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TRACEABILITY SYSTEM OF ROCKWELL HARDNESS C SCALE IN JAPAN

Koichiro HATTORI, Satoshi TAKAGI, Hajime ISHIDA and Takashi USUDA

National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

Abstract – In the early of 2003, the traceability system of the Rockwell hardness standard have been developed in Japan. The National Metrology Institute of Japan (NMIJ) started to provide the national primary hardness standards, one of which is the hardness reference blocks, and the other one is the accreditation of the Rockwell hardness tester.

In this paper, we present the detail of uncertainty transfer between the NMIJ and the secondary standard laboratories.

Keywords: Rockwell hardness, traceability, uncertainty

1. CALIBRATION SERVICE AND ACCREDITATION PROGRAM IN JAPAN

NMIJ started calibration service of secondary standard Rockwell testing machine (jcss) in 2002, and the National Institute of Technology and Evaluation (NITE) also started two accreditation program of traceability of Rockwell hardness, one is the traceability of calibration of testing machines and the other is calibration of standard blocks. The name of the service is Japan calibration service system (JCSS). The JCSS accredits company, supplying the calibration service to a customer with the traceable Rockwell hardness values.

Because of the traceability system operated under the measurement-law of Japan, jcss and JCSS have some difference. The NMIJ only calibrates the secondary standard Rockwell hardness machine on the jcss calibration system, and there are no difference of machines between calibration of standard blocks and calibration of testing machine at this point. The calibrated laboratories declare their calibration services (calibration of testing machine/ standard block) and their uncertainty, after jcss calibration.

The uncertainty sources of Rockwell hardness block issued by secondary laboratory are shown in the table 1 that is calculated for the standard blocks provided by the secondary laboratory. The terms 1, 2, 3 and 4 is determined as the result of jcss calibration, certified by NMIJ. The uncertainty of standard indenter is calculated of combination of the accidental error and uncertainty of national primary indenters when the indenter is compared with the primary indenter.

Finally the declared uncertainty of the Rockwell hardness value is tested under the accreditation program of the JCSS traceability system conducted by NITE. The NMIJ certified standard hardness blocks, which are used in this proficiency test (Fig.2).

The details of the uncertainty calculations and evaluation of declared uncertainty are presented as following sections.

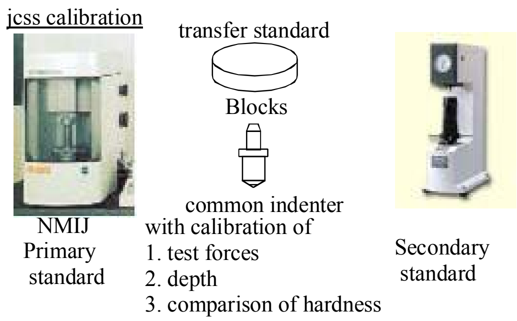

Fig. 1 schematic of secondary standard on the jcss calibration system.

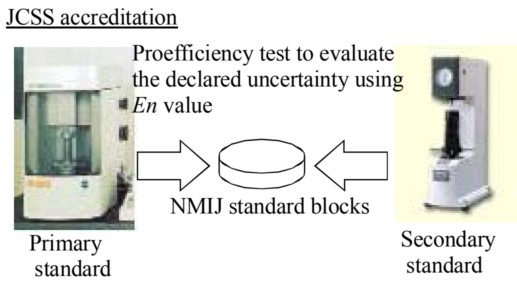

Fig. 2 evaluation of declared uncertainty through the proficiency test on the JCSS accreditation program.

Table 1. The uncertainty sources of the JCSS certified block.

	Source of uncertainty	
1	Preliminary test force	u_{F0}
2	Total test force	u_F
3	Depth measuring device	u_h
4	Hardness comparison with common indenter	u_{comp}
5	Standard indenter	u_{Ind}
6	Hardness variation of the block	u_{block}

Sources 1-4 are evaluated by NMIJ
5,6 are evaluated by secondary laboratory.

