performance of the machine by comparing its hardness results with the hardness value of the certified reference block.

There has been a considerable change from the total preliminary force time in the current standard. Previously, a total time of the preliminary force of up to 3 s was allowed, currently a total time of duration of the preliminary force of up to 4 s is allowed, that is, this longer time may represent variations in the results of the hardness tests, since the accommodation of the deformations in the material can be more efficient, due to the extension of the time of application of the preliminary force.

In the obsolete version of the standard, the total time of the preliminary force was presented according to equation (1).

$$T_p = \frac{T_a}{2} + T_{pm} \leq 3\,s \qquad (1)$$

Where:
T_p – total time of preliminary force;
T_a – time of preliminary force application;
T_{pm} – duration of preliminary force.

Currently, the duration of the preliminary force is inserted into the text as follows: 3^{+1}_{-2} s. Where the preliminary force application interval is from 1 to 4 s. Regarding the preliminary force application time (T_a), the current standard states that it should be up to 2 s.

Regarding the application of the additional force, the current norm also presented significant changes. For surface hardness, the additional force application time cannot be less than 4 s. Previously, the standard mentioned an interval of 1 to 1.5 s for applying additional force during the Rockwell hardness test.

Regarding the reading of the permanent depth "*h*" there is also a change: the new version of the standard defines that the time to carry out this reading is from 1 to 5 s. Previously, there was no recommended time for the reading of "*h*" to be performed.

In the current standard there is a clear mention that "*h*" is a measure of the depth of the indenter guaranteed by the maintenance of the preliminary force. It is interesting to point out that in this measure of "*h*" there is a contribution of the elastic deformation of the material that, after the removal of the preliminary force, causes the indentation in the material to present a smaller depth than that registered in "*h*".

3.8 Uncertainty of the results

In the conceptual part and in the theoretical framework for the expression of measurement uncertainty, there were no changes.

3.9 Test report

There were no relevant changes. However, the technical translation of item "g" of the current standard could be improved. In the current standard, the item "g" was translated as "the actual duration of time of the total extended force used", which means "the actual extended duration used of the time of the current force" and it would be more appropriate to be rewritten in this way.

3.10 Conversions to other hardness scales or tensile strength values

The item dealing with conversion to other hardness scales or tensile strength values was not present in the obsolete version of the standard. In this case, the approach refers to the relationship between Rockwell hardness and Vickers and Brinell hardness. In addition, there is a relationship between Rockwell hardness and other mechanical properties of materials, such as tensile strength. This methodology can be better understood from the analysis of the ISO 18265:2013 standard (Metallic materials – Conversion of hardness values) [13].

3.11 Annex A (normative)

There were no changes to Annex A by comparing both standards [6, 7].

3.12 Annex B (normative)

There were no significant changes in relation to the X and Y axes of Figure B1 (Test with conical diamond indenter (scales A, C and D)) in the annex. The X axis, referring to Rockwell hardness, ranges from 10 to 95, expanding the range from 20 to 95 HRA [6], which was previously 20 to 85 HRA in the obsolete standard [7]. It also extended the Rockwell C hardness range from 10 to 70 HRC [6], which was previously 20 to 70 HRC [7]. The Y axis, which refers to the thickness of the specimen in millimeters, has an expanded range from 0.1 to 1.8 mm [6], while in the previous version the Y axis had a range from 0.2 to 1.6 mm [7].

In Figure B2 (Test with spherical indenter (scales B, E, F, G, H and K)) of this Annex there were also changes in the current standard. The X axis, referring to Rockwell hardness ranges from 10 to 100 now, expanding the range from 10 to 100 HRBW [6], which was previously 20 to 100 HRB in the obsolete standard [7]. The Y axis, which refers to the thickness of the specimen in millimeters, has the extended range from 0.75 to 3.6 mm [6], while in the previous version the Y-axis had the range from 0.75 to 3.3 mm [7].

In Figure B3 (Rockwell Surface Test (N and T scales)) of the current standard, the only change was the adding of a letter W to all superficial Rockwell T scales [6] that was not present before [7], which refers to the use of a spherical indenter made of tungsten carbide, also known as hardmetal.

3.13 Annex C (normative)

There were no changes to Annex C by comparing both standards [6,7].

3.14 Annex D (normative)

There were no changes to Annex D by comparing both standards [6,7].

3.15 Annex E (normative)

Annex E in the old standard [7] was for information purposes only whereas in the current version of the ISO 6508-1 standard it is normative [6]. Moreover, there is a detailing of the daily check procedure of the testing machine.

The concepts of bias and repeatability range were presented, as well as examples were included on how to assess whether the daily verification of a test machine was to be considered acceptable according to the criteria presented below in Table 3 [6].

