CONSIDERING THE APPROPRIATENESS OF THE INTERNATIONAL STANDARDS FOR HARDNESS TESTS

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Abstract: Not only because ISO standards for hardness tests have a large impact on the revision of corresponding industrial standards, but also because of the recent tendency of ISO to tighten regulations, the authors investigated technically the appropriateness of some important ISO standards for hardness tests.

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1. SPECIFICATION OF THE GEOMETRY OF THE SPHERICAL TIP OF A DIAMOND INDENTER FOR ROCKWELL HARDNESS

Regarding the spherical tip geometry of a Rockwell diamond indenter, ISO 6508 (Rockwell hardness) Part 2 (testing machines) specifies that the conical angle shall be $120 \pm 0.35°$ and the radius of curvature R shall be 0.200 ± 0.01 mm, and specifies a detailed method for measuring these dimensions. ISO 6508 Part 3 (reference blocks) specifies tighter tolerances, or $120 \pm 0.10°$ and 0.200 ± 0.005 mm, respectively, and also assumes using a standardized indenter[1].

Fig. 1 shows ratios of three dimensions—diameter d, differential depth Δh, and depth h—of indentations made on hardness blocks with various hardness values between a Rockwell diamond indenter and a $120°$ conical indenter with a sharpened tip [2]. As shown in the figure, Rockwell testing, which uses differential depth Δh to obtain hardness values, is less subject to the shape of the indenter tip than instrumented indentation testing (IIT), which uses indentation depth h. Fig. 2 shows the results of a study made with commercially available diamond indenters on how the indenter tip, or the radius of curvature R, influences the hardness values obtained[3]. According to the results, it can hardly be concluded that the radius of curvature R has a significant effect on hardness measurements even for the 60 HRC test, which has a relatively shallow indentation. If it is possible to remove all factors that can influence hardness measurements except tip geometry, it would be possible to determine the influence of geometrical errors more accurately. However, it is a proven fact that even a ball indenter, which is well known for its excellent geometrical accuracy, can cause a
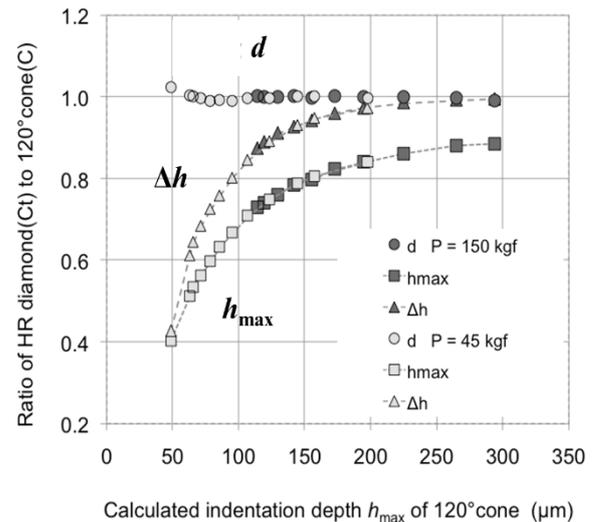

Fig. 1 Comparison of indentation dimensions between $120°$ conical and Rockwell diamond indenter

significant variance in hardness measurements due to the quality of its indenter holder.
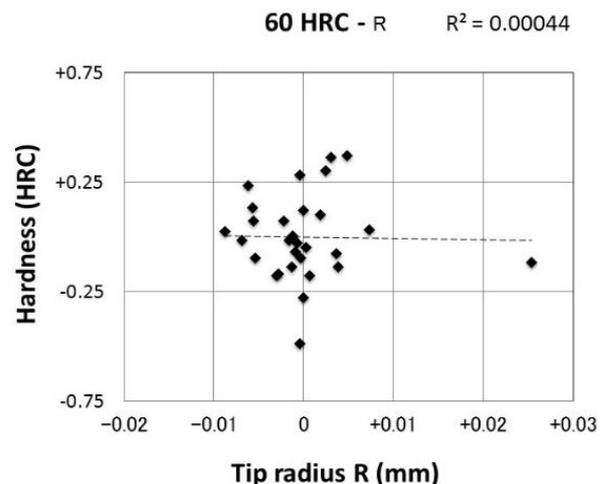

