

THE EFFECT OF SUGGESTED CHANGES TO THE ROCKWELL HARDNESS TEST METHOD

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Abstract: In the latest revision of the ISO Rockwell hardness test standard (ISO/FDIS 6508(E), 1999), the introductory paragraphs introduce changes to the test practice; one new to this revision, and one suggested as a possibility for the next revision. The change to the new revision is the addition of allowing the use of hardmetal or tungsten-carbide balls for all Rockwell scales that use ball indenters. The change suggested for the next revision is to redefine the standard test forces presently based on rounded kilogram-force values, to converted and rounded Newton values. Since the development of the test method over 80 years ago, an incalculable amount of Rockwell hardness measurements have been made following essentially the same procedures. This paper discusses how these new changes could effect the Rockwell hardness measurement results.

Keywords: hardmetal ball, indenter, Rockwell hardness

1 INTRODUCTION

Stanley P. Rockwell developed the Rockwell hardness test method in 1919 [1]. The test is performed by applying two specified levels of force to a specific type of indenter at specific rates and with specific dwell times. These force levels, indenters, rates and dwell times are specified in national and international Rockwell hardness test method standards, such as Standard Test Method E18 published by ASTM in the United States [2]. The ASTM E18 standard was first published in 1932, demonstrating the long use of the Rockwell hardness test by industry. As with most test method standards, advances in technology have brought changes to the prescribed procedures for performing the Rockwell test, some minor and some major. Recently, the Rockwell hardness test method standard ISO/FDIS 6508(E) [3, 4, 5], published by the International Organization for Standards (ISO), has been revised to allow the use of hardmetal (tungsten carbide, WC) balls for all Rockwell scales that use ball indenters. Until now, only steel balls were allowed for use as an indenter. The revised standard also suggests that for the next revision, the standard test forces may be redefined from the traditional force levels based on rounded values of kilogram-force, to more acceptable rounded Newton units. It is important that users of Rockwell hardness be aware of what effect these changes may have on measurement results. Tests have been conducted at the National Institute of Standards and Technology (NIST) to examine these effects.

2 ROUNDED SI FORCE VALUES

The Rockwell hardness test was developed and evolved at a time before the adoption of SI units in the United States. The traditional unit of force defined for the Rockwell hardness test was kilogram-force (kgf). This now presents a problem to industries and metrological laboratories that have been mandated to report measurements in SI units only. The ISO Rockwell standard specifies the standard applied forces in converted Newton units, which, in some cases, approximates the exact kilogram-force value. To overcome this problem, it has been proposed to redefine the standard forces. ISO 6508 suggests changing to converted and rounded Newton units; for example, the total force of 1471 N (150 kgf) for the Rockwell C scale would be redefined as 1500 N. This proposed change would affect users of the Rockwell hardness test in two ways. Firstly, there would be a shift in the Rockwell hardness scales due to a change in the applied force levels. Secondly, test machines would have to be modified to accommodate the changed force levels.

2.1 Comparison to test method standards

The proposed change in forces would re-define the standard force levels as shown in Table 1. As shown in the table, the magnitude of the proposed changes to the total force levels are, in some cases, far outside the allowable force tolerances for Rockwell test machines specified in the current versions

Table 1. Traditional and proposed test forces with tolerances.

Traditional forces N (kgf)	Proposed forces N	Change in Applied Forces N	ASTM Tolerances on Applied Forces N	ISO Tolerances on Applied Forces N
98.07 (10)	100	+ 1.93	± 1.96	± 1.96
588.4 (60)	600	+ 11.6	± 4.41	± 5.88
980.7 (100)	1000	+ 19.3	± 4.57	± 9.81
1471 (150)	1500	+ 29.0	± 8.83	± 14.71
29.42 (3)	30	+ 0.58	± 0.589	± 0.588
147.1 (15)	150	+ 2.9	± 0.981	± 1.471
294.2 (30)	300	+ 5.8	± 1.961	± 2.942
441.3 (45)	450	+ 8.7	± 2.943	± 4.413

of ASTM E18 [2] and ISO 6508-2 [4]. This means that Rockwell tests made using the proposed test forces would not be valid tests in accordance with today's test method standards.

