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THE INFLUENCE OF THE TIME EXTENSION ON THE PRELIMINARY TEST FORCE IN ROCKWELL HARDNESS MEASUREMENTS

Renato Reis Machado [1], *Jorge Trota Filho* [2], *Sergio Pinheiro de Oliveira* [3], *Islei Domingues da Silva* [4], *Bianca da C. O. Muniz* [5]

[1] National Institute of Metrology, Standardization and Industrial Quality (INMETRO), Rio de Janeiro, Brazil, rrmachado@inmetro.gov.br
[2] National Institute of Metrology, Standardization and Industrial Quality (INMETRO), Rio de Janeiro, Brazil, jtfilho@inmetro.gov.br
[3] National Institute of Metrology, Standardization and Industrial Quality (INMETRO), Rio de Janeiro, Brazil, spoliveira@inmetro.gov.br
[4] Oswaldo Cruz Foundation (FIOCRUZ), Rio de Janeiro, Brazil, isleidomingues@gmail.com
[5] National Institute of Metrology, Standardization and Industrial Quality (INMETRO), Rio de Janeiro, Brazil, bcmuniz@inmetro.gov.br

Abstract – In the light of the ISO 6508 revision, under the ISO TC 164 Technical Committee on Mechanical Testing of Metals, a study on the influence of the extended duration of the preliminary test force was taken, which in some cases a longer time could be required. Several HRC tests were performed with different conditions of time and materials by using the Hardness Standardisation Machine of INMETRO/Brazil.

Keywords: ISO 6508 revision; hardness testing; preliminary test force.

1. INTRODUCTION

The phenomenon called creep refers to the variation of strain with time when a constant stress is applied to a workpiece or, for example, a part of a machine. This phenomenon is observed in metals, ionic and covalent crystals and semi-crystalline and amorphous materials such as glass and polymers .[1]

There are several factors that affect the creep characteristics of materials, such as the melting temperature, the elastic modulus, grain size, testing temperature and existing stresses. Obviously, a higher stress causes a greater deformation for a while as a function of time and temperature. For the majority of metals the creep rate is not linearly dependent on stress. The effect of creep increases with temperature – and this increase is quite dramatic – as a consequence of an exponential variation of viscosity of the material with temperature.

ISO TC 164 Technical Committee on Mechanical Testing of Metals has started discussion on the possibility of testing materials that exhibits excessive plastic flow (e.g. indentation creep) during the application of the total test force. This phenomenon could require special considerations since it is possible the indenter will continue to penetrate into the material no matter the application of force by the hardness machine through the indenter axis has stopped at all. Moreover, some similar concerns have been arising as a consequence of the extended duration of the preliminary test force, although it can be considered high creep rate materials are more prone to this effect.

This paper aims at an investigation the influence of the extension of the duration of the preliminary test force can cause to reference hardness blocks in the low, medium and high Rockwell C hardness ranges.

2. METHODS AND PROCEDURES

The development of this work was based on the requirements of ISO hardness testing 6508-1 standard [2]. The planning of experiments has included duration of the preliminary test force related to several testing times, which varied between 1 s and 6 s.

All tests were performed in the Hardness Standardisation Machine installed at the Hardness Laboratory of the Brazilian NMI INMETRO and used hardness reference blocks related to low, medium and high hardness ranges (calibrated previously according to hardness testing 6508-2 standard [3]). A reference indenter (calibrated in advance in accordance to hardness testing 6508-3 [4]) was used as well.

Regarding the tests there were depicted points on several graphs (x,y), where x is the time and y is the hardness value; these mentioned points were relative to the hardness value as a function of the extended duration of the preliminary test force. Straight line fitting was applied to these depicted points. Relative uncertainty pictures were depicted as well for each hardness range analysed in this work.

From the acquisiton of the experimental data it was possible to determine the uncertainty contribution of extended duration of preliminary test force. Afterwards, this work compares the uncertainty of measurement estimated by the experimental conditions and those taken from EURAMET´s Guidelines on the Estimation of Uncertainty in Hardness Measurements [5]. In addition, there have been an analysis of the impact of uncertainty on the total uncertainty of the Hardness Standardisation Machine of INMETRO/Brazil that is 0.2 Rockwell Hardness units.

3. RESULTS AND DISCUSSION

ISO 6508-1 standard recommends that the maximum application time of preliminary test force is 3 s [2]. However, during this study it was used a range of 1-6 s.

These times were used in order to generate enough data to make an assessment of the influence of the parameter time of preliminary test force on the values of hardness measured in reference hardness blocks.

The results of the hardness values as a function of time of preliminary test force are shown in figures 1, 2 and 3 for low, medium and high hardness Rockwell C measurements.

