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# INFLUENCING PARAMETERS OF EQUIVALENT INDENTATION TEST

*Takashi Yamamoto, Masayuki Yamamoto* [1], *Kensuke Miyahara* [2] , *Tatsuya Ishibashi* [3]
[1] Yamamoto Scientific Tool Laboratory, Funabashi, Japan, fwga7870@mb.infoweb.ne.jp
[2] National Research Institute for Metals , Tsukuba, Japan, MIYAHARA.Kensuke@nims.go.jp
[3] Niigata University , Niigata, Japan, isibasi@eng.niigata-u.ac.jp

**Abstract** −A newly developed hardness test based on equivalent indentation depth is currently expected to be the only hardness test method that enables seamless evaluations of hardness across different hardness scales in all load ranges from nanoscopic to macroscopic in an industrial friendly manner because the new method is free from the shortcomings of the instrumented indentation method, which requires calibration of tester frame compliance and detection of true specimen surface. However, as it is still in the early days of application, extensive data have yet to be accumulated concerning the equivalent indentation test. In this report, we discuss some major factors that can influence equivalent indentation depth, including the geometrical shape of the indenter used and the load ratio "*r*" (preliminary-to-total test force ratio).

As a result, it is found that the results of the equivalent indentation test using a pyramidal or conical diamond indenter are mutually convertible, and that the difference in equivalent indentation depth among Vickers, Berkovich, and Modified Berkovich indenters, which are probably the most popular indenters for the test, is as small as around ±1%. From our experiments, it is also confirmed that the equivalent indentation test is less susceptible to indenter tip wear than the instrumented indentation test.

Understandably, equivalent indentation depth is influenced by load ratio *r*, but the conversion formula developed by introducing an appropriate model into load curves is found to be effective for mutual conversions of the values of equivalent indentation depth at different load ratios for a practical range of applications.

**Keywords**: Hardness, Equivalent Indentation Depth, Nanoindentation

## 1. HARDNESS TEST BASED ON EQUIVALENT INDENTATION DEPTH $\Delta h_e$

"Equivalent indentation depth $\Delta h_e$" is an index of indentation depth, which depends only on the strength of a material, not on the magnitude of the test force as shown in Fig. 1 and (1) . It is determined by dividing $\Delta h$—which is the difference in indenter penetration depth when the preliminary test force $P_0$ is applied before and after application of total test force $P$ using a pyramidal or conical

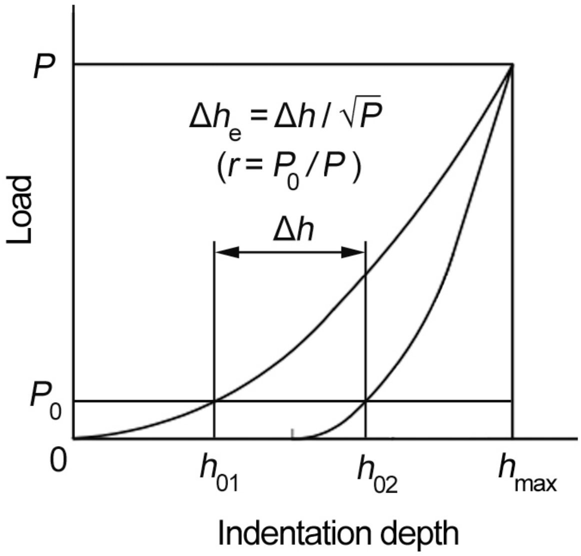


Fig. 1 Schematic drawing of indentation test and equivalent indentation depth

$$\Delta h_e = \Delta h / \sqrt{P} \quad (1)$$

diamond indenter, such as for Vickers, in the same way as for Rockwell testing—by the square root of the total test force *P*. The authors found that the values of equivalent indentation depth satisfy the similarity rule of hardness and do not require complicated adjustments and microscopic indentation measurements, therefore, they are qualified as an index of strength that is applicable to all load ranges from nanoscopic to macroscopic[1]. Fig. 2 and Fig. 3 show the good agreement of $\Delta h_e$ values at different magnitude of testing loads from 0.0015 kgf to 100 kgf for various hardness standard blocks of 100 HV to 1650 HV.