Fig. 2 Effects of the tip radius of curvature R of a Rockwell diamond indenter on HRC measurements on a 60 HRC block

2. SPECIFICATIONS OF THE RIDGELINE AT THE TIP OF A VICKERS DIAMOND INDENTER

Along with a Rockwell diamond indenter, a Vickers diamond indenter often becomes a subject of ISO discussions regarding its tip shape. Concerning the ridgeline that tends to appear at the indenter tip, ISO 6507 (Vickers hardness) Part 2 (testing machines) requires the length of the line to be between 0.5 µm and 2.0 µm, depending on the test load, and ISO 6507 Part 3 (reference blocks) requires it to be between 0.25 µm and 1.0 µm, depending on the test load[4].

However, there is almost zero variance in indentation diameter measurements even between indenters whose tip shape differs considerably as shown in Fig. 1. This result can be seen as something that verifies the equation suggested by D. Tabor, $H = P / Ap = const$., where H is hardness as an indicator of material strength, P is the test force applied, and Ap is the projected area of an indentation[5].

Therefore, if the ridgeline ad is produced at the tip of a Vickers diamond indenter when the indentation's diagonal length is d, the error in Vickers hardness will be $(d'/d)^2$, as shown in Fig. 3.

$$\left(\frac{d'}{d}\right)^2 = 1 + a^2 \qquad (1)$$

Calculating the error term of equation (1), the results of which are shown in Fig. 4, you find that an error in Vickers hardness measurements attributable to the tip line measuring one percent of the diagonal length d is only 0.01%.

3. CONCEPT OF "REFERENCE INDENTATION" FOR VICKERS AND BRINELL HARDNESS

In one of its deliberations, ISO suggests that indentations on hardness blocks, produced in Vickers or Brinell hardness tests, are offered as "reference" to inspections with measuring microscopes. However, when observing the contrast caused by the undulation on sample surfaces with an optical microscope, the boundary between bright and dark changes according to the brightness of illumination and method used, as well as adjustments on numerical aperture (NA), aperture opening and focal point of the objective lens. Fig.5 is an example of a glass-made objective micrometer (for microscope calibration) and a Vickers indentation on a steel hardness standard block observed under the exact same conditions. When the two are compared, the contrast of the Vickers indentation is obviously much inferior to that of the objective micrometer, which by itself is a reason not to provide the Vickers indentation as a "reference" of length. Added to this, if the brightness of illumination is changed as mentioned before, both the width of the black lines of the objective micrometer on Fig.5 (not the space between them) and the size of the dark area in the Vickers indentation suffer visual changes. For example, the Fig.6 is an example
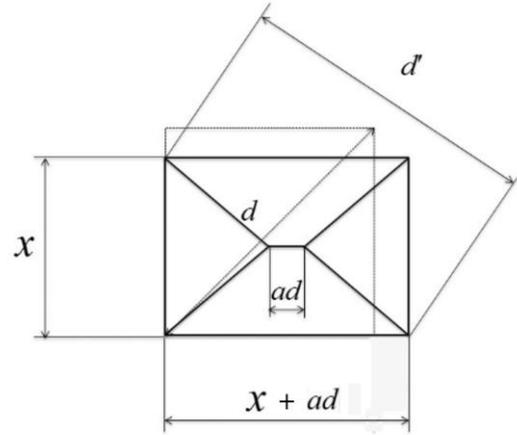

Fig. 3 When a ridgeline of length ad is produced at the tip of a Vickers diamond indenter
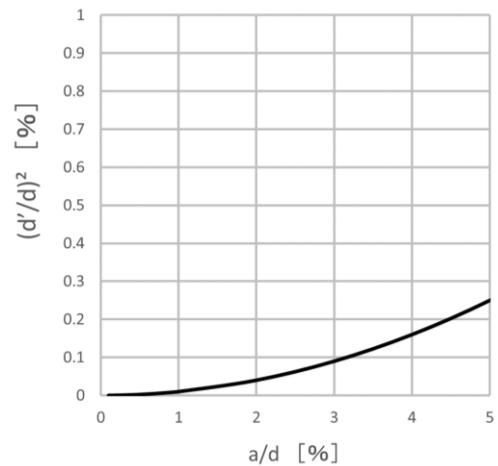

