

# A STUDY OF THE HRC HARDNESS STANDARD - EVALUATION METHOD USING VICKERS DIAMOND INDENTERS -

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*Abstract: Due to the practical convenience of fast testing conditions and the reliability of comparative accuracy, HRC hardness tests are more often used in the industrial world than such theoretical hardness scales as HV and HB. On the other hand, the HRC scale still has an uncertainty of  $\pm 0.4$  HRC, which may result from the technical difficulty of machining crystal diamond into a precisely spherical tip of a diamond indenter and the non-elastic error from a complex indenter structure under test load. Historically, loading conditions for HRC hardness tests have not been very consistent.- Faster conditions were conveniently used in the early years, but the advent of hardness blocks encouraged a preference for stricter conditions. In recent years, however, the wider industrial application of HRC testing is again making people choose faster conditions - an international trend now followed by the ISO standards. It is natural for hardness measurements to vary when testing conditions - the tester, indenter and loading requirements - are not fixed. This problem is especially true with the HRC standard - a subject discussed in this paper.*

*Keywords: Rockwell hardness, Vickers hardness, Indentation*

## 1 INTRODUCTION

Indentation hardness, such as Rockwell, is determined by measuring the deformation caused when a certain force is applied to a test piece. In this sense, force and length determine hardness. In general, Rockwell hardness testers are likely to cause errors in measuring the amount of deformation, or depth of indentation, due to their frame rigidity and mechanical backlash, as well as the way in which an indenter is mounted. Besides, in terms of the precision of loading conditions, Rockwell is less reliable than Vickers and Brinell tests. The authors used a Vickers diamond indenter mounted on a Rockwell hardness tester to obtain tester indicated values and HV values from indentation measurements, to study the subjects of HRC diamond indenters, initial test force and reference indentation depth, and test force loading conditions. For these experiments, hardness standard blocks with a high uniformity of hardness values were used as specimens [1].

## 2 DIAMOND INDENTERS FOR ROCKWELL HARDNESS

It is said that the difficulty of machining crystal diamond into the precisely spherical tip of a diamond indenter causes variations in measurements obtained by different HRC indenters. Past experiments by the authors also revealed that a range of about  $\pm 0.4$  HRC was produced in hardness measurements between different HRC indenters. 2) Conversely, it is known that it is easier with HV diamond indenters to attain uniform geometry, so HV measurements agree well among different HV indenters. Therefore, the authors compared ten HV diamond indenters by mounting them on a Rockwell hardness tester and applying the same force as for the HRG scale to obtain indicated values of the tester and HV values from diagonal length measurements of the resulting indentations.

Figs. 1 and 2 show the results of the comparison. The data plotted represent  $n = 5$  average. According to these results, the HV values agree very well for the indenters, indicating the high geometrical uniformity of their tips. However, the indicated values of the Rockwell tester, identified as HRC-V, do not show such a good agreement. The data in Figs. 1 and 2 are plotted on different scales, which are generated from the relationship between HV and HRC-V values shown in Fig. 3 to enable a comparison between the different hardness scales.

This result indicates the need to address the rigidity of Rockwell diamond indenters; in other words, the embedding of the diamond tip, or other structural problems that may affect the uncertainty of Rockwell hardness values, in addition to spherical tip geometry [2].

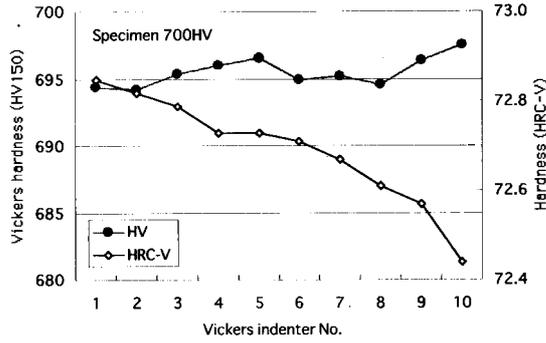


Figure 1. Comparison of ten Vickers diamond indenters at the 700 HV level

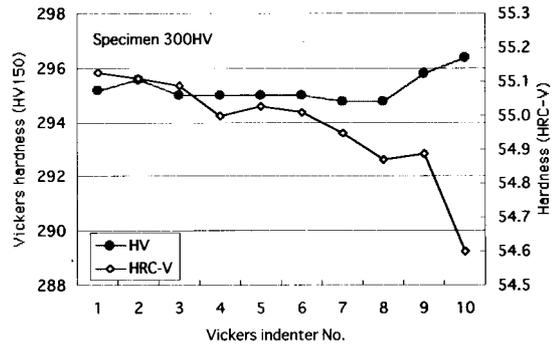


Figure 2. Comparison of ten Vickers diamond indenters at the 300 HV level

### 3 INITIAL TEST FORCE AND REFERENCE INDENTATION DEPTH

A single HV diamond indenter was mounted on eight different Rockwell hardness testers, and only the initial test force of 10 kgf was applied to obtain HV values from the resulting indentations. The results are shown in Fig. 4, which includes data obtained from one Vickers tester for reference. The data plotted represent the average of  $n = 5 \times 2$ .

