XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia

EFFECTS OF BENDING IN BRASS ROCKWELL B SCALE TEST BLOCKS

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Abstract – As part of a project to produce primary hardness reference blocks for the Rockwell B hardness scale at the National Institute of Standards and Technology (NIST), studies were conducted to observe the stability of the hardness value of the blocks over a period of time and with use. A study of brass test blocks at the 42 HRBW level revealed some interesting instability results when tested using the NIST standardizing machine with it's large diameter sample support.

After a relatively small number of indentations, each block exhibited an abrupt change in the apparent hardness of the test block. Examination of this phenomena revealed that the abrupt change in hardness was the result of a combination of the bending of the block and the use of the NIST machine's large diameter flat anvil. This paper discusses the reasons that block bending affects the hardness measurement.

Keywords: bending, Rockwell hardness, test block

1. INTRODUCTION

It is well recognized that the test surface of Rockwell hardness reference test blocks gradually increases in hardness as more and more indentations are made [1]. This is true for blocks made of steel, brass or other metals. The generally accepted explanation is that each indentation induces a compressive stress in the block material surrounding the indentation. A compressive stress acts to increase the material's resistance to penetration and thus increases the apparent hardness of the test block. As an increasing number of indentations are made, this accumulation of compressive residual stress at the test surface also causes the blocks to bend as a means to relieve the stress. As one would expect, the blocks become concave on the bottom surface. It is also widely believed, although not well documented, that Rockwell test blocks made of brass tend to be unstable in maintaining the hardness over time, often exhibiting erratic increases and decreases in hardness.

Studies were conducted at NIST to examine the effects of the passage of time and usage on the hardness stability of Rockwell B scale test blocks. Tests were conducted on brass blocks in the 42 HRBW range over several days in which the blocks were filled with indentations. The tests provided some surprising results that may explain some of the time instability reported for brass test blocks.

2. EXPERIMENT

Rockwell B hardness tests were performed on six brass test blocks in the 40 HRBW range. All blocks were manufactured by the same company and were of the same material with a diameter of 64 mm and a thickness of 9,4 mm. The sequence and locations of the indentations were identical for all six blocks. After initial groups of seven and six indentations were made at locations across the test block surface, the tests were continued in groups of four indentations until the block was filled with 53 indentations. Each of the four indentations in a single group was made in one of four quadrants of the test block. The testing schedule for each block, however, was varied. Two blocks were tested to completion without stopping (on different days), and the tests on the other four blocks were made following different schedules with some overlap, but each completed in seven days of testing.

To examine how much a test block will bend due to repeated indentation, Rockwell B hardness tests were performed on a seventh brass block. Periodically during the indentation process, the flatness of the bottom surface was measured by observing the interference pattern created by an optical flat against the bottom surface of the block while illuminating the interface with a monochromatic light source of known wavelength.

All hardness tests were performed using the NIST Rockwell hardness standardizing machine [2], using the NIST standard test cycle 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 of the support. Keep in mind that the NIST hardness machine, as well as many commercial hardness machines, measures the depth of the indenter with respect to the test sample support surface, and not the block test surface. Therefore, bending in the block will be indicated as a change in the indentation depth.

3. RESULTS

The interference fringe patterns, as shown in Fig. 1, clearly indicate how the bottom surface of the brass test

