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## POSSIBILITY OF IMPROVING CORRECTIONS FOR ROCKWELL HARDNESS VALUE OBTAINED ON CONVEX CYLINDRICAL SURFACES

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**Abstract** – Evaluation of measurement uncertainty when correction value in ISO 6508 and ASTM E18 is applied is disputable. Using corrections, discrete and without uncertainty, is a difficulty to provide best measurement capability related to the application using the corrections. In order to study the possibility to complete the corrections to be in term of equations together with uncertainty of the equation, cylindrical shafts at nominal hardness 20 HRC, 40 HRC, and 60 HRC with diameter 6 mm to 38 mm were supplied in this experiment. In addition, this study includes the accuracy of the corrections by considering the effect of frame deformation of flat anvil and v anvil, effect of misalignment between indenter and cylindrical shaft, as well as effect from indenters. The corrections in form of equations for nominal hardness 20 HRC, 40, HRC, and 60 HRC along with uncertainty less than  $\pm 0.25$  HRC are reported. This confirms the possibility to revise the corrections with uncertainty for convex cylindrical surfaces in ISO 6508 and ASTM E18.

**Keywords** Rockwell hardness, Corrections, Convex cylindrical

### 1. INTRODUCTION

Rockwell hardness measurement was established since 1919[1]. As same as other hardness measurement, this method was initially applied to flat surface specimens. In 1954, the tables of corrections to be added to Rockwell hardness values obtained on cylindrical specimens were published in ASTM E18 [2] and have been used until today. These tables are also found in ISO 6508, but the values in the two standards are slightly different because of the different unit of diameter of cylindrical specimens.

Sources of inaccuracy of convex cylindrical hardness surface measurement include quality of v-anvil as well as misalignment between indenter and center of curvature of cylindrical specimens. Thus, users must evaluate the effect of V-anvil and check alignment of the testing machines. However, because the corrections are discrete, twice interpolations, for radius of curvature and hardness measured on convex cylindrical surface, must be done to determine the corrections.

Correction values in terms of equation with uncertainty of the equation will help hardness testing laboratories to be

able to measure more accurately and to evaluate complete uncertainty of measurement.

### 2. EXPERIMENT PROCESS

Hardness standardized machine model SHT31 manufactured by Akashi/Mitutoyo company and 3 reference diamond indenters, passed ISO 6508-3:2005, were used in this study. In order to compare the correction value with the correction table in ISO 6508, set of convex cylindrical shafts 40 mm long, and 6 mm to 38 mm diameter were prepared with steel grade SUJ2. The workpieces were under heat treatment process separately in 3 sets of hardness level; 20 HRC, 40 HRC, 60 HRC.

The study started from identifying error from frame deformation of using flat anvil and V-anvil. This error will be compensated in the measurement result. Then, identifying the test angle of anvil that gives the best alignment between tip of indenter and the center of the cylindrical workpieces and this angle will be used throughout this study.

Every cylindrical shafts were measured by all three reference indenters to study the effect of indenters. The measurement process started from measurement convex cylindrical surface. Then the shafts were grinded from convex surface to flat surface with 4 times of indentation wide and hardness measurement on flat surface was carried out.

The hardness difference between convex and flat surface after compensated with frame deformation error of all shafts is presented in equation with uncertainty of equation.

### 3. MEASUREMENT RESULT AND DATA ANALYSIS

#### 3.1 Error due to frame deformation

Mean error due to frame deformation of flat anvil was determined from 5 indentations (At least two preliminary indentations were made) on different locations on 900 HV hardness reference block, by dummy indenter with spherical tip of 10 mm diameter instead of diamond indenter.

Average errors of frame deformation of V-anvils were also identified as flat anvil, but 60 HRC cylindrical shaft with 38 mm diameter was used instead of 900 HV block. The result of error from frame deformation is shown in table 1.

Table 1 Frame deformation error from flat anvil and V-anvil

Frame Deformation	1	2	3	4	5	Average $\mu\text{m}$	Error in hardness $\Delta\text{HRC}$
Flat Anvil	-0.19	-0.19	-0.19	-0.20	-0.19	-0.19	-0.10
V-Anvil for $\phi \leq 38 \text{ mm}$	-0.91	-0.93	-0.85	-0.93	-0.90	-0.90	-0.45

Frame deformation of the two types of anvil shows that the hardness measurement result on convex cylindrical surface could include frame deformation error more than measurement on flat surface. This results from the wider gap between shaft and v-anvil than one between block and flat anvil. If this effect is neglected, hardness measurement on convex surface would have corrections higher than they actually are.

