Tolerancing Form Deviations for Rockwell Diamond Indenters

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Abstract: The form deviations of Rockwell diamond indenters can cause significant differences in Rockwell hardness readings. In order to control that effect, tolerances for form error deviations of Rockwell diamond indenters have been specified in both the American Society of Testing and Materials (ASTM) and the International Organization for Standardization (ISO) standards. In this paper, experimental data on the effects of form deviations of Rockwell indenters are analyzed. Finite Element Analysis (FEA) is used to simulate the effect of form deviations on HRC readings. Theoretical analyses are verified by experimental results. Based on these results, as manufacturing and measurement techniques for Rockwell diamond indenters improve, it is suggested that a tighter tolerance be specified for the form deviations of Rockwell indenters used for calibrations of reference blocks.

Keywords: Rockwell hardness, HRC, diamond indenter, form deviation, finite element analysis, FEA, ASTM E18-2002, ISO 6508-3:1999.

1. Introduction

Rockwell C hardness (HRC) is the most widely used mechanical test method for metal products. Influence quantities for measurement uncertainty of HRC tests include those from the testing machine, testing block, test conditions and Rockwell diamond indenter. The influence of the Rockwell indenter microform geometry plays an important role [1]. Technical specifications for Rockwell indenters include tip radius and form deviations, cone angle and cone flank straightness, and holder axis alignment error (Table 1) [2-4]. These geometrical specifications aim to control the uniformity of hardness performance of Rockwell indenters within a given tolerance [2-4].

In 1998, the National Institute of Standards and Technology (NIST) issued Standard Reference Material (SRM) 2810-2812 Rockwell C hardness (HRC) blocks in 25 HRC, 45 HRC and 63 HRC levels, respectively [5]. The NIST SRM Rockwell diamond indenter project is currently in progress. Based on the tolerances specified in ASTM (American Society of Testing and Materials) E18-02 [2] and ISO (International Organization for Standardization) 6508-3 [4] standard, technical requirements were specified for these NIST SRM Rockwell indenters. Based on the previous experimental data, however, we suspected that tolerances for form deviations of Rockwell indenters specified in both ASTM and ISO standards may be too large for NIST SRM Rockwell indenters. Finite Element Analysis (FEA) is used to simulate the effects of form deviations on the hardness performance of Rockwell indenters. The FEA results are in accordance with experimental data. In this paper, we introduce technical specifications for Rockwell diamond indenters specified in ASTM and ISO standards in Section 2. We discuss experimental data and FEA results in Section 3 and Section 4. Based on these results, tighter tolerances are suggested in Section 5 for the production of NIST SRM Rockwell indenters.

2. Specifications in ASTM and ISO Standards

There are two grades of Rockwell diamond indenters specified in ASTM and ISO standards [2-4]. The working grade indenters specified in ASTM E18-02 [2] and ISO 6508-2 [3] are used for ordinary hardness tests. The calibration grade indenters specified in ASTM E18-02 [2] and ISO 6508-3 [4] are used for calibrations of Rockwell hardness blocks. The geometric tolerances and hardness performance requirements for the two grades of diamond indenters are shown in Table 1.

The spherical tip of Rockwell diamond indenters tends to be manufactured as either a flat- or sharp-shaped surface because of the anisotropic property of the diamond. This can cause significant differences in the hardness readings. In order to control that effect, tolerances for form error deviations of Rockwell diamond indenters were specified in both ASTM and ISO standards. For the calibration grade Rockwell diamond indenters, ASTM E18-02 standard specifies a 0.002 mm tolerance for "local deviations from a true radius" [2], that means a ±2 μm tolerance for the form error deviations. The ISO 6508-3:1999 standard specifies a 0.002 mm tolerance for "the distance between the (two) concentric circles" by which the tip radius is determined [4].