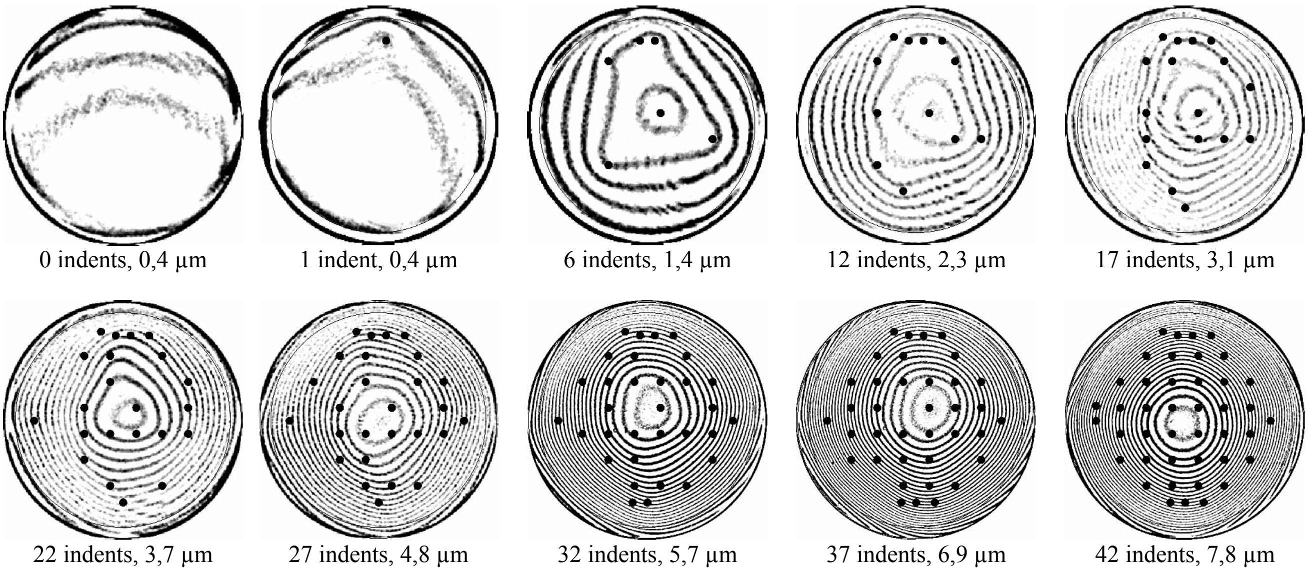


Fig.1. Ten photographs of interference fringe patterns indicating the increasing concave bending of the bottom surface of a 42 HRBW brass test block as the number of indentations is increased. The view is the bottom of the test block superimposed with the indentation locations made on the opposite side test surface of the block. Given below each photo are the number of indentations that were made and the approximate amount of deflection of the block center, in µm, with respect to the edge of the block.

blocks bend as an increasing number of indentations are made in the block. The bending occurs such that the bottom of the block becomes concave and the test surface becomes convex. The center-to-center spacing between the topographic-like fringe lines indicates a difference in depth of approximately 0,27 µm. The interference patterns also show that the orientation of the bending is very dependent on where the indentations are made.

The hardness measurement results of the tests on the six blocks exhibited a surprising effect. For most of the blocks, after 20 to 25 indentations, the average hardness shifted abruptly and significantly, as seen in Fig. 2. For example, an abrupt drop in hardness is clearly seen for test block 99B42071 to have occurred between the fourth and fifth groups of tests. Because the blocks were tested following different testing schedules, as indicated in Fig. 2, an influence from the hardness machine or operator could be ruled out as the cause of this phenomenon. (Note: In this paper, the uncertainty in the HRBW measurements is not an issue because the focus is on the difference between Rockwell measurement values calculated from the indicated measurements of indenter depth. All depth measurements reported in this paper are estimated to have an expanded uncertainty no larger than ±0,0001 mm ($U = 2u_c$ where u_c is the combined standard uncertainty),