**3.2 Test angle of V-anvil**

Hardness machine manufacturer normally well adjust the alignment of the machines by dimensional measurement method. However, practical limitation and asymmetry of each v-anvil could cause misalignment between indenter tip and cylindrical surface specimen. The hardness measurement under misalignment condition leads to lower hardness value than actual value. When the tangent of curvature of the shafts at the point of indenter contact being not perpendicular to the line of force through indenter as illustrated in figure 1, there is only one-sided surrounding material to support the indenter. The magnitude of tilt angle depends on rotation position of V-anvil and only one position can make them perpendicular.

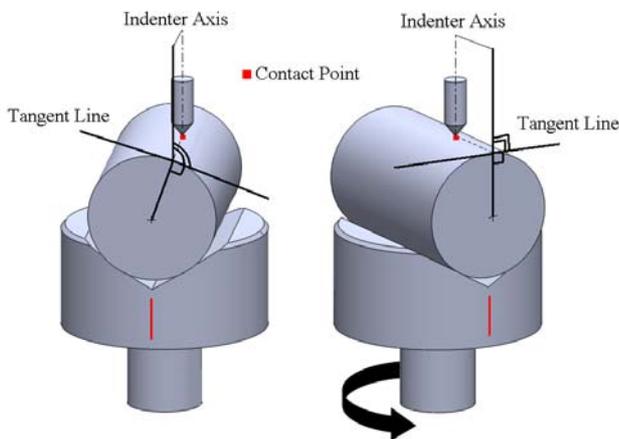


Fig 1. Proper rotation position of V-angle

The relationship between convex cylindrical surface hardness and test angle of 6 mm and 38 mm diameter shaft of nominal hardness HRC is shown in figure 2. The graph of measurement on 38 mm diameter shaft shows no different for any rotation position of V-anvil. It is uncertain to determine test angle by using large diameter shaft, so smaller shaft was used to get more accurate test angle. Measurement result from 6 mm diameter shaft shows distinctive result between different positions of V-anvil. The

more precise position of V-anvil was further studied from 45° to 90° as shown in figure 3.

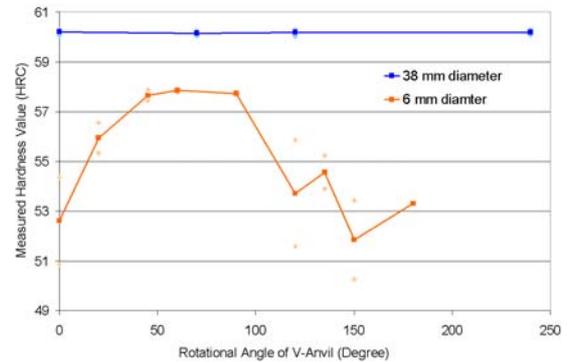


Fig 2. Determining V-anvil rotational position with 6 mm and 38 mm diameter shaft.

Test angle giving the highest value and smallest repeatability is the best alignment position. Figure 3 shows the relationship between hardness of cylindrical convex surface and small range of test angle of 6 mm diameter shaft at hardness 60 HRC. From the graph, the test angle of this V-anvil is 70°.

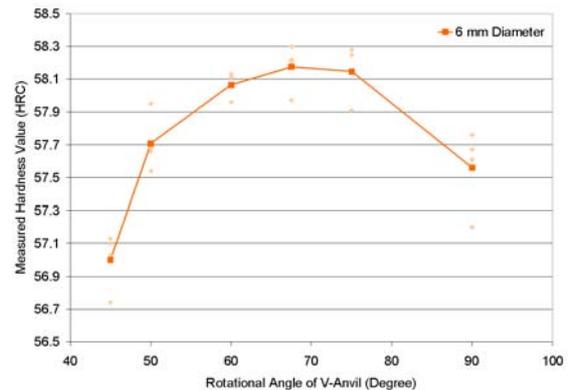


Fig 3. Fine determining V-anvil rotational position between 45° to 90°

**3.3 Indenter effect on convex surface**

In this study, three reference indenters with the best available shape of indenter according to ISO 6508-3 were used. They were manufactured by Tokyo Diamond Tool MFG. Co.,Ltd, Japan with calibration result shown in table 2.

Table 2 Detail of shape of three reference indenters used.

S/N	Cone Angle (°)	Curvature Radius (mm)
53655	119.95°	0.202
53657	120.06°	0.209
54161	119.98°	0.208

The three sets of measurement were carried out from three indenters. Each set consists of convex surface and flat

surface measurement result of 6 mm to 38 mm diameter shafts with hardness level of 20 HRC, 40 HRC, and 60 HRC as described in experiment process.

