Technique to reduce bending issues in Rockwell B scale hardness reference blocks: preliminary results

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Abstract

This paper describes a new design for HRBW scale reference blocks, that has the potential to greatly reduce the bending of brass blocks and thus improve short time stability of the block’s apparent reference value. The experimental results given here are preliminary and only reflect short time period stability effects. The work was carried out in 2017 at the National Institute of Standards and Technology (NIST) in Gaithersburg, USA.

1. Introduction

Rockwell hardness is an ordinal quantity that is dependent on a defined test method, such as those specified by ASTM [1] and ISO [2]. Consequently, there is no fundamental property measurement that can provide traceability to the SI. Therefore, transfer standards in the form of reference test blocks are used to ensure measurement agreement and stability for industry and to provide measurement traceability to a National Metrology Institute (NMI). There are over 30 Rockwell hardness scales defined by ASTM and ISO, which vary according to the applied indentation forces and the geometry and material of the indenter. The choice of using a particular Rockwell scale is dependent on the properties of the material being tested. The Rockwell B hardness scale, designated as HRBW, is the second most often used Rockwell hardness scale by industries worldwide, typically used for evaluating softer metals such as aluminum and copper based alloys. Consequently, HRBW reference blocks are typically made of brass or aluminum. Unfortunately, there are time-dependent and usage-dependent hardness instability problems associated with HRBW scale reference blocks. HRBW block instability is well known throughout the industries that utilize HRBW scale hardness testing for their product evaluation and acceptance criteria.

Previous NIST investigations of the causes of the hardness instability of brass HRBW scale reference blocks by Low and Fink [3] found that a major contributor to the instability is due to the bending of the blocks as an increasing number of indentations are made in the test surface. The extensive deformation surrounding the indentations causes the bottom of the block to become concave in a non-uniform manner. As a result, the contact surface between...
the block and the hardness machine’s block-support transforms from a flat contact surface to random points of contact at the outside edge of the block. This allows the block to flex during the indentation process, much like a leaf-spring. Flexure of the block during indentation may affect the measurement in ways that add error to the hardness value.

This paper describes a new design for an HRBW scale reference block that has the potential of greatly reducing the bending of brass blocks and thus improving the stability of the block’s apparent reference hardness value. The experimental results given here are preliminary and only address short-time stability effects related to bending.

2. Bending in brass HRBW reference blocks

Common materials used to produce HRBW reference blocks are alloys of copper-brass that because of heat treating processes and the availability of material are typically produced in the 6 mm to 9 mm range of thickness. The previous NIST investigations [3] examined how much a 9 mm thick test block will bend due to repeated indentations and how the bending affects the measurement results. That examination was made by performing Rockwell B hardness tests over the surface of a brass test block, and periodically measuring the flatness of the block’s bottom surface. The bending was measured by placing an optical flat against the bottom surface of the block while illuminating the interface with a monochromatic light source of known wavelength. An observable interference pattern was created that indicated the extent of bending. Figure 1 illustrates the increasing bending as the number of indentations is increased (number adjacent to each block photo). An increasing number of fringe lines indicates increased bending since the separation between lines corresponds to a constant amount of bending, similar to elevation lines on a topographical map. This work also showed that the shape of the bottom surface bending is not uniform since it is dependent on where the indentations are made on the block test surface.

The bending of the block can affect the measurement results due to flexure of the block during the application and removal of the indentation forces. The amount of deflection, with respect to the block test support surface, varies in magnitude with the maximum deflection occurring near the block center and lessening towards the block edge. During indentation, the block flexes under load causing an increase in the compressive stress at the test surface during force application, and a decrease during force removal, thus varying the material’s resistance to indentation. The measurement results are also affected if hardness machines are used that measure the indentation depth with respect to the block support surface rather than the top surface of the block. This type of Rockwell hardness machine is the most common design in use, including the NIST standardizing machine. These machines incorrectly interpret the block flexure during the application and removal of the indentation forces as actual indentation depth. Each of these effects may produce erratic hardness results when measuring the hardness of test blocks over the useful life of the block.

3. New HRBW reference block design

A simple test block design was developed with the goal of preventing or at least reducing the adverse bending effect of the current HRBW brass reference blocks. The proposed technique
is to mechanically fasten a brass hardness reference block on top of a thick steel block using a single screw at the center of the blocks as shown in figure 2. The screw is inserted through the steel block from the bottom and is screwed to a specific torque level into a tapped hole in the bottom of the brass block (figure 3). The steel block will not be indented and thus will not bend, therefore holding the brass and steel mating surfaces securely together, and preventing the bottom of the brass block from becoming concave.

