

ESTABLISHMENT OF A HARDNESS METROLOGICAL SYSTEM IN BRAZIL

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Abstract: In the present work, part of a large project, developed in partnership among INMETRO, ITUC/PUC-Rio and INT since 1995, to establish a national hardness metrological system in Brazil to Brinell, Vickers and Rockwell hardness scales, is presented, e.g. the development of reference blocks, for different ranges of Rockwell B and C hardness scales. These results and the installation of a hardness standardization machine and an indenter calibration system at INMETRO will fill the existing voids up in the Brazilian traceability chain in hardness metrology.

Keywords: hardness reference blocks, traceability, hardness metrological system.

1. INTRODUCTION

The present work, part of a large project, has been developed in partnership among INMETRO, ITUC/PUC-Rio and INT since 1995, and its main purpose was the establishment of a national metrological system with hardness scales, whose procedures and standards must have traceability to metrological institutes recognized worldwide.

One of the stages of this project aimed the development of reference blocks in Brazil, for some ranges of Brinell, Rockwell and Vickers hardness scales [1-4]. All the performed research work followed international standards ISO 6508, ASTM E 18 and EN 10109. The technology of this development was transferred to the MITUTOYO SUL AMERICANA at the end of 2002 in order to manufacture and commercialize the hardness reference blocks in Brazil and Latin America.

The main reasons for the manufacture of national reference blocks were the increase in demand by research institutes and national industries, estimated in 20,000 blocks/year and the high prices of the imported blocks in Brazil.

The second stage of the project has been the installation of both a hardness standardization machine (HSM) and an indenter calibration system at INMETRO, in order to establish a national hardness metrological system, guaranteeing the traceability of this quantity in Brazil. In

many parts of the cited project, there were a technical collaboration with the Italian NMI “INRIM – Istituto Nazionale di Ricerca Metrologica”, formerly “IMGC – Istituto di Metrologia Gustavo Colonnetti”, and, to some extent, in the hardness standard blocks part, the American NMI “NIST - National Institute of Standards and Technology”.

2. EXPERIMENTAL

Five hardness ranges were studied in this work: 60-80HRB, 85-100HRB, 20-30HRC, 35-55HRC and 60-70HRC. For each hardness range a different raw material (700 mm diameter cylindrical bar) was used: material A – low carbon steel (about 0.1 % C), material B – high carbon steel (about 0.7 % C), material C – high carbon steel (about 1 % C), material D - high carbon steel (0.9 % C), material E – non ferrous alloy (AA 6351 aluminum alloy).

The bars were cut and machined to attain the final dimensions of the blocks: 650 mm diameter and 12 mm thickness.

In order to reach not only the desired hardness ranges but also the uniformity requirements different heat treatments were performed with variable parameters such as austenitizing temperature, cooling rates, tempering times and temperatures. For each condition at least 3 samples were analyzed in order to evaluate the reproducibility of the process.

Rockwell hardness tests were performed afterwards along the whole surface of the blocks. These hardness measurements were performed in hardness testing machines belonging to the three Brazilian Institutes involved in the research. The non uniformity values were calculated according to EN 10109 standard [5].

The microstructural changes resulting from the different heat treatments were studied by means of optical and electronic microscopy, in order to establish a correlation between the non-uniformity of the hardness values and the microstructural aspects.

Besides, X-ray diffraction techniques were used to look for the presence of undesirable retained austenite.

3. RESULTS AND DISCUSSION

The obtained hardness and non uniformity results for each different studied condition are presented in table 1. Table 2 shows the maximum permissible values of non-uniformity according to EN 10109 standard [5].

The X-ray diffraction analysis did not show the presence of any retained austenite. This is an important result, since this undesirable metastable phase is harmful to the mechanical properties of the material.

Table 1. Hardness and non uniformity values for the studied hardness ranges along with the used materials and heat treatments.

