Current state of Rockwell hardness in the world

Takeshi Sawa
Mitutoyo Corporation
20-1, Sakado 1-Chome, Takatsu-ku, Kawasaki-shi, Kanagawa 213-8533, Japan
E-mail: takeshi_sawa@mitutoyo.co.jp

Abstract. For the purpose of finding out the difference of the hardness value of major countries, we obtained the hardness reference blocks for Rockwell scales that were certified at the national metrology institute and four other equivalent institutions, and evaluated them using the hardness testing machines that we own. The experimental result showed a large difference among the institutions; 0.7 HRC with 30HRC and 1.4HRBW with 30HRBW at maximum. ISO6508-2 and ASTM E18 specify the allowance for the indirect verification. However, taking the expected difference of the hardness value and the experimental result into consideration, the verification result implies that the difference may exceed the allowance specified by the ASTM standard.

1. Introduction
The hardness value is an industrial quantity, yet sometimes it is handled as a physical quantity. For example, key comparison is being conducted BIPM (Bureau international des poids et mesures). However, the hardness round-robin measurement contains difficulties such as a difference of machine principle or variation factor that may influence the test conditions. Consequently, only a partial test method or only some scales are implemented. Furthermore, the evaluation method for uncertainty of the hardness test is not unified. Giving consideration to the above situation, the hardness value may vary in each country and judging the validity of the difference can be difficult. On the other hand, there is a case where the value of the reference block is considered as an absolute indication for the accuracy of the testing machine. However, due to the previously stated reasons, it is difficult to evaluate the accuracy of the testing machine based on only the amount of difference of the reference block. This can be a great issue for the testing machine manufacturers. For the purpose of finding out the difference of the hardness value of major countries, we obtained the hardness reference block that were certified at the national metrology institute and other equivalent institutions, and evaluated the difference of the calibration values. Also, referring to the standard that specifies the requirements for the reference block calibration, we estimated uncertainty of the calibration value and calculated the variation of the hardness value. This time, we evaluated Rockwell hardness, which is commonly used world-wide and tends to show a large difference depending on the testing machine.

2. Experiment
2.1. Evaluation method and target scale
We obtained the hardness reference block from the national metrology institute and other equivalent institutions, A, B, C, and D, and checked the difference of the calibration value. Since each reference blocks is different, directly comparing the calibration value is impossible. In this evaluation, we used
hardness testing machines that we own (testing machine for the calibration of the hardness reference block), and compared the measurement value obtained with the hardness testing machine and the calibration value of the reference block. Table 1 describes the obtained Rockwell scales and how we obtained them. We either purchased the calibrated reference block or sent the reference block and requested a calibration. We both purchased and requested the calibration for the institution D, and each case is represented as D1 and D2. Also, Table 2 describes the hardness range for each scale and the material of the reference block.

Table 1. Evaluating scales and how we obtained

| Institutions | Obtained scale | How to |     |
|--------------|----------------|--------|-----|
| A            | HRC            | Calibrated |     |
| B            | HRC, HR30N, HR15N | Purchased |     |
| C            | HRC, HR30N, HR15N | Calibrated |     |
| D1           | HRBW, HR30TW, HREW | Purchased |     |
| D2           | HRBW, HR30TW, HREW | Calibrated |     |

2.2. Experimental Condition

For evaluation, we used Mitutoyo Rockwell hardness testing machine SHT-31. The specifications and accuracy are conforming to ISO6508-3 Calibration of reference blocks 1. Also, the test condition including the test force application time and dwell time are set conforming to the same standard.

3. Test results

Figure 1 describes the difference between our measured value of each scale and the calibration value of the reference block. The median is the average value of the differences of the institution. Error bars indicate the expanded uncertainty reported by each institution. R in the figure indicates the maximum difference of the results. In general, R is 0.5 HR or lower. However, 30 HRC and 30 HRBW showed a large difference, 0.7 HRC and 1.4 HRBW respectively.

Figure 1. Evaluation result of each scale

4. Estimation of uncertainty in the reference block calibration

As shown in Figure 1, considering the uncertainty of each institution for 30 HRC and 30 HRBW, there is a possibility that the hardness value may not be consistent. Therefore we decided to examine these scales. Even though the calibration condition of each institution conforms to ISO6508-3, it may not be necessarily the same and have some degree of differences within the specified range. For example, the total test force application time is specified as 1s to 8s in the standard. However, the median of this range is not managed in the recommended condition but in the one defined by each institution or in the
one the testing machine in use can apply to. Therefore, the hardness value may differ due to the difference of the conditions within the allowance specified by the standard.