To enable practical application of the equivalent indentation test, however, it is necessary to examine the factors affecting the method: (1) geometrical shape of the indenter used, and (2) load ratio "*r*," or the ratio of the preliminary test force $P_0$ to the total test force $P$ : $r = P_0/P$. In this report, we examine factors (1) and (2) by testing a large number of hardness standard blocks that have excellent uniformity of hardness using Rockwell and

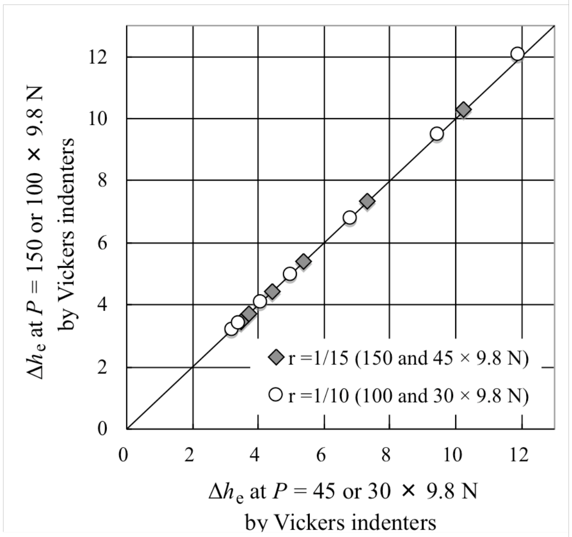


Fig. 2 Comparison of $\Delta h_e$ between different macro range testing load

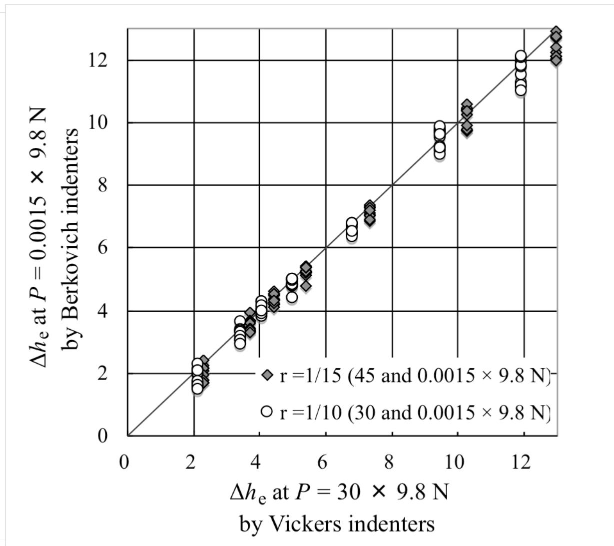


Fig. 3 Comparison of $\Delta h_e$ between macro and nano range testing load

Rockwell Superficial hardness testers. For convenience, the equivalent indentation depth $\Delta h_e$ is calculated using the indentation depth shown in μm, and the test force shown in kgf in this report.

## 2. INFLUENCE OF GEOMETRICAL SHAPE OF DIAMOND INDENTERS ON EQUIVALENT INDENTATION DEPTH $\Delta h_e$

To satisfy the similarity rule of hardness, it is required to use an indenter that produces identical cross-sections of indentation, irrespective of the depth of an indentation. To examine the influence of indenter shape on equivalent indentation depth, we chose to use three types of pyramidal indenter—the most standard Vickers square pyramid indenter (V), the Berkovich indenter for nanoindentation (B), and the Modified Berkovich triangular pyramid indenter (MB)—and a 120$^o$ cone diamond indenter (C). As test specimens for the experiment, we used Vickers standard blocks with 12 different levels of nominal hardness from 100 HV to 1650 HV. These blocks were made of high-purity steel, except the 100 HV block, which was made of copper alloy, and the 1650 HV block, which was made of $Si_3N_4$ ceramics. The total test forces $P$ used were 45 kgf and 150 kgf, or 441.3 N and 1471 N, respectively. The load ratio $r$ used was 1/15. We also examined the influence of truncation of indenter tip using the Rockwell diamond indenter (Ct), which is assumed to be a conical indenter (C) that develops wear of 200 μm in curvature radius and about 30 μm in depth at its tip.

The results of comparing equivalent indentation depth $\Delta h_e$ between the Vickers indenter (V) and the other indenters are as follows.