Hardness Range	Material and Heat Treatment	Average Hardness Values	Non-uniformity (%)
20-50 HRB	A Annealing	39.8 HRB	4.0
20-50 HRB	E As received	57.8 HRB	1.9
60-80HRB	A Oil quenching	74.2 HRB	10.1
60-80HRB	A Normalization	63.2 HRB	2.2
85-100 HRB	B Quenching and tempering	103.4 HRB	0.9
85-100 HRB	B Normalization	92.2 HRB	1.3
20-30 HRC	B Quenching and tempering	26.5 HRC	0.8
35-55 HRC	B Quenching and tempering	37.0 HRC	0.5
60-70 HRC	B Quenching and tempering	59.4 HRC	2.5
60-70 HRC	C Quenching and tempering	59.3 HRC	1.18
60-70 HRC	D Quenching and tempering	63.7 HRC	0.63

Table 2. Maximum permissible values of non-uniformity according to EN 10109 standard [5].

Hardness Scale	Permissible Non-Uniformity (%)
HRB	3,0
HRC	1,5

Figures 1 to 9 present typical microstructures of the heat treated hardness standard blocks for each studied range.

The results of hardness and non-uniformity presented in table 1 show that for the 20-50HRB hardness range the heat treatments for both material A and material E do not yield

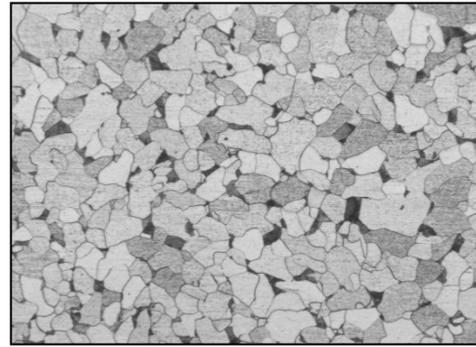


Figure 1. Typical microstructure of a material A 20-50 HRB hardness block in the annealed condition. Presence of ferrite and colonies of pearlite. 130 X.

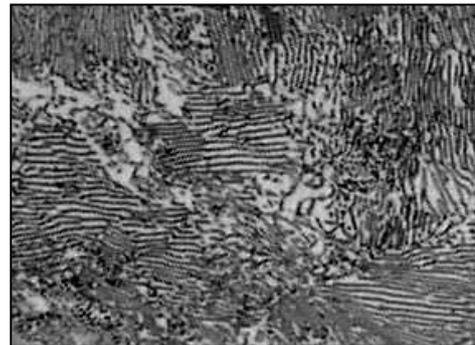


Figure 2. Typical microstructure of a material E 20-50 HRB hardness block in the as received condition. 100 X.

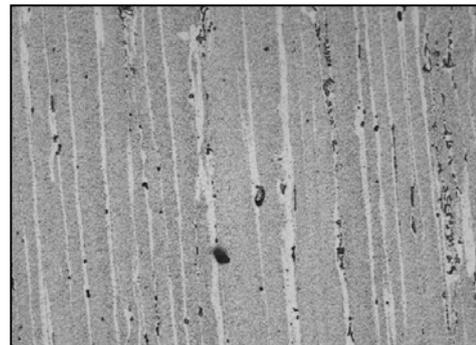


Figure 3. Typical microstructure of a material A 60-80 HRB hardness block in the oil quenched condition. Presence of ferrite, pearlite and bainite. 190 X.

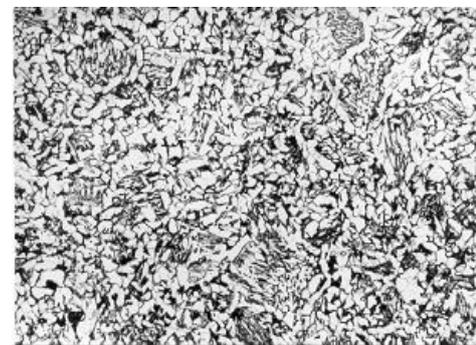


Figure 4. Typical microstructure of a material A 60-80 HRB hardness block in the normalized condition. Presence of ferrite and colonies of pearlite. 130 X.