2.2 Shift in hardness scales

A change in either the preliminary-force level or the total-force level will result in a change in the Rockwell hardness measurement value. The reason for this hardness change is illustrated in figures 1a and 1b and figures 2a and 2b, which are plots created from Rockwell HRA test data measured at NIST. Figure 1a shows the applied force versus time during the HRA test, and Figure 1b shows the resulting indentation depth versus time. Each figure shows two overlapping HRA tests; the solid line represents a test using the standard preliminary-force of 98.07 N (10 kgf), and the dashed line represents a test where the preliminary-force was increased to 103.95 N (10.6 kgf). The test having the higher preliminary-force (dashed line) resulted in a slightly increased indentation depth at the first application of preliminary-force. Changing the preliminary-force level appears to have had negligible effect on the remaining part of the hardness test. Thus, an increase in the level of the preliminary-force causes an increase in the indentation depth at the first application of preliminary-force. This reduces the Δ depth measurement value used for the calculation of the hardness number (e.g.,

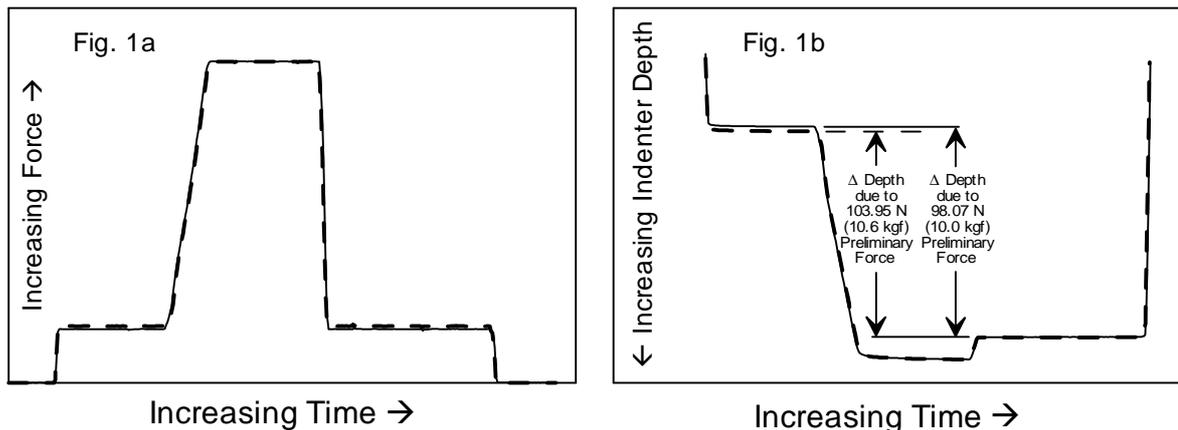


Figure 1. Force vs. time plot (figure 1a) and indenter-depth vs. time plot (figure 1b) demonstrating the effect of an increase in the preliminary-force for a Rockwell HRA test.

$HRA = 100 - \Delta\text{depth} / 0.002 \text{ mm}$ [2,3], and results in a higher hardness value. For the same reasons, a decrease in the level of the preliminary-force results in a lower hardness value.

Figures 2a and 2b demonstrate what occurs when the total-force level is increased. The test having the higher total-force (dashed line) resulted in an increased indentation depth at the application of total force. Following the application of total force, as the additional force is removed returning to the

preliminary-force level, most of the increased increment in indentation depth is maintained. The increased indentation depth decreases the Δ depth measurement value, which results in a lower hardness value. This is the opposite effect discussed previously for an increase in the preliminary-force level.