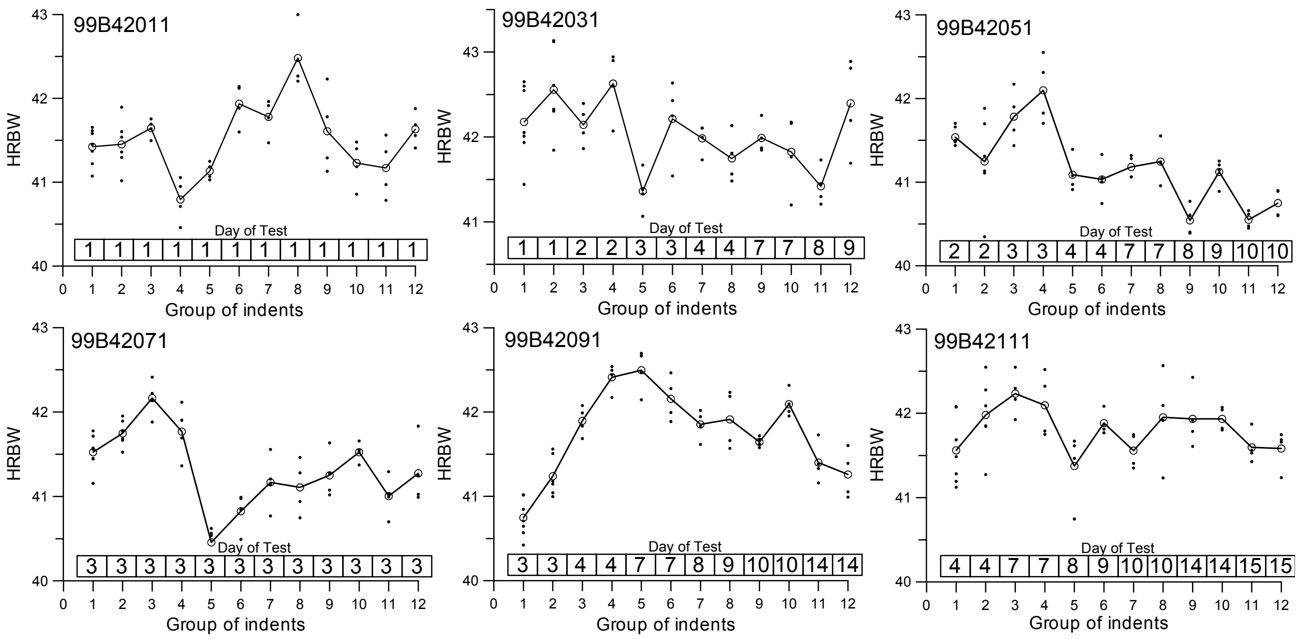


Fig. 2 Test results for six brass Rockwell B blocks (serial numbers 99B42011, 99B42031, 99B42051, 99B42071, 99B42091, and 99B42111) indicating the individual groups of measurement values (small solid circles) and the average of value for each group (larger open circle). The test day is also given below each group of data.

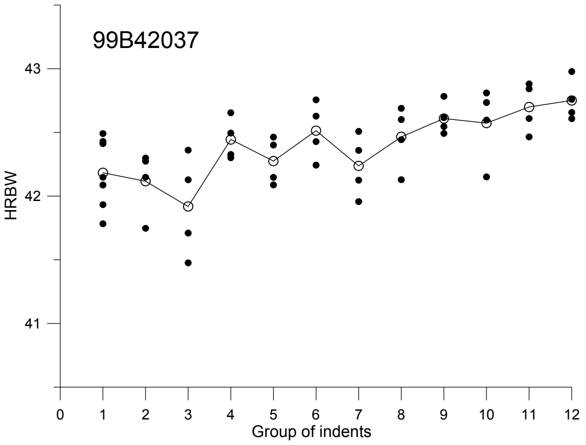


Fig. 3 Test results for brass block 99B42037, which was tested on a 9,5 mm diameter sample support.

which translates into a Rockwell hardness error of no larger than ±0,1 HRBW.)

It was suspected that this abrupt shift in hardness was not an actual sudden change in the material hardness, but was due to bending in the block and testing on the large flat sample support. To investigate this, an additional block was tested using a smaller 9,5 mm diameter support in place of the large diameter flat support. In this case, the significant change in hardness did not occur, as shown in Fig. 3 for test block 99B42037.

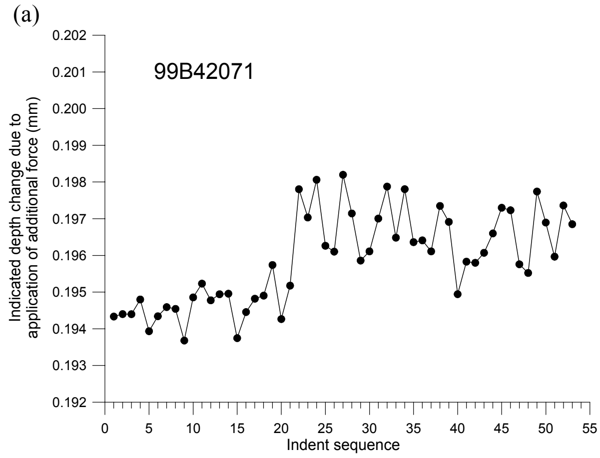
4. ANALYSIS

A question to answer is why is the bending of the block causing this effect? One plausible explanation is that as indentations are made in the block, bending in the block increases to the point that the preliminary force of 98 N is no longer adequate to force the block flat against the sample support. As a result, the application of the additional force (increase from 98 N to 980 N [3,4,5]) is needed to force the block flat against the anvil. The NIST hardness machine would measure the deflection of the block as an increase in indentation depth in addition to the actual material indentation. Fig. 4a shows that this began for test block 99B42071 after the 21st indentation, between the fourth and fifth group of indents. However, another effect caused by the block deflection while loading is that the bending induces a compressive stress in the test surface of the block, which acts to decrease the actual indentation depth into the block material. These offsetting effects may explain why the indentation depth due to the application of the additional force, as shown in Fig 4a, does not continue to increase due to increased bending caused by additional indents.