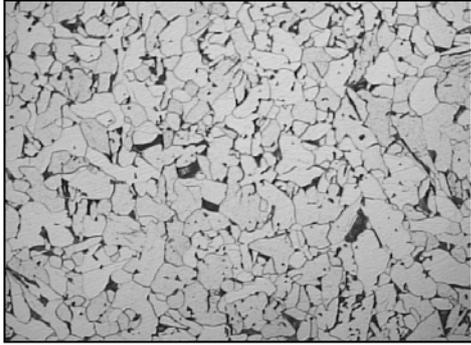


Figure 5. Typical microstructure of a material B 85-100 HRB hardness block in the normalized condition. Presence of a large volumetric fraction of pearlite. 380 X.

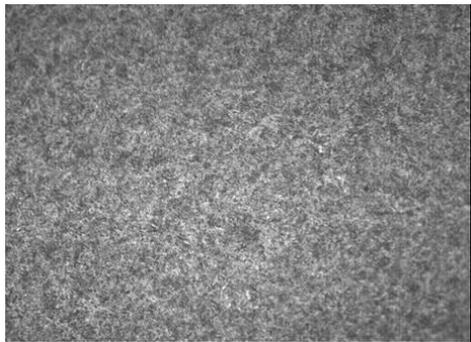


Figure 6. Typical microstructure of a material B 20-30 HRC hardness block in the quenched and tempered condition. Prevalence of tempered martensite. 190 X.

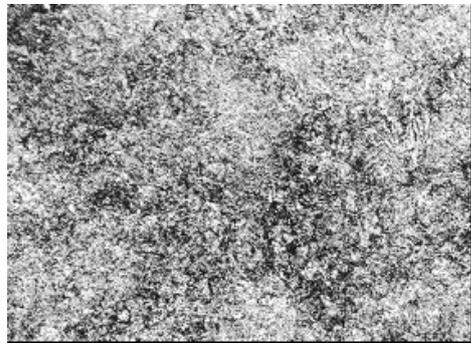


Figure 7. Typical microstructure of a material B 35-55 HRC hardness block in the quenched and tempered condition. Prevalence of tempered martensite. 190 X.

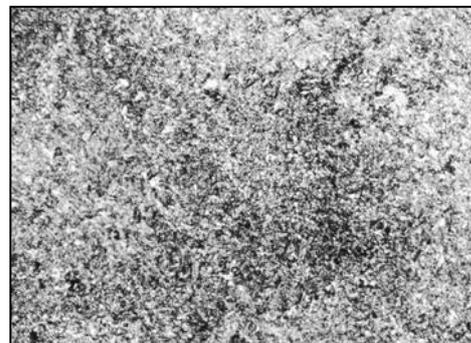


Figure 8. Typical microstructure of a material C 60-70 HRC hardness block in the quenched and tempered condition. Prevalence of tempered martensite. 310 X.

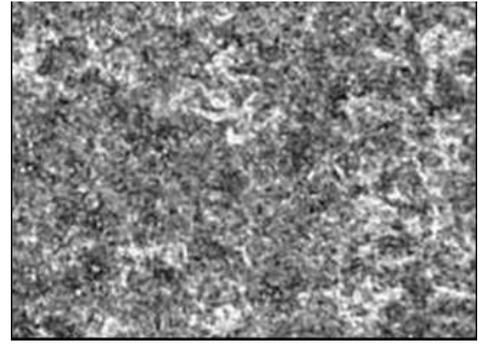


Figure 9. Typical microstructure of a material D 60-70 HRC hardness block in the quenched and tempered condition. Prevalence of tempered martensite. 310 X.

satisfactory results. Although material A in the annealed condition presents a hardness value within the range specified by the standards, its non-uniformity is higher than than the maximum value specified by the same standards.

This fact is associated to the type of microstructure which stems from the annealing treatment, which originated high grain size heterogeneity (fig.1).

The non-ferrous alloy (material E) in the as received condition shows hardness values above the upper range limit, however, its non-uniformity is satisfactory. It is expected to reach hardness levels compatible with the aimed range through overaging heat treatments [6].

The results obtained for 60-80 HRB (table 1) indicate that the oil quenched material A produced non-uniformity values above the upper limit specified by the standards. These results can be related to a high degree of microstructural heterogeneity observed in the samples after heat treatment (fig.3). On the other hand the application of normalization heat treatment in the same material produced a more homogeneous microstructure with a large volumetric fraction of ferrite (fig.4) and, as a consequence, lower non-uniformity when compared to the previous quenching treatment.