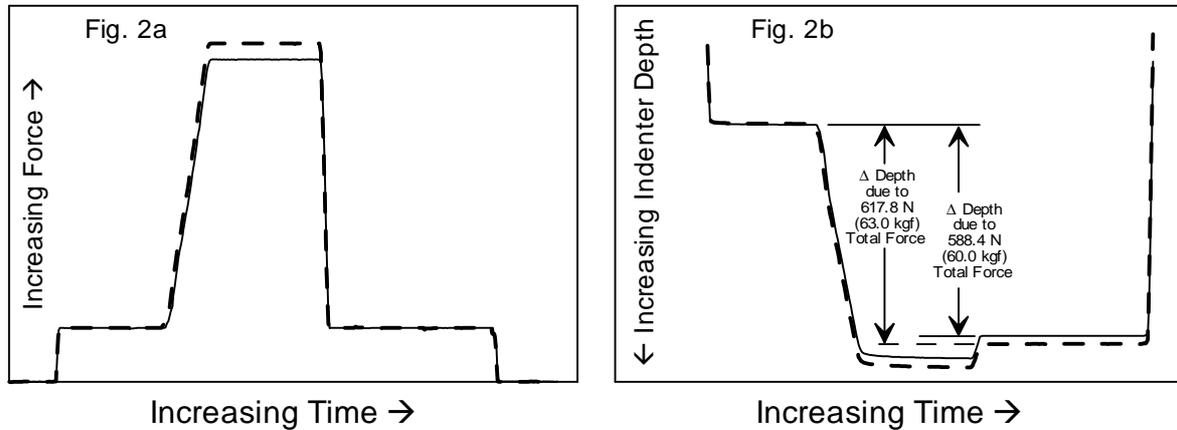


Figure 2. Force vs. time plot (figure 2a) and indenter-depth vs. time plot (figure 2b) demonstrating the effect of an increase in the total-force for a Rockwell HRA test.

To determine the magnitude of the shift in the Rockwell scales due to redefining the force levels, the relationship between applied force and the hardness result must be determined for each Rockwell scale. These relationships have been determined experimentally by several researchers [6] in the past; however, the measurement results between laboratories are too variable for accurately determining the effect of the proposed changes in forces. To obtain consistent data, the above relationships were measured experimentally at NIST using the Rockwell dead-weight standardizing machine [7]. Multiple hardness tests were performed for each Rockwell scale varying the test force by small increments, as shown in figures 3a and 3b for a 73 HRA material. Small changes in force were used to ensure that the effect was linear in the region of interest. The tests were made using steel and brass test blocks, and with the same test cycle. The relationship was determined for at least three levels of hardness for each Rockwell scale. The data for each hardness level was fit with a linear line, and the slope of the fitted line was plotted as a single data point for each Rockwell scale. This data was used to produce the plots given in figures 4a and 4b for preliminary-force, and in figures 5a and 5b for total-force.

In the case of changing to rounded Newton values, there are changes in both the preliminary-force and the total-force, which affect the hardness results in different ways. From figures 1 and 2, it appears that the two effects are independent of each other, which allows the two effects to be summed to obtain the total effect of changing both force levels. This assumption was found to be true, as indicated in figure 6, by making HRC tests at three hardness levels using the standard force levels, then

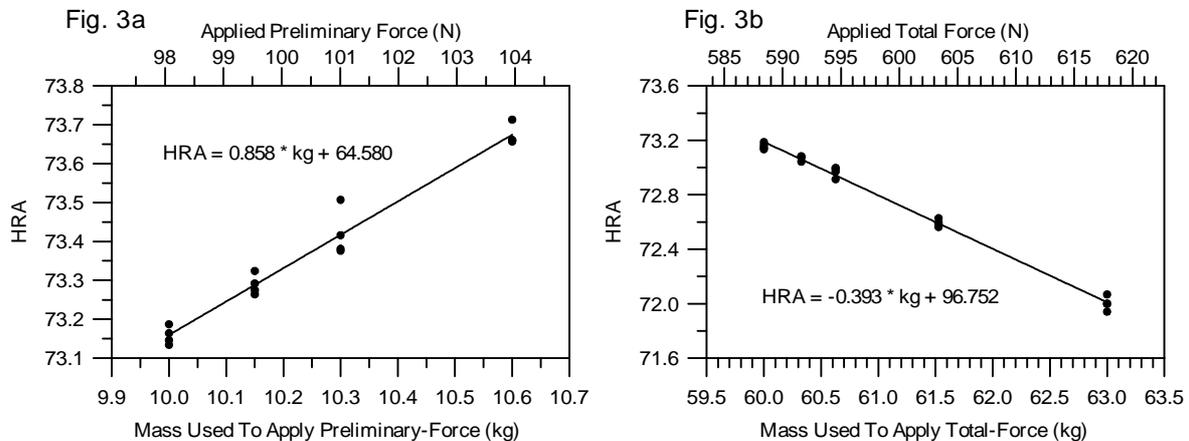


Figure 3. HRA test results where the preliminary-force (figure 3a) and total-force (figure 3b) were varied in small increments.