(1) Compared to the equivalent indentation depth of the V indenter, that of the B indenter was slightly larger and that of the MB indenter was slightly smaller, both by within 1%, whereas that of the C indenter was larger by as much as 56% as indicated in Fig. 4. Considering the current status of

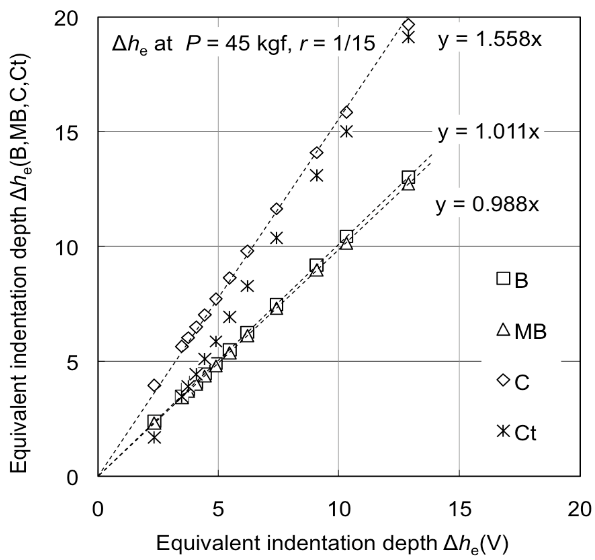


Fig. 4 Comparison of $\Delta h_e$ of different shaped indenters to Vickers diamond indenters. ($P$ = 45 kgf, $r$ = 1/15)

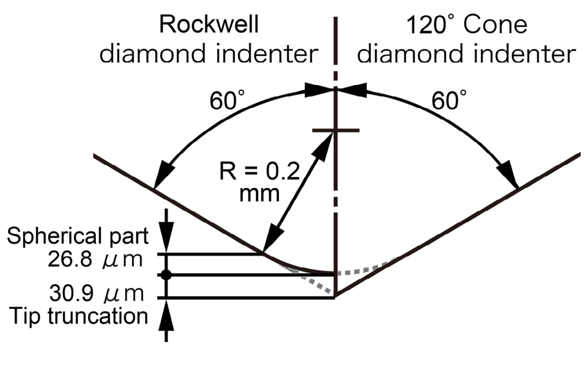


Fig. 5 Geometries of Rockwell (left half) and 120°cone (right half) diamond indenters.

hardness testers, the V indenter can be used for macroscopic and microscopic load ranges and the B or MB indenter for the nanoscopic load range. Even if the C indenter is added, test results can be made mutually comparable by multiplying the respective values of $\Delta h_e$ by appropriate coefficients as necessary.

(2) Comparing the equivalent indentation depths of C and Ct indenters (Fig. 5), it was found that the difference was within 3% at indentation depths of about 200 µm or larger as shown in Fig. 6. This shows that the equivalent indentation depth method is less susceptible to the effects of indenter tip truncation compared to the instrumented indentation method for nanoindentation.

## 3. INFLUENCE OF LOAD RATIO *r* ON EQUIVALENT INDENTATION DEPTH $\Delta h_e$

To change the total test force $P$ according to the purpose or the specimen used for an equivalent indentation depth test, it is necessary to change the preliminary test force $P_0$ in proportion to changes in $P$. In the case of instrumented indentation tests, the displacement at a given preliminary test force is available, so it is allowable to choose any load ratio $r$. Conversely, the traditional Rockwell and Rockwell Superficial testers do not have the liberty of changing preliminary test force $P_0$. Therefore, we made large changes to the total test forces for the Rockwell ($P_0$ fixed at 10 kgf) and the Rockwell Superficial ($P_0$ fixed at 3 kgf) testers, and compared equivalent indentation depths at different values of load ratio $r$, using Vickers indenters. The specimens used were the abovementioned Vickers blocks with four scales of nominal hardness: 100 HV, 300 HV, 900 HV and 1650 HV. With the exception of total test forces that are supposed to be used for the testers, we adjusted the mass of the weight according to the leverage (about 25) of the loading lever of the tester's loading mechanism. As indicated in Fig. 7, equivalent indentation depth $\Delta h_e$ decreases according to increase of load ratio $r$.

The resulting values of equivalent indentation depth were converted into those that would be obtained at $r = 1/10$, using the following conversion (2) for equivalent indentation depth between different values of load ratio $r$[2].

$$\Delta h_B = (1 - r_B^{1/2}) / (1 - r_A^{1/2}) \times \Delta h_A \qquad (2)$$

These results show that it becomes possible to compare $\Delta h_e$ even for different values of $r$ by using the conversion formula (1). The range of errors was less than 2%, as far as our experiments are concerned as shown in Fig 8.