In Figure 1, there is a decrease of hardness value measured in the beginning of the test – up to a 2 s time of duration of the preliminary test force. From 2 s on in the duration of the preliminary test force there was an increase in hardness values. In softer materials the creep influence is more pronounced due to a less hard microstructure [1].

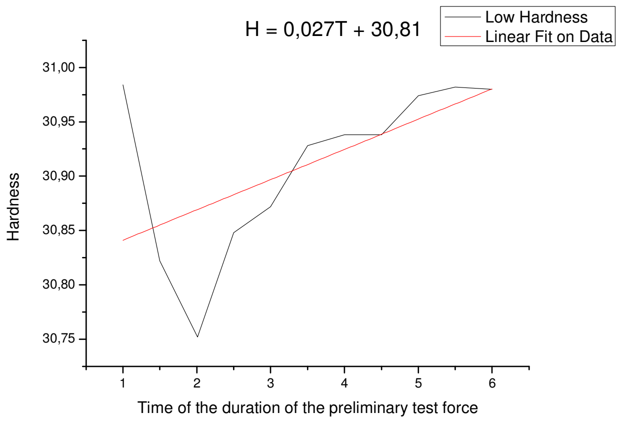

Figure 1 - Behavior of low hardness reference block as a function of the duration of the preliminary test force.

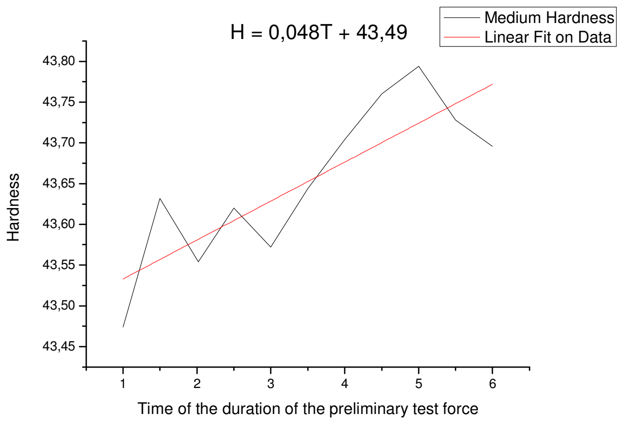

Figure 2 - Behavior of medium hardness reference block as a function of the duration of the preliminary test force.

Figures 1, 2 and 3 show the variation of hardness as a function of the duration of preliminary test force applied on the Rockwell C hardness blocks. It can be realized there's a common behavior in figures 1, 2 and 3 since there is an increase in hardness when the time of application of preliminary test force increases. Figures 2 e 3 show similar behavior in terms of an initial increase in the hardness values for Rockwell C medium and high hardness ranges blocks, respectively.

Nevertheless, figure 1 shows a slight different behavior when compared to figures 2 and 3: for shorter times up to 2 s there is a decrease in the hardness values. For higher times the behavior seems to be the same as the medium and high hardness ranges because there appeared higher hardness values. The general behavior of all hardness blocks (low, medium and high ones) can be outlined by linear fitting to the respective experimental curves as presented in figures 1, 2 and 3, which show a superimposition of these fitted curves on the experimental ones.

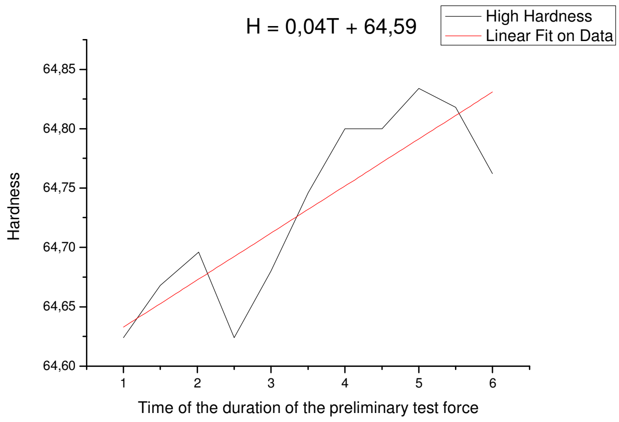

Figure 3 - Behavior of high hardness reference block as a function of the duration of the preliminary test force.

In analyzing the behavior of the three hardness blocks depicted in figures 1 through 3 an explanation for these phenomena comes from the existence of mechanisms related to blocking of dislocations by intersticial chemical elements (locking and release of dislocations by point defects inside the microstructure of blocks dependent on the balance of both rear and front stresses acting on dislocations crossing over the internal structure of crystalline materials). In order to seek for evidences for this theoretical explanation a dislocation-based phenomenology is proposed.