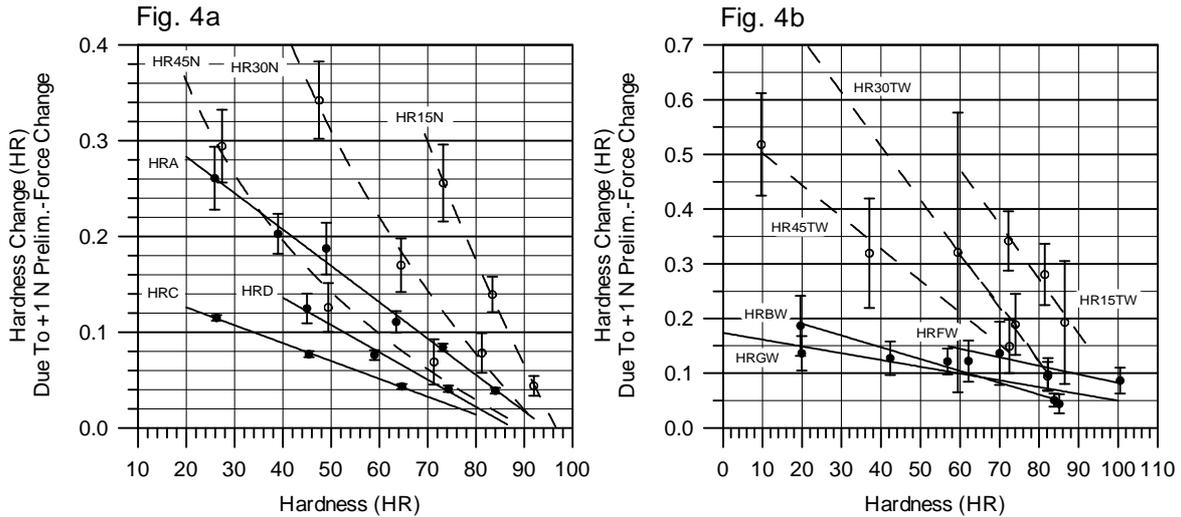


Figure 4. Measured hardness change due to preliminary-force change for diamond scales (figure 4a) and ball scales (figure 4b). The error bars represent one standard-deviation of the slope of the measurement data such as is presented in figure 3a.

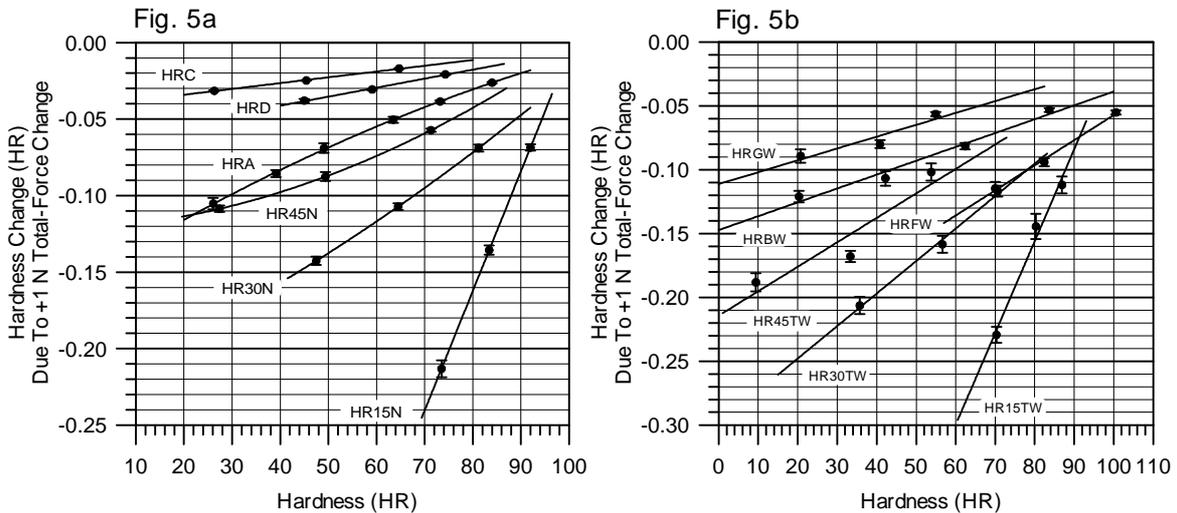


Figure 5. Measured hardness change due to total-force change for diamond scales (figure 5a) and ball scales (figure 5b). The error bars represent one standard-deviation of the slope of the measurement data such as is presented in figure 3b.