As shown in the figure, there is a difference of about 0.5,um in HV indentation depth between the Rockwell machines tested - a difference that may be translated into reference indentation depth errors for Rockwell hardness. This result also indicates the importance of the dynamic accuracy of test force, given the structure of Rockwell testing machines. For this reason, it may be reasonable for the spring-loaded mechanism, not deadweight, to be used to apply the initial test force in general Rockwell testers.

### 4 TEST FORCE LOADING CONDITIONS

It is a basic rule in material testing for the amount of deformation to change if loading conditions change. In determining hardness standard, the application of loading conditions other than those used generally should be strictly avoided, as indicated by the agreement in loading conditions between ISO 6508 Part 1 and Part 3, as well as the results of experiments given by the authors and other researchers [2], [3], [4], [5]. To confirm this, the following experiments were conducted.

#### 4.1 Effect of Loading Speed

A Wilson 2000 Rockwell hardness tester was used for this experiment. The tester uses a Fig. 5 Test force loading curve for the Rockwell hardness tester load cell and a servo motor to control test force, enabling us to easily set a wide range of test force loading conditions. The tester also uses a linear encoder with a resolution of 0.01  $\mu\text{m}$  to measure indentation depth. Load rise time (LRT) - time required for the test force to reach the setting (150 kgf) was used as an index of loading speed.

Fig. 5 indicates load cell measurements of the loading conditions used for this experiment. As the figure shows, even with fast loading, the loading mechanism of the hardness tester used achieved much less variation in test load compared to traditional deadweight testers, around the point when the 150-kgf load is reached.

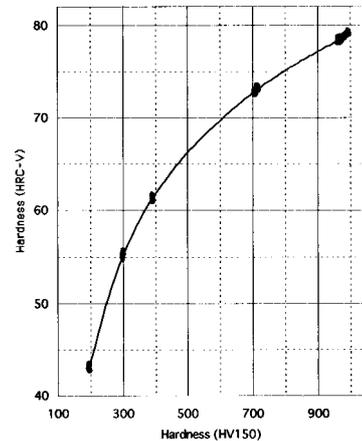


Figure 3. Relationship between Vickers Hardness and HRC-V hardness

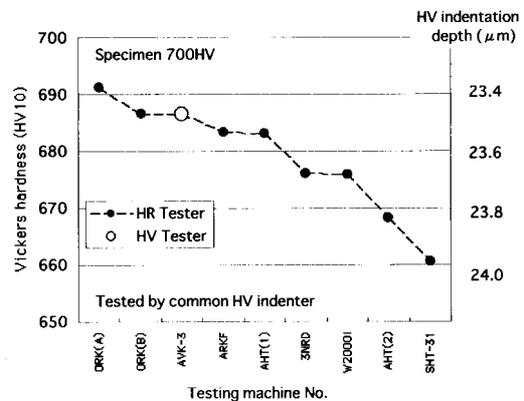
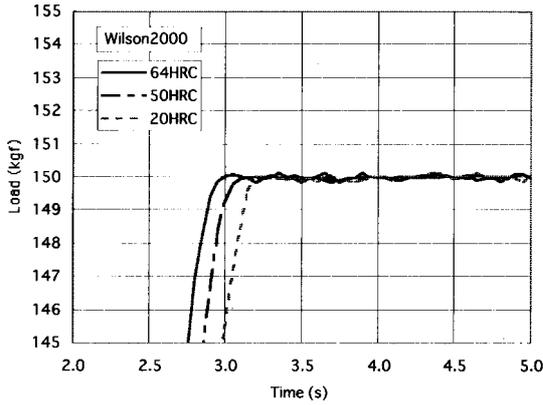


Figure 4. Comparison of HV 10 test results under the initial test force using Rockwell hardness testers