Table 3 - Permissible bias and repeatability range for the Rockwell test machine

Rockwell Hardness Scale	Hardness Range of the Reference Block	Permissible Bias, b	Maximum Permissible Repeatability Range, r, of the Test Machine
A	20 to ≤ 75 HRA > 75 to ≤ 95 HRA	± 2 HRA ± 1.5 HRA	$0.02(100 - \bar{H})$ or 0.8 HRA
B	10 to ≤ 45 HRBW > 45 to ≤ 80 HRBW > 80 to ≤ 100 HRBW	± 4 HRBW ± 3 HRBW ± 2 HRBW	$0.04(130 - \bar{H})$ or 1.2 HRBW
C	10 to ≤ 70 HRC	± 1.5 HRC	$0.02(100 - \bar{H})$ or 0.8 HRC
D	40 to ≤ 70 HRD > 70 to ≤ 77 HRD	± 2 HRD ± 1.5 HRD	$0.02(100 - \bar{H})$ or 0.8 HRD
E	70 to ≤ 90 HRE > 90 to ≤ 100 HRE	± 2.5 HREW ± 2 HREW	$0.04(130 - \bar{H})$ or 1.2 HREW
F	60 to ≤ 90 HRFW > 90 to ≤ 100 HRFW	± 3 HRFW ± 2 HRFW	$0.04(130 - \bar{H})$ or 1.2 HRFW
G	30 to ≤ 50 HRGW > 50 to ≤ 75 HRGW > 75 to ≤ 94 HRGW	± 6 HRGW ± 4.5 HRGW ± 3 HRGW	$0.04(130 - \bar{H})$ or 1.2 HRGW
H	80 to ≤ 100 HRHW	± 2 HRHW	$0.04(130 - \bar{H})$ or 1.2 HRHW
K	40 to ≤ 60 HRKW > 60 to ≤ 80 HRKW > 80 to ≤ 100 HRKW	± 4 HRKW ± 3 HRKW ± 2 HRKW	$0.04(130 - \bar{H})$ or 1.2 HRKW
15N, 30N, 45N	all ranges	± 2 HRN	$0.04(100 - \bar{H})$ ou 1.2 HRN
15T, 30T, 45T	all ranges	± 3 HRTW	$0.06(100 - \bar{H})$ ou 2.4 HRTW

3.16 Annex F (normative)

Before, this Annex was only informative [7] and now, in the current version, Annex F, which deals with the inspection of diamond indenters, has become normative [6] where it can be seen that a defective indenter does not have a valid verification. And for this verification to be carried out properly, this annex refers to the requirements of the ISO 6508-2 standards [9, 10].

3.17 Annex G (informative)

Appendix G refers to the measurement uncertainty of hardness values. Figure G1 of the obsolete standard dealing with traceability [7] has been removed and re-inserted in Annex I of the current standard [6] dealing with traceability of Rockwell hardness measurements.

There were no significant changes in the measurement uncertainty approach methodology. In the current version [6] there is an example of a calculation involving five measurements of Rockwell C hardness, which makes Annex G more didactic in relation to the execution of the measurement uncertainty calculation methodology.

3.18 Annex H (informative)

This annex H in the published standard [6] was not present in the withdrawn version of the ISO 6508-1 standard [7]. This annex contains information about the Working Group on Hardness of the Consultative Committee on Mass and Related Quantities (CCM), which is part of the International Committee for Weights and Measures (CIPM). This working group does all the work of harmonizing international standards on hardness, among other quantities, having close liaison with ISO Technical Committee 164 to ensure the dissemination of hardness scales.

3.19 Annex I (informative)

Annex I, which deals with the traceability of Rockwell hardness measurement, was included in the current version of the standard. In this case, the definition of both metrological traceability and calibration chains that guarantee the validity and metrological reliability of the hardness measurement results are detailed.

3.20 Bibliography

In the current standard, there was an update and modifications of the references [6]. Four more references were added in relation to the previous version of the standard. These additional and up-to-date references can help users and professionals who work using Rockwell hardness quantity.

4. Conclusion

This work was able to demonstrate that there were significant changes in the methodology for the determination of Rockwell hardness by comparing the published (current) ISO 6508-1:2016 with the withdrawn (obsolete) ISO 6508-1:2005 mainly in relation to the possibility of increasing the duration of the preliminary force. The current version shows advances in relation to the visualization of the position of the indenter when performing the method. In addition, Annex E of the current version of the ISO 6508-1:2016 standard makes the daily verification of a Rockwell hardness testing machine mandatory and shows how to carry out this procedure. Thus, the published standard shows a clear emphasis on the metrological validity and reliability of the results obtained through the application of the Rockwell hardness method. Moreover, it is not unreasonable that the hardness values obtained under the particular conditions of the two cited standards, the current ISO 6508-1:2016 and the obsolete ISO 6508-1:2005, present discrepant hardness values in some degree. Future work will be conducted in order to quantitatively evaluate the influence of the changes introduced in the published ISO 6508-1:2016 standard on the Rockwell hardness values of various metallic materials´ types.

5. References

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