Table 1. Technical specifications for two grades of Rockwell indenters

Microform Geometry and Performance Uniformity Requirements	Tolerance	
	Working Grade (ASTM E18-02 [2], ISO/6508-2 [3])	**Calibration Grade (ASTM E18-02 [2], ISO/6508-3 [4])**
1. Spherical Radius		
1a. Least Squares Mean	200 ± 10 μm	200 ± 5 μm
1b. Maximum Variation	200 ± 15 μm	200 ± 7 μm
1c. Profile Deviation	± 2 μm[2], 4 μm [3]	± 2 μm[2], 2 μm [4]
2. Cone Angle		
2a. Least Squares Mean		120° ± 0.1°
2b. Maximum Variation	120° ± 0.35°	120° ± 0.17° [4]
2c. Cone Flank Straightness	< 2 μm [3]	< 0.5 μm [4]
3. Holder Axis Alignment	± 0.5°	± 0.3°
Performance Uniformity Requirements	± (0.5-1) HR [2] ± 0.8 HR [3] with respect to a standard indenter	± 0.4 HR [4] with respect to a standard indenter

3. Some experimental data

The purpose of specifying tolerances for form error deviations, combined with the other tolerances specified for tip radius and cone angle (Table 1), is to ensure the uncertainty in the hardness performance of Rockwell indenters. For example, ±0.4 HR for the calibration grade indenters (Table 1) [4]. In order to investigate the effect of form deviation on HRC readings, two sets of previous experimental data were analyzed. First, the microform geometry of nine Rockwell diamond indenters was measured at NIST using a stylus instrument [1]. The geometry measurement results showed that the mean tip radii of the nine indenters ranged from 198.34 μm to 202.90 μm, and the mean cone angles ranged from 119.94° to 120.07°. The average profile deviation for these indenters was 0.47 μm (maximum peak) and 0.41 μm (maximum valley). These nine indenters were combined with two other indenters previously measured at NIST with close geometric parameters. These eleven indenters were tested for hardness performance using the NIST standard deadweight machine. The testing results showed a total performance variation range of -0.17 HRC to +0.23 HRC over a range of 25 HRC to 60 HRC for all 11 indenters (Fig. 1).

As a comparison, a second set of data was analyzed from tests using four NIST indenters and five NRLM (National Research Laboratory of Metrology, Japan) indenters, all measured at NIST using the same stylus instrument. Their microform geometry parameters were very close to the first set of 11 indenters. The mean tip radii of the second set of nine indenters ranged from 197.25 μm to 202.43 μm, and the mean cone angles ranged from 119.89° to 120.21° [1]. As to the form deviations of the second set of nine indenters, eight of them were very close to the first group of Rockwell indenters. Their average form deviations were 0.33 μm (maximum peak) and 0.38 μm (maximum valley). However, one indenter in the second group, numbered No.13392, showed significant bias in form deviation with respect to the other eight indenters. Its maximum peak deviation was 0.92 μm, which was significantly larger than the other eight indenters [1].