## 4. CONCLUSIONS

The equivalent indentation depth hardness test has great potential as a promising hardness test method for industrial applications for the following reasons. First, it shares the convenience of Rockwell testing because it does not involve microscopic measurements of indentations as is required for Vickers tests. Second, it is free from the disadvantage of Rockwell tests that

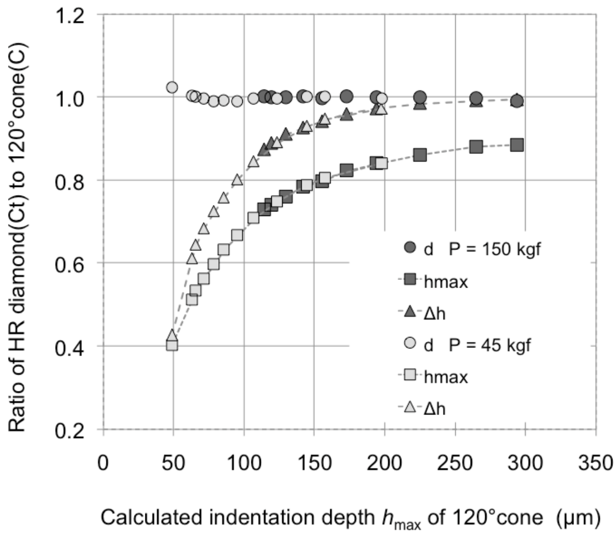


Fig. 6 Comparison of dimensions of indentations made with 120° cone (C) and Rockwell diamond indenters (Ct).

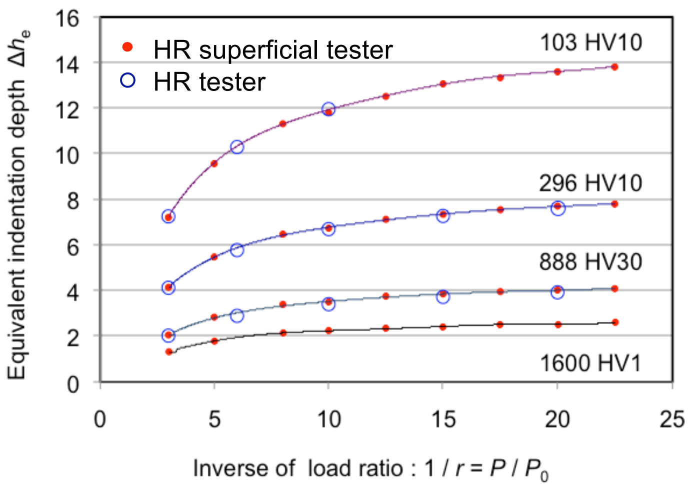


Fig. 7 Difference of $\Delta h_e$ by load ratio $r$

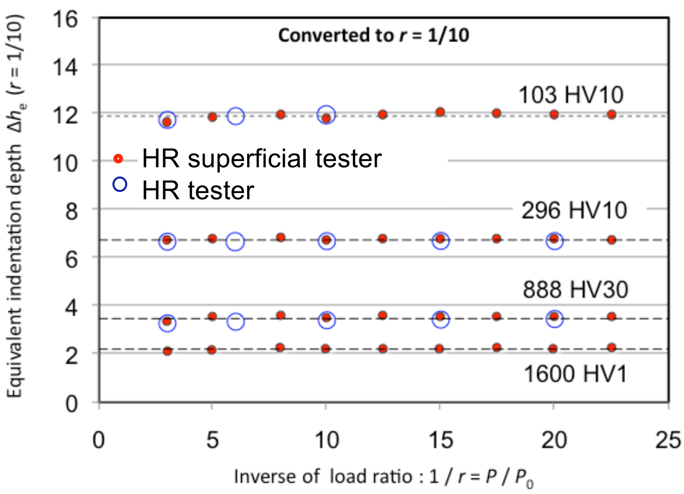


Fig. 8 Converted $\Delta h_e$ by different load ratio $r$

hardness values are mutually incomparable across different hardness scales. Third, it does not require a complicated calibration process using a standard specimen, which is required by the instrumented indentation method for nanoindentation, and it is affected less by truncation of the indenter tip [3]. As a result of examining the influencing factors—indenter shape and load ratio *r*—that determine the practical applicability of the equivalent indentation test, there seem to be no problems with its practical application no matter which of V, B, or MB indenter is used and different values of load ratio *r*, as long as the values obtained of equivalent indentation depth are converted appropriately. In the future, the authors intend to examine the effects of load ratio in the nanoscopic range using a nanoindentation tester. The results of such an experiment will be examined together with the results provided in this report to determine the most suitable indenter, load ratio, and other standard requirements. Eventually, we would like to propose a specific method to define hardness values obtainable by the equivalent indentation depth method.

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