Although the non-uniformity results of the quenched and tempered material B for the 85-100 HRB range were considered satisfactory, the hardness values do not fit the specified range. In spite of the application of a high tempering temperature, this material was not approved for this application due to high carbon and other alloying elements contents. This way, even for high tempering temperatures the martensite hardness is above 100 HRB.

The application of the normalization heat treatment to material B resulted in adequate hardness values, but higher non-uniformity compared to the ones obtained through quenching and tempering, although still within the specified limits established by the standards. Normalization heat treatment applied to material B generated a microstructure comprised by a thin lamellar pearlite in a ferritic matrix (fig.5).

For the 20-30 HRC and 35-55 HRC ranges the behavior of the quenched and tempered material B was satisfactory regarding both hardness and non-uniformity values. As can

be seen on figures 6 and 7 the microstructures of both HRC ranges blocks presented a fine dispersion of carbides in a tempered martensite matrix.

In reference to 60-70 HRC range the non-uniformity values of the three analyzed materials (B, C and D) fulfill the requirements of the standards. However, only material D attained a satisfactory hardness value since materials B and C presented average hardness values lower than the minimum limit of the hardness range (60 HRC).

Figure 8 shows the typical microstructure of steels B and C where dispersed carbides in a tempered martensite can be revealed. Figure 9 presents the same kind of microstructure with martensite and carbide, although in this case the carbide particles are much finer and the volumetric fraction is lower than the ones found in the materials B and C. The main reason for the higher hardness of material D is the higher contents of carbide forming elements such as tungsten and vanadium, along with a high manganese content allowed yielded a higher hardness value of steel D when compared with steels B and C.

Besides the tempered martensite found in steel D is finer than the ones found in the other steels thus producing a higher microstructural homogeneity which resulted in lower values of non uniformity than the ones obtained for the steels B and C.

In addition to the development of the hardness standard blocks, there were the installation of a hardness standardization machine “HSM” and the reference metrological system “Gal-Vision” in Hardness Laboratory at Brazilian NMI Inmetro in last February. Both systems comprise the Hardness Standardization System, whose overall view can be seen in Figure 10.

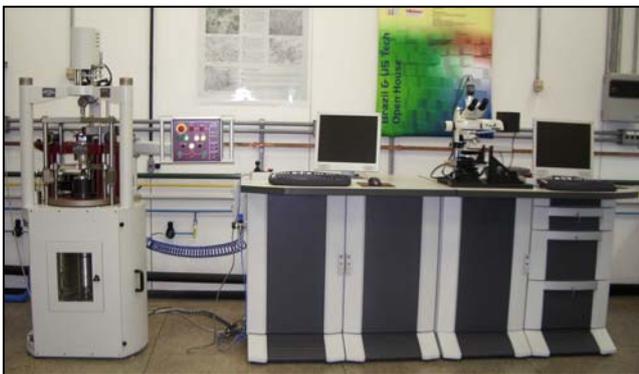


Figure 10. Hardness Standardization System installed in Hardness Metrology Laboratory at Brazilian NMI Inmetro. To the left there is the Hardness Standardization Machine along with its control system at the middle of the picture, whereas the accessory system Gal-Vision to measure Brinell and Vickers indentations is at the right.

HSM machine (to the left part of Figure 10) will be used to indirect calibration of Brinell, Rockwell, Superficial Rockwell and Vickers hardness standards blocks as well as hardness indenters. The control part of HSM is the one seen in the middle of Figure 10. To the right of Figure 10 it can be seen the Gal-vision, which is an accessory system to automatically measure the Brinell and Vickers indentations made previously by HSM.

It's been planned using the hardness primary standard HSM in future BIPM Brinell, Rockwell and Vickers hardness scales key comparisons.

Moreover, in order to have the completion of the hardness traceability chain in Brazil, Inmetro is going to have an indenter calibration system “Gal-Indent” installed at its hardness laboratory by the end of next July. This system will be used to calibrate dimensional and geometrical characteristics in Rockwell and Vickers indenters.