2. UNCERTAINTY OF FORCE

To Estimate the uncertainty of the force, we measured the force at three different heights and evaluate the uncertainty as

$$u_{f2} = \sqrt{\frac{\sum_{h=1}^{3}\sum_{n=1}^{3}(f_{h,n\,\mathrm{mesured}} - f_{\mathrm{standard}})^2}{h \cdot n}}, \quad (1.)$$

where the h is the number of measured height and n is the number of repeat at the same height. f_{standard} is the 98.07 and 1471 N for the preliminary test force and the total test force, respectively. The total standard uncertainty of force is calculated by the combination of uncertainty of force measuring device, u_{f1}, as

$$u_f = \sqrt{u_{f1} + u_{f2}}\ . \quad (2.)$$

In this method, the uncertainty of the force is estimated as a total standard deviation from the standard values. The advantage of this method is that it can be all measured deviation can be considered, and the bias component can be also considered.

The coverage factor is useful when the uncertainty is given only by the accidental error in the measurement. In addition the treatment of the effect of non-corrected bias component is not easy. We believe that this method is one of the best solutions of the uncertainty evaluation including the non-corrected bias component.

3. UNCERTAINTY OF THE DEPTH-MEASUREING DEVICE

Depth measuring device is evaluated as follows: determination of the zero point as a set position, where the equivalent of 100HRC. After the depth measuring device is once moved to the downward over the 200μm (0 HRC) and after moved to measurement position (ex. 200μm). Then the measurement was carried out at each position that interval is the 20μm (~10HRC). The corrected depth measuring data was evaluated as,

$$u_{h2} = \sqrt{\frac{\sum_{i=1}^{11}\sum_{j=1}^{3}(h_{ij} - h_{std\,i})^2}{n}} \quad (3.)$$

where the i is the position and the j is the number of repeats, and the n is the total number of measurement, respectively. The total uncertainty of the depth-measuring device is given by the combination of the standard uncertainty of the depth-calibration device, u_{h1}, and the uncertainty due to the resolution of the depth-measuring device (or hardness indicator), u_{hres} and u_{h2},

$$u_h = \sqrt{{u_{hstd}}^2 + {u_{h2}}^2 + {u_{hres}}^2}\ . \quad (4.)$$

4. UNCERTAINTY OF THE INDENTER

The indenter characteristic is the most significant parameter for measurement value, even if the indenter is suitable for the ISO requirements [1].

4.1 Standard indenters

It is recommended that the each secondary laboratory should have one or more standard indenters. The definition of the standard indenter in the JCSS system is: the indenters a) are suitable for the ISO requirement [1] and b) have the correction values for each hardness levels. The hardness values of the JCSS certified blocks expressed as a corrected hardness values.

To determine the correction values the comparison of the hardness values between the national primary indenter are carried out using stable testing machine and made a sufficient number of indentations to the same blocks [2]. The correction values are determined as a bias from the national primary indenters. The correction values are determined 10HRC interval, from 20 to 65 HRC, typically.

The national primary indenters also have correction values. This is based on the following assumptions that the hardness variation of each indenter comes from the variation of the contact area and this variation can be comparable if the stable testing machine is used to the comparison.

4.2 Uncertainty of national primary standard indenters

The NMIJ has about 30 national primary standard indenters. These indenters have the correction values, which value is defined as a hardness deviation from the ideal standard indenter [3]. The detail of the determination of the correction values is given in the other presentation[4]. We introduce it briefly: There are six characteristic parameters for each indenter, the five different average curvatures (for five different average angle for the sphere part of the indenter) and one parameter for the cone angle. Many actual shape indenters are prepared and the hardness measurement was carried out for each indenter. The multiple regression analysis was carried out using following model,

$$\begin{aligned} H_i - H_0 &= a_1(p_{1i} - 200) + a_2(p_{2i} - 200) + \ldots \\ &+ a_5(p_{5i} - 200) + a_6(p_{6i} - 120) + \delta_i \end{aligned}, \quad (5.)$$

where H_i and H_0 are the hardness values of measured and ideal for the block, respectively. The parameters p_{ni} is the measured characteristic parameters and a_n is the coefficients of the regression. The error term δ includes accidental error and the error due to the hardness variation of the position. The ideal hardness is estimated, as that is the value of the regression curve at characteristic parameters set to that of ideal shape indenter, i.e. 200μm for curvature and 120° for cone angle. The uncertainty of the indenter is determined by the remained error of the regression analysis.