Upon removal of the additional force during a Rockwell hardness test, the material surrounding the indentation elastically recovers causing the indentation depth to decrease. If the block has deflected during the application of the additional force, it follows that when the force is removed, the center of the block will elastically deflect up and away from the sample support. The deflection of the block on unloading would be expected to provide a false indication of increased elastic recovery in the indented material. However, as a result of the block deflecting as the force is removed, the compressive stress at the test surface of the block decreases and thus the actual elastic recovery of the material surrounding the indentation decreases. These two effects partially offset each other resulting in little change in the measured indentation depth as shown in Fig. 4b for test block 99B42071.

Another confirmation that the deflection of the block is affecting the indicated indentation depth can be seen in Fig. 5a, which shows how the indentation depth due to the application of the additional force varies with the location of the indent. If the block deflects during the application of the additional force, a larger indentation depth should be measured at the block center since there would be larger deflection at the center than at the edge of the block. This effect can be seen in Fig. 5a, which shows that for the initial tests prior to the abrupt shift in hardness, the indicated indentation depth is not dependent on the indentation location. However, after the abrupt shift, there is a definite increasing trend in indentation depth, as the indents are made closer to the block center. Fig. 5b also indicates that the magnitude of the indicated elastic recovery of the indentation after removal of the additional force is also dependent on the test location, being higher for indentations made at the block center. The hardness measurement results for test block 99B42071 are given in Fig. 6 with respect to the indentation location to illustrate that an actual variation in the hardness of the material from the block center to the

(a)



(b)

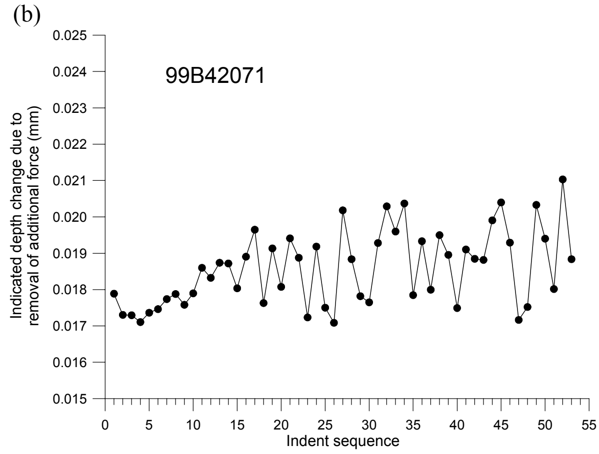


Fig. 4. The indicated indentation depth due to the application (a) of the additional force, and the removal (b) of the additional force, shown in the order that the indentations were made.

block edge is not the cause of this effect. This figure shows no trend in the material hardness with respect to the distance that the indentation is made from the block center.

It would also be expected that if the block is deflecting during the application and removal of the additional force, then the indicated indentation depth dependence on test location would cause the measured indentation depths to vary much more than for the initial tests when the block is not deflecting. Fig. 4a and Fig. 4b clearly indicate that the there is significantly increased variation in the results once the bending is thought to have initiated at about the 21st indentation.

The measurement of Rockwell hardness is not solely dependent on the total depth of indentation, but is calculated from the difference in indentation depths, prior to and after the application and removal of the additional force [3, 4, 5]. The hardness value is therefore directly related to the difference in the indentation-depth values given in Fig. 4a and Fig. 4b. These tests have indicated that, for this material, all of the effects discussed above combine in a manner that produces the erratic measurement behavior of the test blocks as shown in Fig. 2.