Researcher tried to measure one shaft with all three indenters in order to evaluate the effect of indenter on convex cylindrical surface hardness measurement. However, with the surface area limitation, all three indenters cannot be used to measure in single shaft for shaft diameter less than 19 mm, 10 mm and 8 mm for 20 HRC, 40 HRC, and 60 HRC shafts.

The standard deviations of corrections among different reference indenters were calculated and illustrated in figure 4. These are the deviations from using indenters according to ISO 6508-3. However, for testing laboratory users who use indenters according to ISO 6508-2, the deviation would be larger. Thus, the effect of indenter shape should be one of uncertainty contribution.

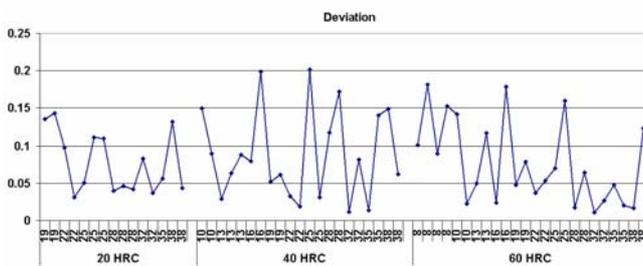


Fig 4. Standard deviation of corrections from different indenters.

### 3.4 Correction hardness curve

To eliminate the effect from non-homogeneity of the test pieces, numerous measurements were used to calculate a reliable average. The cylindrical shafts for measurement under 3 reference indenters were supplied to achieve 2,200 measurements.

Corrections from all measured value were calculated and plotted in figure 5 with average value for each shaft diameter. Then the average points were used to determine interpolation equations for correction value prediction. The equations describe corrections in a function of shaft diameter as in (1), (2), and (3) with coefficients of determination ( $R^2$ ) at 0.996, 0.995, and 0.9912 respectively.

Interpolation errors were used to evaluate the uncertainty of equations,  $\pm 0.18$  HRC,  $\pm 0.17$  HRC and  $\pm 0.20$  HRC, for 20 HRC, 40 HRC, and 60 HRC. However, if one would like to include the deviations of all correction data from this experiment in uncertainty, they are  $\pm 0.07$  HRC,  $\pm 0.05$  HRC and  $\pm 0.04$  HRC at  $1\sigma$  for 20 HRC, 40 HRC, and 60 HRC. These values were added up in uncertainty and the expanded uncertainties are  $\pm 0.23$  HRC for 20 HRC,  $\pm 0.20$  HRC for 40 HRC, and  $\pm 0.22$  HRC for 60 HRC.

The equations are in power interpolation form. The slope of graph is high for shaft diameter smaller than 10 mm; so other diameters of convex cylindrical shaft between 5 mm to 10 mm should be investigated for more accurate prediction equation.

At 60 HRC, correction of convex cylindrical with diameter 38 mm equals to zero and corrections of larger

diameters are also assumed to be zero. Thus, the larger diameters of convex surface should be examined.