repeating the tests after increasing the preliminary-force by 1.961 N (0.2 kgf) and the total-force by 29.42 N (3 kgf). The three measurement data show good agreement with a prediction line calculated from the NIST curves given in figures 4a and 5a.

Using the data presented in figures 4 and 5 and the proposed changes in force data given in table 1, predictions can be calculated for how much the hardness value would shift from current levels due to changing to rounded Newton forces. This was done for all diamond indenter scales (figure 7a) and all 1.588 mm (1/16 in.) diameter ball indenter scales (figure 7b). The figures show that the shift in hardness would be as high as -0.8 HR points for the low hardness levels of the diamond indenter scales, and almost -3.0 HR points for some of the ball indenter scales. This would be a significant shift for many industries that use Rockwell hardness testing.

2.3 Hardness machine modification

A more significant effect on industry than the shift in the hardness scales would be the cost associated with modifying all Rockwell hardness testing machines to meet the new force levels. For testing machines that use masses (weights) for force application, either new weights would have to be

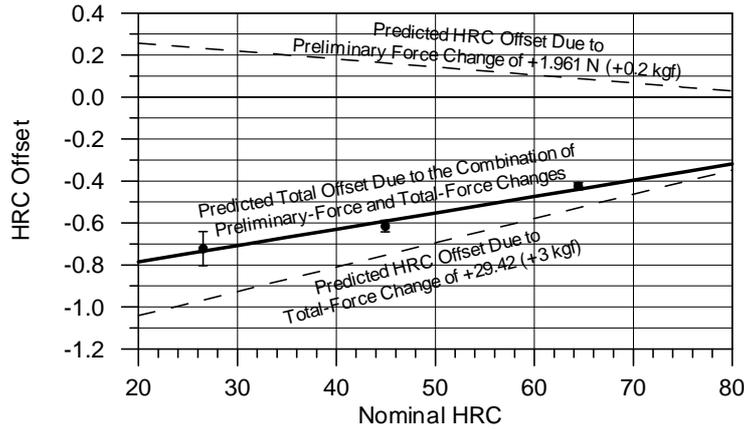


Figure 6. HRC offset from traditional HRC value due to increasing the preliminary-force by 1.961N (0.2 kgf) and the total-force by 29.42 N (3 kgf). The solid line indicates predicted values and the three data points indicate measured data. The error bars represent one standard-deviation of the mean of four measurements.