Then, to obtain the standard uncertainty of each factor, we assumed the allowance of the standard as the rectangular distribution except for the indentation depth measurement device specified by the expanded uncertainty. The allowance of the deformation of the testing machine is specified as ±1.0 HR by ISO. However, we assumed the variation as ±0.3 HR since the machine is each country's standard machine. Also, for the uniformity of the reference block, we considered the variation of measurement values (the average of 5 points) as the standard uncertainty. Since the hardness value is an industrial quantity, it is impossible to calculate the change of the hardness value (sensitivity coefficient) theoretically. However, in this evaluation, we used the coefficient experimentally calculated for some scales and indicated in the guide line by EU National Metrology Institute or posted on the web site of NPL. Only for the sensitivity coefficient of the diameter of the ball indenter, we referred to COOMET comparison, issued by BIPM. The estimated uncertainty budget for the reference block calibration is described in the table 3 and table 4. The result of each scale showed small influence with the test force and the indenter form. Therefore, the main factor can be the deformation of testing machine or the uniformity of the reference block.

Table 3. Uncertainty of calibration value using 30HRC

| Uncertainty factors             | Standards  | Variation | Standard uncertainty | Sensitivity coefficient | Standard uncertainty |
|---------------------------------|------------|-----------|----------------------|-------------------------|----------------------|
| Preliminary test force          | ±0.20%     | ±0.196N   | 0.113N               | 0.1                     | 0.0113 HRC           |
| Total test force                | ±0.10%     | ±0.119N   | 0.849N               | 0.036                   | 0.0306 HRC           |
| Preliminary test force duration | ±3±1s      | ±1s       | 0.5774s              | 0.008                   | 0.0046 HRC           |
| Force application time (speed)  | 1.8s       | ±0.10µm/s | 5.77µm/s             | 0.013                   | 0.0751 HRC           |
| Test force duration             | 3±1s       | ±1s       | 0.5774s              | 0.06                    | 0.0346 HRC           |
| Reading stabilization           | ±4±1s      | ±1s       | 0.5774s              | 0.002                   | 0.0012 HRC           |
| Depth measurement device        | 0.2 µm     | ±0.2µm    | 0.1 µm               | 0.5                     | 0.050 HRC            |
| Radius of indenter tip          | 200±5µm    | ±5µm      | 0.289 µm             | 0.02                    | 0.058 HRC            |
| Cone angle of indenter          | 120±0.1°   | ±0.1°     | 0.058°               | 1.2                     | 0.0693 HRC           |
| Deformation of machine          | ±1±0HR     | ±0.3HR    | 0.173HR              | 1                       | 0.173 HRC            |
| Uniformity of reference block   | 0.7±HR     | ±0.35HR   | 0.090HR              | 1                       | 0.0904 HRC           |
|                                 |            |           |                      |                         |                      |
| Combined standard uncertainty   | 0.238 HRC  |           |                      |                         |                      |
| Expanded uncertainty (k = 2)    | 0.5 HRC    |           |                      |                         |                      |

Table 4. Uncertainty of calibration value using 30HRBW

| Uncertainty factors             | Standards  | Variation | Standard uncertainty | Sensitivity coefficient | Standard uncertainty |
|---------------------------------|------------|-----------|----------------------|-------------------------|----------------------|
| Preliminary test force          | ±0.20%     | ±0.196N   | 0.113N               | 0.1                     | 0.0113 HRBW          |
| Total test force                | ±0.10%     | ±0.098N   | 0.566N               | 0.06                    | 0.0303 HRBW          |
| Preliminary test force duration | ±3±1s      | ±1s       | 0.5774s              | 0.05                    | 0.0289 HRBW          |
| Force application time (speed)  | 1.8s       | ±0.7s     | 4.042s               | 0.02                    | 0.0808 HRBW          |
| Test force duration             | 3±1s       | ±1s       | 0.5774s              | 0.1                     | 0.0577 HRBW          |
| Reading stabilization           | ±4±1s      | ±1s       | 0.5774s              | 0.12                    | 0.0693 HRBW          |
| Depth measurement device        | 0.2 µm     | ±0.2µm    | 0.1 µm               | 0.5                     | 0.050 HRBW           |
| Diameter of ball indenter       | 1.588mm ±2µm| ±2µm     | 1.155 µm             | 0.007                   | 0.0081 HRBW          |
| Deformation of machine          | ±1±0HR     | ±0.3HR    | 0.173HR              | 1                       | 0.173 HRBW           |
| Uniformity of reference block   | 0.7±HR     | ±0.4HR    | 0.258HR              | 0.258 HRBW               |                      |
|                                 |            |           |                      |                         |                      |
| Combined standard uncertainty   | 0.347 HRBW |           |                      |                         |                      |
| Expanded uncertainty (k = 2)    | 0.7 HRBW   |           |                      |                         |                      |