The brass blocks used for this work were uncalibrated and untested high-quality HRBW reference blocks in the shape of a round disk, approximately 64 mm in diameter and 9 mm thick. A nominal 42 HRBW hardness block was used because it had previously been determined that the lower hardness brass would produce the greatest bending among the three available block hardness levels (42 HRBW, 62 HRBW and 82 HRBW). An uncalibrated and untested nominally 25 HRC reference block was chosen for use as the mating steel block. The steel reference block used was the same diameter as the brass blocks, but having a 15 mm thickness. As shown in figure 2, a hole was machined through the axial center of the steel block slightly larger than the screw threads. The hole was widened at the block bottom so that the screw head could be recessed deeper than the block bottom surface. A mating hole was machined into the axial center of the bottom of the brass block to a depth of approximately 1/3 the block thickness (approximately 3 mm), and tapped to the thread size of the fastening screw. The brass and steel blocks were fastened together with the screw without any substance being placed between the mating block surfaces. The screw was tightened by a hand torque-wrench to a torque level that would produce a fastening force greater than the repulsive bending force at the block center.

4. Experimental methodology

For this limited study, one steel block and two 42 HRBW brass blocks were prepared as described above. The single steel block was reused with both of the prepared brass blocks. To examine the effect of the fastened brass/steel reference block, four additional unmodified brass reference blocks of the same type and hardness level were also tested, alternating with the brass/steel block tests. All hardness tests were performed using the NIST Rockwell hardness standardizing machine [4], the NIST standard test cycle (same as the Rockwell C hardness scale test cycle defined by the CCM Working Group on Hardness [5]) and the same tungsten carbide ball indenter. The sample support used for the testing was a flat support having a surface dimension of 120 mm in diameter, which provided full support of the test block at every test location without any overhang off the support.

A test location pattern was designed in which the test surface of the block was divided into six sections of equal area, labelled A to F in figure 4. The test measurements were made at the specific locations indicated by the numbered dots, which maintained a 7 mm indentation separation. A test sequence was devised such that a set of six tests were made at computer-chosen random locations, one in each of the six sections. After completing each set of six measurements, the block and test support were cleaned, the block replaced on the support, and the next six measurements were made. This was repeated until seven sets of six measurements were made, filling the block surface. This identical sequence of test locations
was used for all blocks tested. The center black triangular area was used for block-seating indentations since it was directly over the fastening screw.

5. Analysis

The results of testing are given graphically in figure 5 for the brass/steel blocks, and in figure 6 for the brass blocks. The data points are the average values of each individual 6-indentation set of measurements, and the error bars represent a 1-σ standard deviation. Table 1 gives a statistical summary of the results, with the second column showing the average of the standard deviations of the seven individual 6-indentation sets of measurements. The third column displays the standard deviation of the seven average values of the sets of measurements.

The limited test results show that the brass/steel design outperformed the regular brass blocks in all but one case. The brass block 99B42114 test results were only slightly better than for the brass/steel 99B42065 block. Overall, the results for the brass/steel design showed up to a 65% reduction in the standard deviation of the individual sets of six measurements compared to the brass blocks, and approximately a 50% reduction in the standard deviation of the averages of the individual measurement sets.

6. Conclusion

Although these tests are few and preliminary, the results are very promising for a technique to counter the bending issues in brass HRBW reference blocks. Additional tests are needed, particularly to determine whether there is also improvement in the long-term stability of the block reference values. Although the expense of producing blocks of this design will likely prevent common commercial use, the impact on interlaboratory comparisons and possibly test machine calibrations may be significant.

7. References

[1]. ASTM E18-17e1 2017 Standard Test Methods for Rockwell Hardness of Metallic Materials (West Conshohocken, PA: ASTM International)
[2]. ISO 6508-1:2016 Metallic Materials—Rockwell Hardness Test — Part 1: Test method (Geneva: International Organization for Standardization)
[3]. Low S and Fink J 2003 Effects of bending in brass Rockwell B scale test blocks Proc XVII IMEKO World Congress on Metrology in the 3rd Millennium (Dubrovnik, Croatia 6 2003)
[4]. Low S, Gettings R, Liggett W and Song J, Rockwell hardness - a method-dependent standard reference material, Proc. NCSL Workshop and Symposium (Charlotte, NC, 7 1999)
[5]. www.bipm.org/wg/CCM/CCM-WGH/Allowed/International_definitions/HRC_definition.pdf
Figure 1.
Ten photographs of interference fringe patterns [3] indicating the increasing concave bending of the bottom surface of a 42 HRBW brass test block as the number of indentations (labelled number) was increased. The black dots indicate the indentation locations on the test surface.
Figure 2.
Edge-view design illustration of mechanically fastened brass HRBW reference block and steel block.
Figure 3.
Brass/steel block being prepared.
Figure 4.
Test locations
Figure 5.
Brass/steel results.
Figure 6.
Brass results.
Table 1.

Study statistics.

| Test Block | Avg. STDEV of Sets | STDEV of Averages |
|------------|--------------------|-------------------|
| 99B42060 Brass/Steel | 0.23               | 0.34              |
| 99B42065 Brass/Steel | 0.37               | 0.52              |
| 99B42085 Brass     | 0.53               | 0.61              |
| 99B42076 Brass     | 0.67               | 0.75              |
| 99B42075 Brass     | 0.68               | 1.42              |
| 99B42114 Brass     | 0.36               | 0.47              |