5. CONCLUSIONS

Measurements at NIST of brass test blocks in the 42

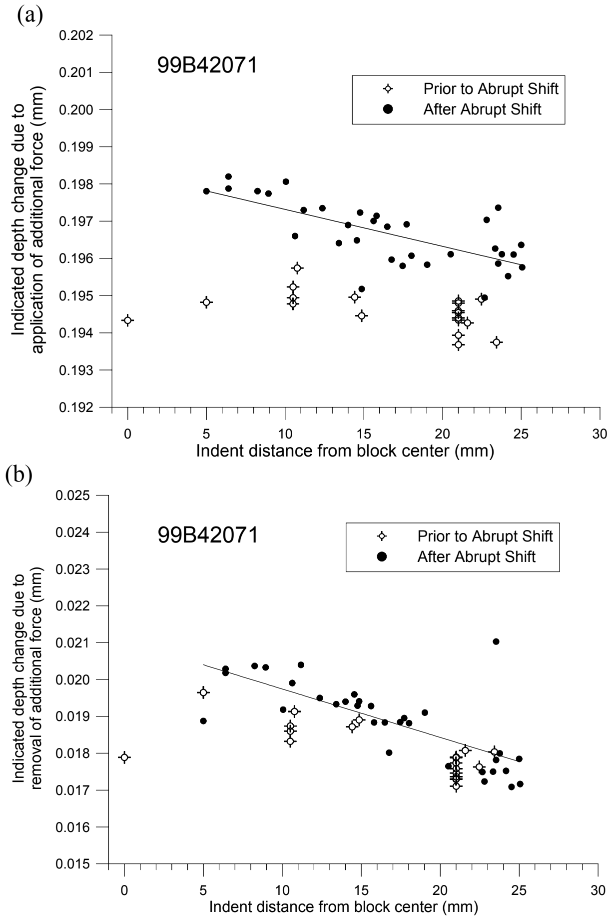


Fig. 5. The indicated indentation depth due to the application (a) and the removal (b) of the additional force, shown with respect to the radial distance that the indentations were made from the center of the block.

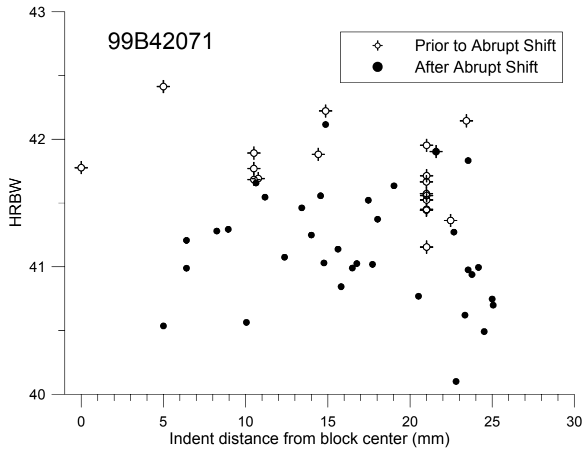


Fig. 6. The HRBW test results for test block 99B42071, shown with respect to the radial distance that the indentations were made from the center of the block.

HRBW range have demonstrated that some brass blocks may give erratic hardness results if tested using a large flat sample support. This is due to the increasing bending of the block as the number of indentations increases. The bending of the block can affect the measurement results due to deflection of the block during the application and removal of the additional force. The deflection causes an increase in the compressive stress at the test surface of the block during force application and a decrease during force removal, thus varying the material's resistance to indentation. The measurement results are also affected when using hardness machines that measure the indentation depth with respect to the sample support rather than the top surface of the block. In this case, the machine may incorrectly interpret the block deflection during the application and removal of the additional force 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.

REFERENCES

[1] F. Petik, Hardness Test Blocks and Indenters, Bureau International de Metrologie Legale, Paris, 1984 (restricted distribution)

[2] S. R Low, R. J. Gettings, W. S. Liggett, Jr., J. Song, Rockwell Hardness - A Method-Dependent Standard Reference Material, *Proceedings of the 1999 Workshop and Symposium (Charlotte, NC, 11-15 July 1999)*, Charlotte, NC, 1999.

[3] ASTM E 18 – 02, Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials, West Conshohocken, PA, ASTM, 2000.

[4] ISO 6508-1 Metallic Materials - Rockwell hardness test - Part 1: Test method (scales A,B,C,D,E,F,G,H,K,N,T), Geneva, International Organization for Standardization, 1999.

[5] Low, S., Rockwell Hardness Measurement of Metallic Materials, NIST Recommended Practice Guide, Special Publication, 960-5, 2001.

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