Fig. 4 Errors in Vickers hardness $(d'/d)^2$ attributable to the ridgeline ad

Fig. 5 Comparing the images of an objective micrometer and a 700 HV indentation made on a hardness block, taken under the same conditions with an optical microscope (objective lens ×100)
Apparent line width and size of an image of the indentation change according to the conditions, but the line-to-line intervals do not.

of an indentation with a diameter of approximately 2.8 mm made on a mirror-polished surface steel hardness block (500 HV) in a HBW 10/3000 test, observed with a tool maker's microscope. When the epi-illumination is changed from weakest to strongest, it is possible to see the indentation diameter appearance changing (this measurement was made
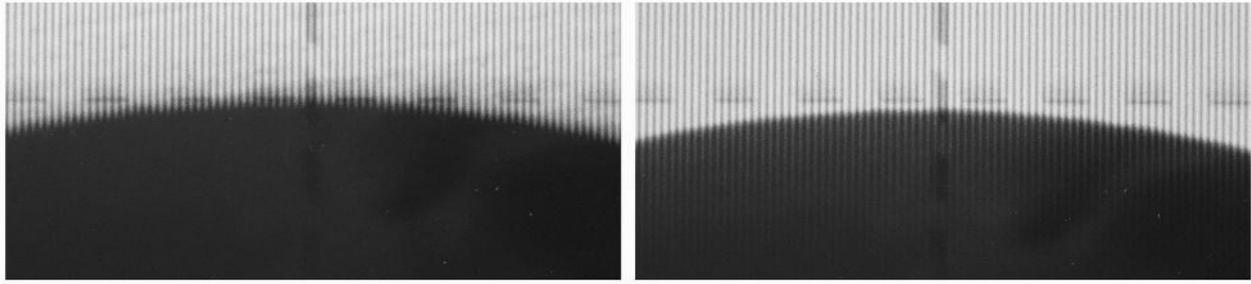
Fig. 6 Visual changes in indentation dimensions caused by epi-illumination variation
Images on a CRT monitor of an indentation produced on a 500 HV block, in a HBW 10/3000 test. The video line and indentation position were fixed, and only the light intensity was changed. The light is minimum on the left, and maximum on the right (images rotated 90°).

by video line, there was a change of approximately 0.6% in the indentation diameter, with approximately 8 μm on each side and 16 μm in the diameter.) These pictures, obviously, show the same indentation at the same position, with the same focal point, changing only the brightness.

In the case of the objective micrometer, since the space between the lines is used as "reference" – and not the line width –, problems like these are unlikely to cause an impact, but in the case of Vickers and Brinell hardness indentation, the length of the indentation's diagonal line and diameter d themselves change visually. The regulation of ISO Part 2 demands the absolute majority of the general users to measure the diameter of the "Reference indentation" in the hardness block, and this value must match that of the measurement made by the hardness block manufacturer, with a maximum variance of 0.5%. However, considering that in this experiment, carried out in an individual test machine with utmost attention, the indentation diameter changed 0.6 % just by adjusting the light intensity, this regulation may be excessively strict. Also, since the term "reference" has a connotation of "standard", perhaps it should be changed to a more appropriate one, e.g. "exemplar", and the tolerance level raised.

4. SUMMARY

In addition to the aforementioned examples, ISO has given proposals to tighten regulations concerning the indication of uncertainty and the increase of test points on hardness blocks. Inevitably, however, those ideas can produce inconsistencies if they are employed for handling an industrial quantity such as "hardness," which does not have a globally unified physical unit of measurement and does not have values unique to materials. Furthermore, needless tightening or complication of hardness test standards could cause not only a cost increase on the user side but also other problems. The authors believe that steady attention to this issue by the parties concerned in hardness tests will lead to the creation and revision of better ISO standards.

5. REFERENCES

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