As a result of the installation of not only the Hardness Standardization System but also the Gal-Indent a sketch of the Brazilian Hardness Metrology Traceability Chain is shown in Figure 11. There the three metrological systems, installed or to be installed at the Hardness Laboratory “Lafor” of the Brazilian National Metrology Institute “Inmetro”, which were discussed in this work are a little darker (in gray).

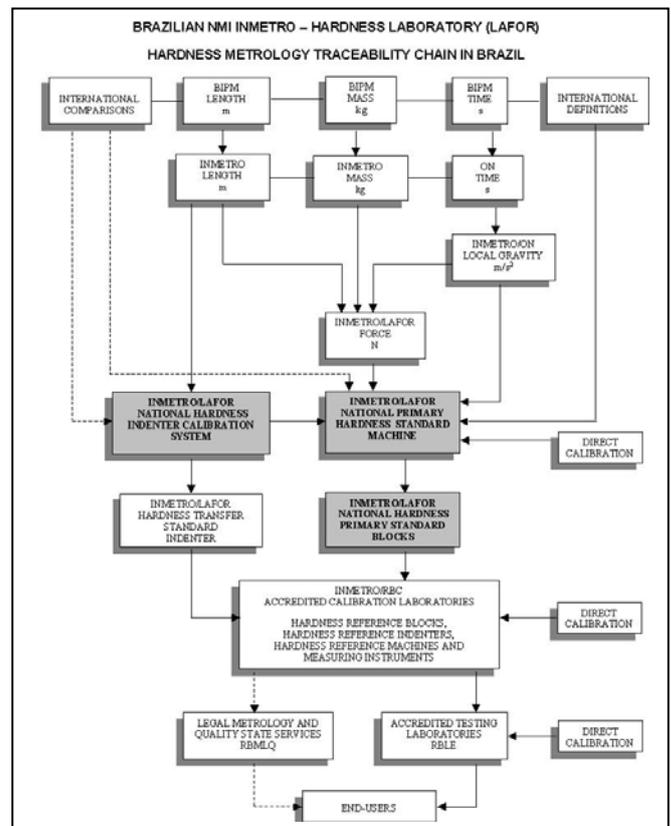


Figure 11. Hardness Metrology Traceability Chain in Brazil. In gray it can be seen the three parts of the metrological system described in this work: “National Hardness Primary Standard Blocks”, the “National Primary Hardness Standard Machine” and the “National Hardness Indenter Calibration System”.

Figure 11 also shows both the Hardness Standard Machine and Indenter Calibration System which will transfer their metrological reliability in hardness by way of hardness standard blocks and standard indenters, respectively. In this same figure there are some boxes entitled “direct calibration”: it means all necessary calibrations unless hardness related ones like force calibration, dimensional calibration and time and frequency calibration.

4. CONCLUSIONS

- For the 20-50 HRB range, the use of a low carbon steel as well as the commercial aluminum alloy did not achieve the non-uniformity values specified in international standards.
- The results achieved for the Rockwell B scale, range 60-80HRB, which employed the low carbon steel, were successful since they were in accordance with the international standards requirements.
- For material B, in the 85-100 HRB range, in any condition (oil quenched or normalized ones) the values of non-uniformity were satisfactory, although in the quenched and tempered condition hardness is above the permissible values.
- For both 20-30 HRC and 35-55 HRC, the material B, in all different conditions of quenching and tempering heat treatments produced satisfactory results regarding both hardness and non-uniformity values.
- Both materials C and D, for the 60-70 HRC range, fulfilled the non-uniformity requirements established by the standards. However, it can be said that material D is more adequate than material C since the former achieved a lower value of non-uniformity than the latter.
- Still about 60-70 HRC, concerning hardness values, material D showed a suitable performance, on the contrary of materials B and C that presented hardness values below the range specified by the standards. This is due to the higher content of carbide forming elements in material D.
- The completion of the national hardness metrology traceability chain in Brazil will be concluded soon, with the arrival and start up of the national indenter calibration system. This system will be added up to the Hardness Standardization System installed, commissioned and qualified in last February.

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