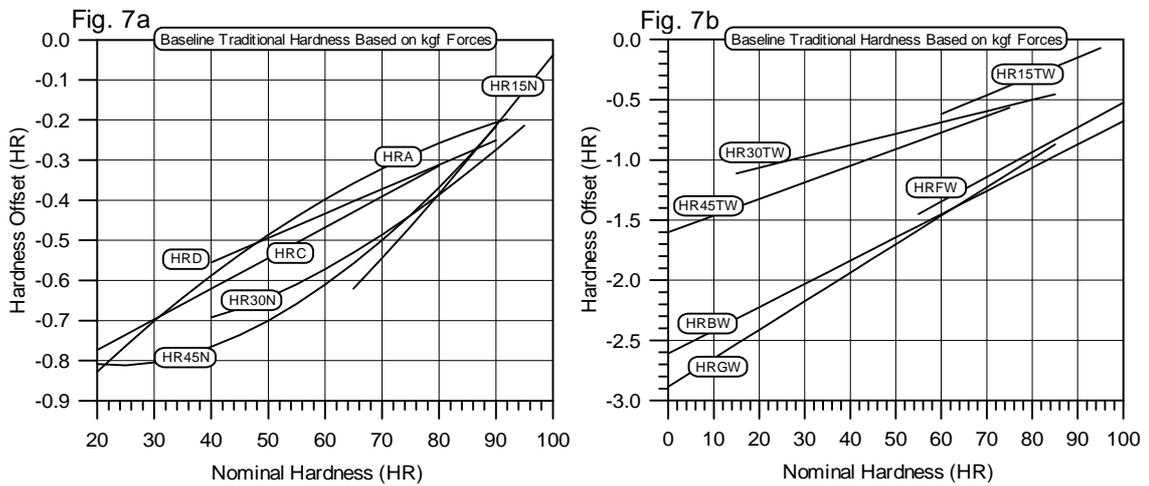


Figure 7. Hardness offset from traditional hardness values due to changing the test forces to rounded Newton values for diamond scales (figure 7a) and ball scales (figure 7b).

purchased or the existing weights modified and re-calibrated. For machines that apply force through a spring mechanism, the mechanism would have to be adjusted, if it is possible. For machines that apply force through a screw mechanism, where the force is maintained by way of feedback from a load-cell, the control software would have to be modified. In some cases, modification of older testing machines would not be possible at all. In addition to the physical modifications, each modified test machine would then have to undergo the costly process of direct verification as specified in the test method standards.

3 HARDMETAL BALLS

Until now, ISO has required that Rockwell tests for scales that use ball indenters be performed using only steel balls. A problem with steel balls is that they tend to flatten over time at the contact point with the test specimen. When used for a Rockwell test, a flattened ball indenter will not penetrate as deeply into test materials as would a round ball, indicating an apparent higher hardness for the material. The hardmetal ball was introduced to help overcome this problem. The harder tungsten carbide is much less susceptible to flattening than steel balls. Tests conducted at NIST have indicated that the use of a hardmetal ball may result in a lower apparent hardness than when a steel ball indenter is used, as shown in figure 8. This is likely to be partly due to differences in the compliance of the two ball materials. Fortunately, the authors of the ISO standard also require that the measurement values be reported with a scale designation ending in the letter "S" when a steel ball is used or "W" when a hardmetal ball is used. Although this designation differentiates between tests made with the two indenters, users of the measurement data must be aware that measurement differences may occur.

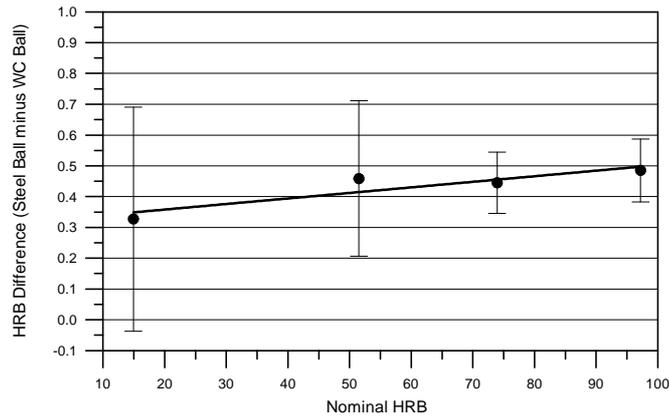


Figure 8. Rockwell B scale measurement results comparing the use of hardmetal and steel balls. The error bars represent one standard-deviation of the measurement data. The large error bars reflect the non-uniformity in the test blocks.

4 SUMMARY

The latest revision of the ISO 6508 Rockwell hardness test standard allows the use of two different materials for indenter balls: steel and tungsten carbide. The tungsten carbide indenter balls have the advantage of being less likely to flatten with repeated use. Users of the Rockwell hardness test must be aware that the use of hardmetal ball indenters may give differing measurement results than tests using steel ball indenters. The machine operator must be careful when reporting data to clearly communicate which type of indenter was used.

An additional change to the test standard is suggested for the next revision. The change would be to redefine the standard applied forces from kilograms-force to converted and rounded Newton units. Tests have shown that changing to the proposed applied forces may result in significant differences in test results as compared to measurements using the traditional force values. This change would require defining all new Rockwell hardness scales. In addition, the change would likely require costly mechanical or software modifications to all hardness testers, followed by direct verification. The advantage gained from redefining the applied forces would seem to be small compared to the costs associated with making this change.

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