Since there is a hard microstructure in figure 3 the contact between the indenter tip and the surface of blocks generates elastic stresses for shorter times. Increasing the time of application of preliminary test force the dislocations are released from the defects and the hardness is reduced accordingly. The released dislocations are blocked again by new barriers and are locked up. As a consequence the hardness increases directly with the time up to the moment the internal elastic stress is enough for unlocking the dislocations again from the internal restrictions. So it can be imagined there is a cyclic behavior in such a way there is a higher and higher hardness value when a new cycle starts (and/or an a additional time is applied).

The block represented in figure 2 has the same qualitative behavior as the block of figure 3. The slight difference between both of them comes from the relative less stressed microstructure of figure 2 when compared to figure 1: it means the supposed consecutive dislocation locking/unlocking cycles generated shorter cyclic periods in the medium hardness material than in the hard one.

One can realize the material in figure 1 has the same qualitative behavior of figures 2 and 3 from time 2 s on no matter the material in this graph is the softest of all of them. Due to the relative softness of the low reference hardness Rockwell C block (compared to the medium and high hardness blocks) up to a time of nearly 2 s the application of preliminary test force for short times generates dislocations that don't have enough energy to surpass microstructural barriers arised in the vicinity of the indenter.

In order to have another evidence of the phenomenology proposed in this paper for the behavior of the hardness in figures 1, 2 and 3 a new experiment was planned. E.g. a bronze 50 HRB hardness block was used for creating a two-axis graph: hardness value as a function of times of preliminary test force, as show in figure 4. The experimental procedures that generate figures 1 through 4 were exactly the same. In figure 4 there are three stages for the hardness behavior as a function of time: from 4.5 s on the behavior is the same as depicted in figures 2 and 3 for medium and high hardness values, respectively. From a little more than 2.5 s to 4.5 s it seems the phenomenon is the same as the first stage of figure 1. So, there is a different behavior in the first stage of figure 4. This arises from the non-similar behavior in the presence of the indenter load of both the material nearby the indenter tip (subjected to a relative local high deformation rate) and the relative harder material surrounding the mobile material layers submitted to creep conditions. It means the softer part of the material creeps in a relatively fast way being restricted by the surrounding harder material. So, the initial hardness of the first stage in figure 4 comes from the relative unrestricted local high deformation rate applied by the indenter to the base material of the hardness block.

Figure 4 shows the superposition of two fitted curves on the experimental curve: a linear and a cubic one. The linear curve shows an overall softening behavior that could be not real in this case since there are high hardness values for short times and for longer times. It can be said the cubic curve seems to provide the best fitting to the experimental points and to the physical and mechanical meanings of the experimental data. So the behavior of the material in figure 4 validates the explanation developed in this paper for the phenomena represented by the curves depicted in figures 1 through 3, which are related to main objective of this work, i.e. Rockwell C hardness tests in creep conditions.

In terms of measurement uncertainty, for every second of increase of time in the preliminary test force the hardness of the material increases by about 0.04 HRC. In 6 s the hardness of the material increased by about 0.24 HRC, this variation being accounted for 120% of the uncertainty of the system of primary standardization in Rockwell C hardness (HSM). Therefore, it is unquestionable the importance of standardising the duration of the time of preliminary test force application.

Table 1 below shows the uncertainty measurement budget for the Rockwell C hardness blocks studied here. This worksheet contains the data of sensitivity coefficients, the maximum hardness variation observed within the Rockwell C measurements (coming from the linear regression applied to the linear fitting of figures 1 through 3 between times 0 s and 6 s) for the low, medium and high hardness ranges, the HSM uncertainty measurement (0.2 HRC) and the percentage of the maximum hardness variation related to the HSM uncertainty (% HSM Uncertainty).

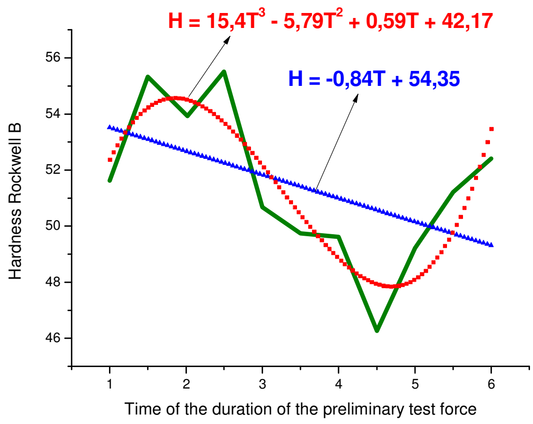

Figure 4 – Behavior of 50 HRB hardness reference block as a function of the duration of the preliminary test force. In the graph there is a superimposition of linear and cubic fitted curves on the experimental data.

Table 1 - Uncertainty measurement budget for the low, medium and high Rockwell C hardness ranges studied.

Hardness Range	Sensitivity Coefficient	Maximum Hardness Variation	HSM Uncertainty	% HSM Uncertainty
Low	0.027	0.162	0.2	81
Medium	0.048	0.288	0.2	144
High	0.04	0.24	0.2	120

From table 1 it can be seen the Maximum Hardness Variation and HSM Uncertainty columns have the same order of magnitude. So, the duration of preliminary test force is a relevant parameter to be taken into account.