The standard uncertainty of correction values of the national primary standard indenters is about 0.13 HRC at 60HRC level, and it depends on the hardness levels due to the difference of non-uniformity of the blocks.

5. COMPARISON OF HARDNESS VALUES USING COMMON INDENTER

To determine the total uncertainty of testing machine of secondary laboratory, we compare the measurement values of same blocks using common indenter. The total deviation from the primary hardness tester including test cycle effect is evaluated through the comparison.

5.1 Hardness comparison using 4d method

The NMIJ adopted the following method for the hardness comparison, the method had developed by the one of the authors, and we call it 4d method. Generally, the hardness varies gently in the block. Therefore the difference of measured values will be very small with decreasing the interval of two indentations. Because of the hardness change due to the pre-performed indentation, the limit of actual distance between the two indentations will be 4 times of diameter of indentation. This interval between the indents is the origin of the name of this method. In the 4d method, the hardness difference between two indentations can be regarded as an accidental error.

The theoretical of this comparison can be calculated as follows: The hardness values of second indentation, H_{2i} and corresponding reference indentation, H_{1i} is given by,

$$\begin{aligned} H_{1i} &= H_0 + m_1 + p_{ij} + \delta_{ij} \\ H_{2i} &= H_0 + m_2 + p_{ik} + \delta_{ik} \end{aligned} \qquad (6.)$$

where H_0 is the ideal hardness value of the block, p_i is the hardness variation depending on the indent position i, m is the hardness variation due to the differences of machines, δ_i is the accidental error and 1, 2 denote the reference and second indentations, respectively. The hardness difference of the corresponding point is given by,

$$\Delta H_i = H_{2i} - H_{1i} = m_2 - m_1 + p_{ij} - p_{ik} + \delta_{ik} - \delta_{ij}\ , \qquad (7.)$$

and the mean value of the hardness difference is,

$$\overline{\Delta H} = m_2 - m_1\ . \qquad (8.)$$

Here, we neglect terms of the mean values of the p_i and δ_i, using after nth measurements using,

$$\frac{1}{n}\sum_{i=1}^{n} p_i \approx 0 \ \text{and}\ \frac{1}{n}\sum_{i=1}^{n} \delta_i \approx 0\ . \qquad (9.)$$

The standard deviation of the comparison using 4d method will be expressed as

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}(\Delta H_i - \overline{\Delta H})^2 = \frac{1}{n}\sum_{i=1}^{n}(p_{ik} - p_{ij} + \delta_{ik} - \delta_{ij})^2\ . (10.)$$

Consider the independence between p_i and δ_i, δ_{ij} and δ_{ik}.. It can be assumed that the amplitude of the accidental error will be the same. We obtain,

$$\sigma^2 = \frac{2}{n}\sum_{i=1}^{n}\delta^2 + \frac{1}{n}\sum_{i=1}^{n}(p_{ij}^2 + p_{ik}^2 - 2p_{ij}p_{ik}) \qquad (11.)$$

On the other hand, the comparison of the hardness values is carried out using the mean hardness values of the block. We also calculate the deviation of the mean hardness comparison. The mean hardness values are given by,

$$\begin{aligned} \overline{H}_{1i} &= H_0 + m_1 \\ \overline{H}_{2i} &= H_0 + m_2 \end{aligned} \qquad (12.)$$

Here the mean terms of the p_i and δ_i are neglected. The difference between the mean values m_1 and m_2 is given by the same as that obtained by the 4d method,

$$\Delta H = m_2 - m_1\ . \qquad (13.)$$

The standard deviation of the mean hardness value for the reference $\overline{H}_{1i}$ is given by,

$$\sigma_1^2 = \frac{1}{n-1}\sum_{i=1}^{n}(H_{1i} - \overline{H}_{1i})^2 = \frac{1}{n-1}\sum_{i=1}^{n}(p_{ij} + \delta_{ij})^2 = \frac{1}{n-1}\sum_{i=1}^{n}(p_{ij}^2 + \delta^2)\ . \qquad (14.)$$

Here we use the result of above discussion, the cross terms can be neglected and the amplitude of standard deviation of the accidental error is set to the δ. The total standard deviation of the mean hardness comparison is given by the adding the two independent deviations of two measurements,

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 = \frac{2}{n-1}\left(\sum_{i=1}^{n}\delta^2 + \sum_{i=1}^{n}p_i^2\right). \qquad (15.)$$

The standard deviation of the 4d method is decreased when the correlation between the p_{ij} and p_{ik} becomes strong. The result of 4d method is corresponding to that of mean hardness comparison if the no-correlation is observed, it is the worst deviation limit of the 4d method. We also check the validity of the method, experimentally.