5. Discussion

5.1. Evaluation of test result with estimated uncertainty

The calibration value of the test reference block is predicted to vary in the range of the expanded uncertainty indicated in the table 3 and table 4: 0.5 HRC with 30 HRC, and 0.7 HRBW with 30 HRBW. These estimated uncertainties are equal to or greater than the uncertainty reported by each institution. This is probably because estimated uncertainty is based on the maximum value of the variation of the test parameter. Furthermore, the experimental result showed the larger value in the comparison between the estimated uncertainty and the hardness value obtained from the experimental
results. Based on the above, it can be assumed that there is an unknown uncertainty factor other than indicated in the table 3 and 4 for these two scales.

5.2. Validity of standards
We compared the allowance for the indirect verification indicated by ISO 5 and ASTM 6, which is used world-wide, and our evaluated value. We estimated the uncertainty of the hardness value measured with the testing machine (general testing machine) twice as much the uncertainty measured with the testing machine for the calibration of the hardness reference block. Practically, the above described unknown uncertainty $\alpha$ is added. The table 5 describes the estimated variation of the hardness value measured with the general testing machine and the allowance for the indirect verification of each specification. For ISO, it is assumed that the value stays within the allowance even considering the variation of the hardness value. For ASTM, on the other hand, it is likely that the value exceeds the allowance.

Table 5. Estimated variation of hardness value and allowance of the specification

|                  | 30 HRC | 30 HRBW |
|------------------|--------|---------|
| Estimated variation of hardness value | ±1.0 HRC + $\alpha$ | ±1.4 HRBW + $\alpha$ |
| Allowance of ISO standard          | ±1.5 HRC | ±4.0 HRBW |
| Allowance of ASTM standard         | ±1.0 HRC | ±1.5 HRBW |

$\alpha$: Unknown uncertainty

6. Conclusion
Based on the evaluation of difference of the hardness reference block calibration value obtained from four institutions equivalent to the national metrology institute, we may conclude the following:

- With 30 HRC and 30 HRBW, the calibration value of each institution showed large differences; 0.7 HRC and 1.4 HRBW, respectively.
- We estimated the uncertainty of the reference block calibration value from the standard's allowance. The expanded uncertainty is estimated 0.5 HRC ($k = 2$) with 30 HRC, 0.7 HRBW ($k = 2$) with 30 HRBW.
- Based on the actual test results and the estimated variation of the hardness value, it is likely that the measurement value of the general testing machine exceeds the allowance for the indirect verification specified by the ASTM standard.

Although the hardness test is performed based on the standards, variations in hardness values are also seen in some countries because there are variation within allowance values of each parameter and unknown uncertainty. On the other hand, under the current circumstances, accredit programs or traceability is effectively used. For the manufactures of the hardness testing machine, this can be a big problem that a company by itself cannot handle. For the sake of industry, we hope that the consistency verification referring to the public standards will be enhanced.

7. Acknowledgments
I would like to express our gratitude to Dr. Hattori, Group Leader of National Institute of Advanced Industrial Science and Technology (AIST) for his advice on this evaluation.

8. References
[1] ISO 6508-3:2016 Metallic materials Rockwell hardness test: Calibration of reference blocks
[2] EURAMET/cg-16/v.01,Guidelines on the Estimation of Uncertainty in Hardness Measurements, 2007
[3] NPL: Hardness methods and sensitivity coefficients, http://www.npl.co.uk/science-technology/mass-and-force/hardness/, Dec. 2017
[4] COOMET Rockwell PTB/KazInMetr comparison Final report, 2008
[5] ISO 6508-2:2016 Metallic materials Rockwell hardness test: Verification and calibration of testing machines
[6] ASTM E18-17e1 Standard Test Methods for Rockwell Hardness of Metallic Materials