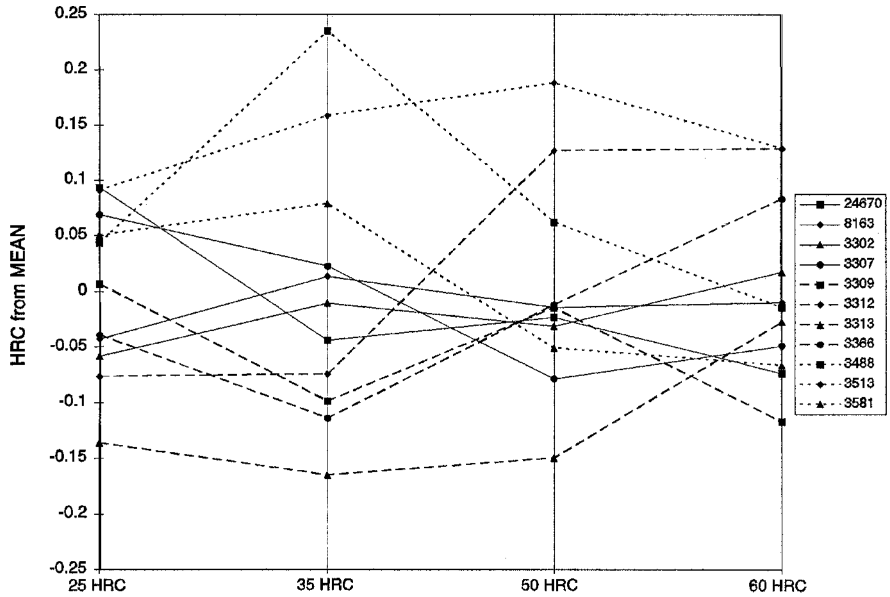

Fig. 1. Performance comparisons of 11 indenters, the variation range is (-0.17 to +0.23) HRC.

For all nine indenters of the second group, the hardness performance tests showed a total variation range of -0.23 HRC to +0.32 HRC over a range of 25 HRC to 63 HRC (see Fig. 2). That variation was larger than that of the first set of 11 indenters, -0.17 HRC to +0.23 HRC. However, the No.13392 indenter with the large form deviation showed performance bias with respect to the other eight indenters (see Fig.2). When the data for this indenter is removed, the other eight indenters show a performance variation range of ± 0.19 HRC HRC (with respect to the recalculated means) , which is close to the first set of 11 indenters.

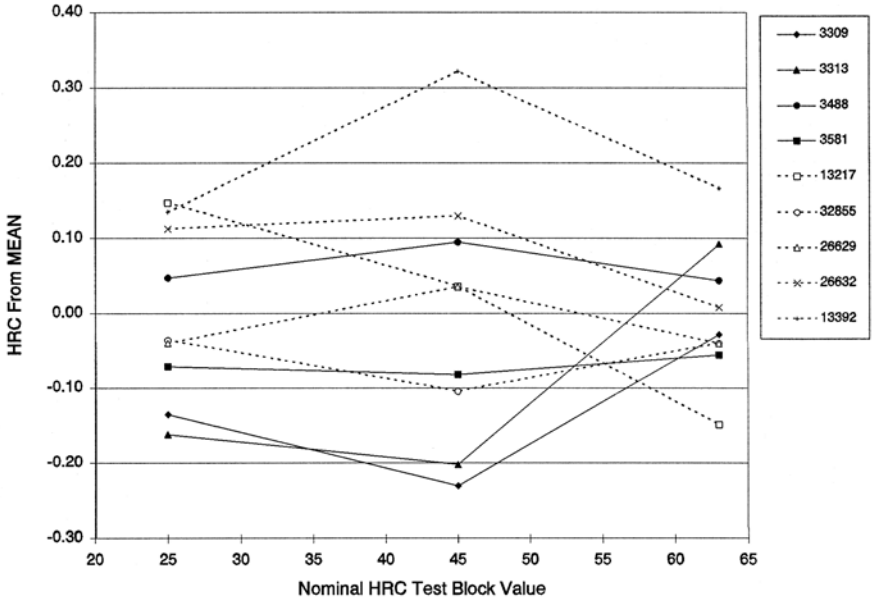

Fig. 2. Performance comparisons of nine indenters from NIST and NRLM, the variation range is (-0.23 to +0.32) HRC.

4. Finite element analysis results

In light of these data, we are investigating how form deviations would affect the function of the NIST SRM Rockwell indenters to be developed. It would be ideal if we could make a group of Rockwell indenters with the same least squares tip radius and cone angle but with different form deviations for controlled experiments. Since this is not possible at this time, FEA was used to simulate the effects of form deviation on the hardness performance of Rockwell indenters [6]. In the FEA model, a cosine function was added on a 200 μm tip radius of a Rockwell indenter. The function amplitude was varied to simulate the effects of different form deviations [6]. When the peak of the cosine function was located in the center of the indenter's tip, it represented a sharp-shaped Rockwell indenter with a central profile peak. Conversely, a central profile valley represented a flat-shaped Rockwell indenter [6].