5.2 experimental evaluation of validity of 4d method

The national primary hardness tester SHT-32 Rockwell hardness tester was used in the experiment. SHT-32 is the lever-amplified dead weight type and the holographic gages used to depth measuring device. The nominal hardness levels are 64, 60, 40, 30 and 20 HRC. The hardness measurement was carried out four times; the intervals of the measurements are about one-week for the 2nd measurement, about four-months for the 2nd-3rd and one-week for the 3rd-4th measurement. Table 1 shows the typical example of measurement obtained the 40HRC block. The 2nd-4th indentation data are obtained by the measurement using 4d method around the 1st indent. The hardness variation of the each measurement point is shown in the Fig. 3. The connecting line shows a measured hardness observed in the same day. The hardness variation depending on the measurement position shows the similar tendency. That means the correlations between the indentations may be strong.

Table 1. The hardness observed using 4d method for 40HRC block.

Indent position	1st 0 week	2nd 1 week	3rd 16 weeks	4th 17 weeks
1	40.3	40.4	40.2	40.4
2	40.4	40.4	40.3	40.4
3	40.3	40.3	40.3	40.3
4	40.6	40.6	40.5	40.5
5	40.3	40.4	40.3	40.4
6	40.3	40.3	40.2	40.3
Average	40.37	40.40	40.30	40.38

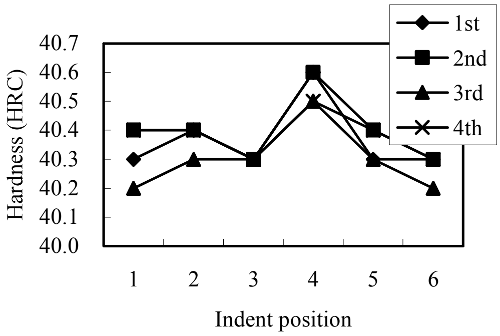

Fig. 3. The hardness observed using 4d method.

Table 2. One-way analysis of variance for 40HRC block.

Indent position

factor	ss	dof	variance	p value
between groups	0.19	5	0.03875	5.20E-05
within groups	0.06	18	0.0034722	

Measured day

factor	ss	dof	variance	p value
between groups	0.03	3	0.0115278	3.96E-01
within groups	0.22	20	0.0110833	

The result of one-way analysis of variance is shown in table 2. We regarding that the line data and the row data as the same group in the analysis of “indent position” and “measured day” in the table 2, respectively. The 4d method and the mean hardness comparison are corresponding to the indent position and the measured day in the table, respectively. The analysis indicates that the effect of testing machine instability depending measurement day is much smaller than that effect of the hardness variation of the block. The calculated standard deviations of these comparisons are 0.06 HRC for 4d method and 0.15 HRC for the mean hardness comparison and that is directly reflected the uncertainty of the calibration. The uncertainty of the transfer block using hardness comparison is estimated as about 0.07 HRC. As the largest uncertainty source, the indenter is neglected because the indenter is commonly used in the comparison.

The result of one-way analysis obtained other hardness levels are shown in table 3. The p values of the comparison is small excepting 60HRC block that is because the 60HRC block is very good so that the measured range of hardness variation was very small (0.1HRC). Then the effect of 4d method looks slightly small.

Table 3. The one-way analysis of variance for 4d method.