In order to evaluate the results of expanded uncertainty found in this paper a comparison (figure 5) was made among: a) the uncertainty values reported in the EURAMET´s Guidelines on the Estimation of Uncertainty in Hardness Measurements; b) HSM uncertainties results related to the time of preliminary test force application; c) the results obtained in this work.

As a consequence of the analysis of figure 5 it can be realized there´s a sequence of results: EURAMET has lower uncertainty values than the one obtained experimentally in this work. Of course, the HSM results are lower than that one obtained in this work since the last was derived from the former.

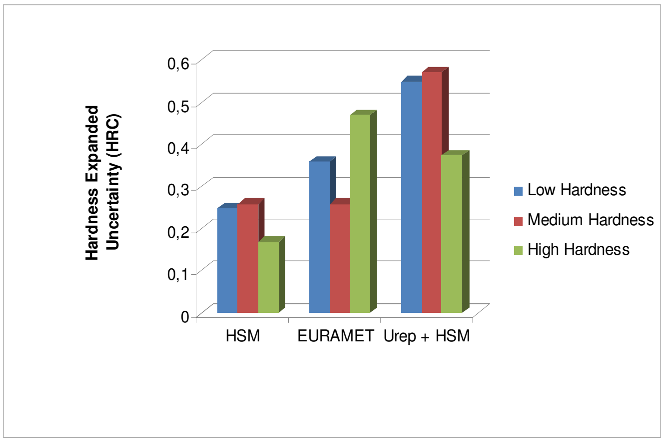

Figure 5 – Uncertainty comparison among HSM, EURAMET and obtained in this work (Urep +HSM). Urep is the standard uncertainty calculated from repeatability.

Regarding figure 5, additionally it can be said there is a reason for the results obtained for low and medium hardness blocks be higher than the uncertainty requirements of the EURAMET Guide: this is due to the high non-uniformity of the low and medium Rockwell C hardness blocks, as shown in figure 6.

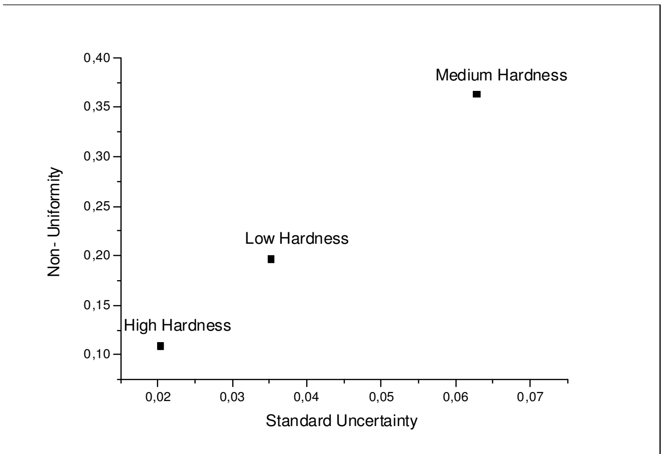

Figure 6 – Non-uniformity of hardness blocks of low, medium and high hardness ranges as a function of the standard uncertainty of the results of repeatibility obtained in this work for the Rockwell C blocks studied.

Figure 6 shows the hardness non-uniformity of low, medium and high hardness range blocks as a function of the standard uncertainty of the results of repeatibility obtained in this work. The high hardness block had the least non-uniformity of all three hardness ranges analyzed in this work. This is the explanation for the occurrence, in figure 5, of a lower hardness expanded uncertainty for the high hardness block than the EURAMET requirements.

4. CONCLUSIONS

This work dealth with the influence of the duration of the time of preliminary test force application on hardness blocks in the low, medium and high Rockwell C hardness ranges. A HRB hardness block was used as well in order to highlight the softening phenomenon in the less hard microstructures used in this work.

In all tested Rockwell blocks the following events were observed:
a) with a very soft material, as an example when using HRB hardness blocks, there appeared three stages (hardening, softening, hardening);
b) when using a soft material (low HRC block) there were only two stages (softening, hardening);
c) for medium and high HRC hardness block, there was only a stage (hardening);
d) the cycles in the hardening stage were longer in the high hardness range block than in the medium one.

A mechanism is proposed for the observed phenomena in this work. Blocking of dislocations by intersticial chemical elements is the main reason for the observed behavior in the hardness block studied.

In the low, medium and high reference hardness blocks the maximum hardness variations related to the expanded uncertainty of the HSM system were 81%, 144% and 120%, respectively.

During the calibration of any reference hardness block it would be important for each NMI make a careful analysis of which would be the best duration of the time of initial force application.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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