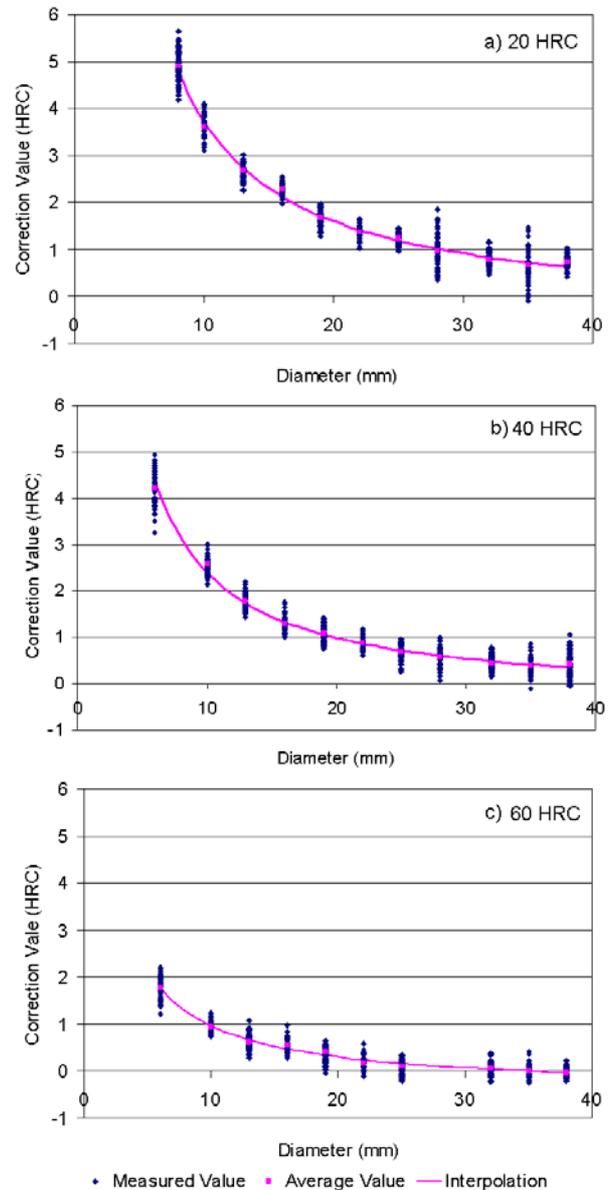


Fig. 5 Corrections and interpolation curve of 20 HRC, 40 HRC, and 60 HRC.

The interpolation equations and their uncertainty are as follows. They are compared with corrections from ASTM E18 shown in figure 6.

$$\Delta H(20HRC) = 44.53D^{-1.05} - 0.41 \quad \text{with } U_F = \pm 0.18HRC \quad (1)$$

$$\Delta H(40HRC) = 32.53D^{-1.09} - 0.27 \quad \text{with } U_F = \pm 0.17HRC \quad (2)$$

$$\Delta H(60HRC) = 10.48D^{-0.86} - 0.50 \quad \text{with } U_F = \pm 0.20HRC \quad (3)$$

Where D is diameter of cylindrical convex surface

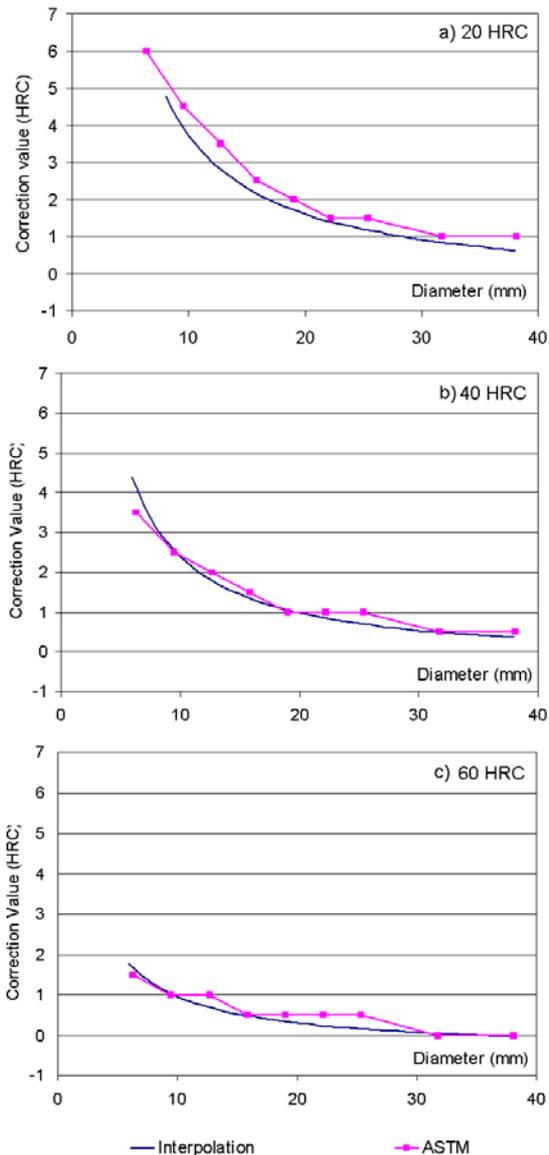


Fig. 6 Comparison of corrections from equation and ASTM standard

Overall, interpolation equations agree with corrections in ASTM E18. On average, the corrections from interpolation equations are lower than corrections in ASTM around  $-0.16$  HRC. The difference could be resulted from the different sources of corrections. ASTM corrections represent not only HRC scale, but also HRA and HRD, while our correction equations were evaluated from HRC scale only.

#### 4. CONCLUSION

Frame deformation error from using each V-anvil directly impact to convex surface hardness measurement and could be larger than the correction itself. Moreover, identifying the appropriate test angle of anvil can also minimize error from misalignment of hardness testing machine. However, testing laboratories, involving in hardness measurement of cylindrical shafts, currently do not focus on these points. The laboratories should have the

measurement procedure that takes the mentioned points in to account rather than using given corrections only.

Result from the study, corrections in the form of equations with uncertainty at 20, 40, and 60 HRC, identifies the possibility to improving the corrections from discrete values to correction equations in a function of hardness and diameter of convex cylindrical surface with their uncertainty. However these uncertainty do not include the effect of shape indenter. Thus the testing laboratory users must define their own uncertainty contribution from indenter shape.

#### REFERENCES

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