64HRC

factor	ss	dof	variance	p value
between groups	0.13	5	0.260	4.51E-10
within groups	0.09	18	0.005	

60HRC

factor	ss	dof	variance	p value
between groups	0.03	5	0.006	9.17E-02
within groups	0.04	18	0.002	

30HRC

factor	ss	dof	variance	p value
between groups	0.07	5	0.014	5.17E-03
within groups	0.05	18	0.003	

20HRC

factor	ss	dof	variance	p value
between groups	0.05	5	0.011	3.06E-02
within groups	0.06	18	0.003	

Finally the uncertainty of hardness comparison using 4d method is given by,

$$u_{comp\_2} = \sqrt{\frac{\sum_i (H_{2i} - H_{1i})^2}{n}} . \qquad (16.)$$

where, the hardness value, H_{2i} is compared with corresponding reference-indentation, H_{1i} and n is the number of indents. Then the uncertainty of comparison is determined after combined with the uncertainty of transfer standard block, u_{comp_1}.

$$u_{comp} = \sqrt{u_{comp\_1}^2 + u_{comp\_2}^2} \qquad (17.)$$

The u_{comp_1} is considered a lower limit of uncertainty, if the measurement values equal to the standard one and is about 0.07 HRC that is determined by the direct calibration result of NMIJ without indenter and discussed standard deviation of the block using 4d method. The uncertainty of comparison will be expected about 0.09 HRC using u_{comp_1} =0.07 HRC and u_{comp_2} = 0.06 HRC when the same tester is used in the comparison.

6 PROFICIENCY TEST

6.1 Proficiency test to evaluate the declared uncertainty

As mentioned at section 1, the declared uncertainty is evaluated by the blind test conducted by the NITE. The standard block certified by the NMIJ is used in the test. Generally the an indenter is selected from the national primary standard indenters, arbitrary, to determination of the hardness of block, and that means the hardness values of the block is dispersed artificially.

The hardness of the block is determined as a mean value of the six indentations; we perform one indentation for each section. The secondary laboratory also perform six indentations for each section, the indentation position is selected arbitrary inside the section. The section of the block is shown in the fig. 4.

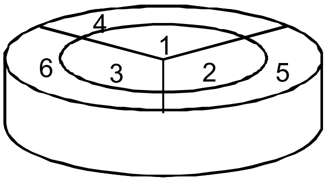

Fig. 4 The section of the block.

6.1 The evaluation of the JCSS uncertainty

In this subsection, we show the result of the simulative hardness blind test, performed at 20, 40 and 60HRC levels. The hardness levels of comparison are selected to cover the Rockwell hardness ranges. The calculated JCSS-equivalent uncertainty is evaluated experimentally using E_n value,

$$En = \frac{|\Delta H|}{\sqrt{U_{NMIJ}^2 + U_{JCSS}^2}} < 1 \qquad (18.)$$

Here, the U_{NMIJ} and U_{JCSS} are the expanded combined uncertainties using coverage factor (k=2). The U_{NMIJ} is our declared expanded uncertainty of the Rockwell hardness block calibration. The U_{JCSS} is the calculated expanding uncertainty following the mentioned method. The sensitivity coefficients of the ref.[5] is used in the uncertainty calculation. Two different testers are used in the evaluation, one of which is the (A) NMIJ primary hardness machine, SHT-32, and the other one is the (B) commercially available tester, which one of the participated machine for the round robin test of the JCSS program. The features of that is the lever-amplified dead weight type and the preliminary test force is applied by the spring.

The result of the tester A is shown in table 5. The "uncertainty equivalent to the jcss certificate" is determined using mentioned uncertainty estimation. The unit of uncertainty in the tables are HRC. The uncertainty of the hardness comparison is determined experimentally using 4d method and common indenter. The determined uncertainty of comparison in the table 5(a) is about 0.08-0.09 HRC, which value is almost same expected in the 5.2.

The total uncertainty of tester A indicated the table 5(b), and is equivalent to the uncertainty of JCSS calibration of block. In the jcss is not involving the uncertainty of indenter, then the uncertainty of the indenter is combined at here.

Finally the result of the JCSS uncertainty is tested by the En value. The difference of hardness between the standard hardness blocks and the hardness of tested machine is about 0.1, which is caused by the difference of indenter in this case. The E_n values are less than 0.3.

In the table 6, we show the result obtained by the commercial tester using the mentioned calibration scheme. The expected uncertainty, shown in the table 6(b), is equivalent to that of JCSS calibration of blocks. The machine used in this evaluation is not suitable for the ISO part 3[1], however, the all En values show less than 1, and that is nearby the En = 0.5. These results show the mentioned scheme may estimate the uncertainty of Rockwell hardness correctly.