The FEA simulation results showed that, for HRC tests of soft materials at the 25 HRC level, form deviation of the Rockwell indenter had very small effect [6]. That was in accordance with previous experimental results and conclusions [7], because the entire tip of the Rockwell indenter was in full contact with the soft material even during the preliminary testing force (98N) period. However, form deviations showed significant effect on HRC tests in the 45 HRC 45 and 64 HRC levels. From Fig. 3, it can be seen that when the central profile peak deviation increased to 2 μm (see Fig. 3, right), it meant that the Rockwell indenter is manufactured with a sharp shape on the spherical tip, that could cause about a 0.8 HRC increase in hardness at the 64 HRC level, and about a 0.6 HRC increase for HRC tests at the 45 HRC level. FEA simulation results also showed that when the central profile valley increased in depth (see Fig 3, left), it meant that the Rockwell indenter was manufactured with a flat shape, that could cause HRC readings to decrease. The effect is not as large as that of the profile peak, and there is no significant difference between the resulting HRC readings at 45 HRC and 64 HRC level. This is also in accordance with previous experimental results and conclusions that Rockwell indenters with sharp tips affect HRC readings more significantly than those with flat tips [7].

It must be noted that when a cosine function Is added to a 200 μm radius, the actual least squares radius for the new profile changes as well, depending on the shape of the new profile (flat or sharp). To calculate the net effect due to profile deviations, the effect due to stylus radius must be factored out of the results in Fig. 3. We are currently investigating the combined effect of tip radius and form error on the 3D topography of the Rockwell diamond indenters.

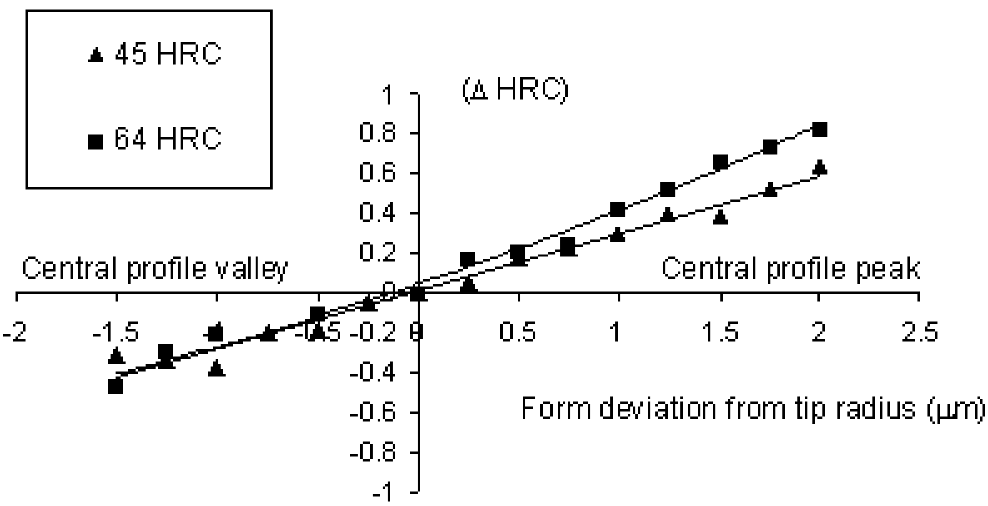

Fig. 3. HRC variations at HRC 45 and HRC 64 level with change of form errors.

5. Summary

From the experimental data and FEA results, it looks like either a ±2 μm [2] or 2 μm [4] tolerance for form deviations specified in ASTM E18-02 [2] and ISO 6508-3 [4] may be too large for the production of NIST SRM Rockwell diamond indenters. We suggest that tighter form deviation tolerance be used as a specification in the future national and international standards for the calibration grade Rockwell diamond indenters used for the calibration of reference hardness blocks.

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