Table 5. The simulative estimation of total uncertainty for NMIJ primary hardness tester (A), unit of uncertainty is HRC.

(a) The uncertainty equivalent to the jcss

Source of uncertainty	20HRC	40HRC	60HRC
Preliminary test force, u_{F0}	0.00	0.00	0.00
Total test force, u_F	0.01	0.01	0.00
Depth measuring device, u_h	0.03	0.03	0.03
Hardness comparison with common indenter, u_{comp}	0.09	0.08	0.08
Comb. std. Uncertainty	0.096	0.087	0.087
Exp. std. Uncertainty (k=2)	0.19	0.17	0.17

(b) Total uncertainty of simulative 2nd machine (JCSS)

Source of uncertainty	20HRC	40HRC	60HRC
Machine (jcss) for A	0.096	0.087	0.087
Standard indenter, u_{std}	0.130	0.130	0.130
non-uniformity of blocks, u_b	0.06	0.06	0.06
Comb. std. Uncertainty	0.173	0.168	0.167
Exp. std. Uncertainty (k=2)	0.35	0.34	0.33

(c) *En*

Source of uncertainty	20HRC	40HRC	60HRC
Difference of Hardness	-0.13	0.01	0.14
Exp. uncertainty of 2nd Lab.	0.35	0.34	0.33
Exp. uncertainty of NMIJ	0.34	0.30	0.30
En value	0.27	0.03	0.30

Table 6. The simulative estimation of total uncertainty for commercial type hardness tester (B), unit of uncertainty is HRC.

(a) Expected uncertainty of commercial tester (B)

Source of uncertainty	20HRC	40HRC	60HRC
Machine (jcss) for B	0.242	0.174	0.185
Standard indenter, u_{std}	0.175	0.175	0.175
non-uniformity of blocks, u_b	0.06	0.06	0.06
Comb. std. Uncertainty	0.305	0.254	0.261
Exp. std. Uncertainty (k=2)	0.61	0.51	0.52

(b) *En*

Source of uncertainty	20HRC	40HRC	60HRC
Difference of Hardness	-0.26	-0.34	-0.31
Exp. uncertainty of 2nd Lab.	0.61	0.51	0.52
Exp. uncertainty of NMIJ	0.34	0.30	0.30
En value	0.38	0.57	0.52

7. CONCLUDING REMARKS

The traceability of Rockwell hardness and uncertainty transfer system in Japan is presented. The uncertainty calculation method is verified two different simulative experiments. We also verify the validity of this uncertainty transfer method through the actual JCSS accreditation program.

The Rockwell hardness traceability system in Japan is just started. The JCSS accredited companies are rapidly increased and many companies are waiting jcss calibration. Because of the jcss allows only the direct calibration of machine by the NMIJ. We are trying to develop another uncertainty estimation system using their certified calibration devices and certified hardness blocks.

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Authors:

Dr. Koichiro Hattori, NMIJ, AIST
Address: AIST Tsukuba Cent.3, Umezono 1-1-1
Tsukuba 305-8563, JAPAN.
Phone: +81-29-861-4048, FAX: +81-29-861-4047
E-mail: hattori-k@aist.go.jp.

Mr. Satoshi TAKAGI, NMIJ, AIST,
Address: AIST Tsukuba Cent.3, Umezono 1-1-1
Tsukuba 305-8563, JAPAN.
Phone: +81-29-861-4048, FAX: +81-29-861-4047
E-mail: satoshi.takagi@aist.go.jp

Mr. Hajime ISHIDA, NMIJ, AIST
Address: AIST Tsukuba Cent.3, Umezono 1-1-1
Tsukuba 305-8563, JAPAN.
Phone: +81-29-861-4048, FAX: +81-29-861-4047
E-mail: h-ishida@aist.go.jp

Dr. Takashi USUDA, NMIJ AIST
Address: AIST Tsukuba Cent.3, Umezono 1-1-1
Tsukuba 305-8563, JAPAN.
Phone: +81-29-861-4048, FAX: +81-29-861-4047
E-mail: takashi.usuda@aist.go.jp