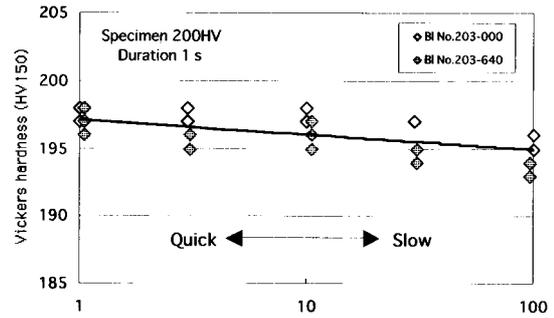


**Figure 5.** Test force loading curve for the Rockwell hardness tester

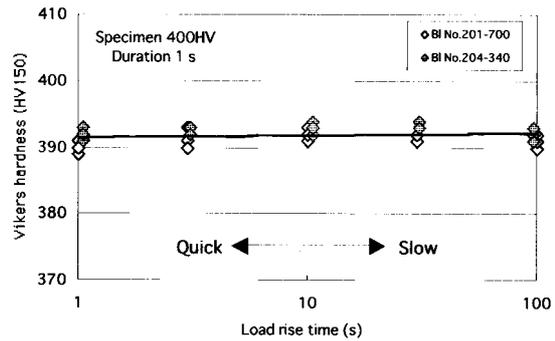
Figs. 6-8 show test results with steel hardness test blocks for 200 HV, 400 HV, and 1000 HV. The plotted data represent the measurements of each test. From these results it is apparent that there is a certain tendency depending on hardness level. At lower hardness levels, HV values tended to get higher as loading speed increased. This tendency is reversed after the middle hardness level. At higher hardness levels, HV values tended to get lower as loading speed increased. There was no significant variation in hardness measurements at each loading speed, which indicates the excellent uniformity of the test blocks used. The load duration time was fixed at one second for all these tests. These results with a Rockwell hardness tester show the same tendency as those we obtained with a Vickers hardness tester, but with virtually zero load duration time [6].

#### 4.2 Effect of Duration Time

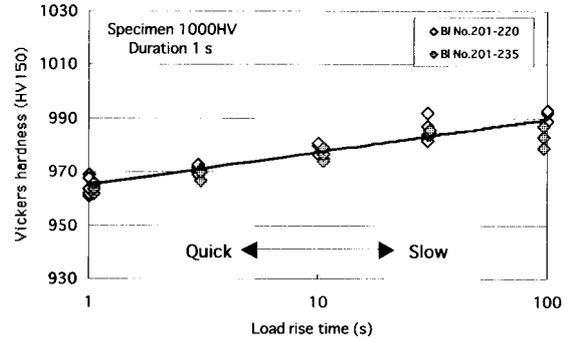
The authors have already studied the effects of duration time with test blocks of various hardness levels and materials, including steel, pure copper, and various ceramics, using a Vickers hardness tester. As a result, it has been confirmed that hardness values decrease almost proportionally to the logarithm of time up to more than ten percentage points between one and 1 0,000 seconds of load duration time, as shown in Fig. 9. There was not even a saturation point, and it was also found that duration did not affect the dispersion of hardness values [3].



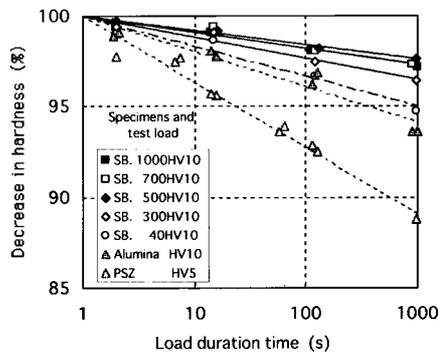
**Figure 6.** Effect of loading speed on Vickers hardness at the 200 HV level



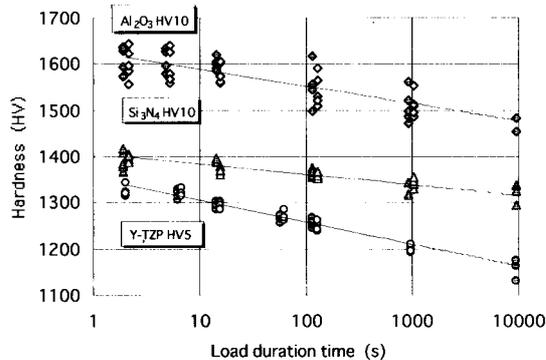
**Figure 7.** Effect of loading speed on Vickers hardness at the 400 HV level



**Figure 8.** Effect of loading speed on Vickers hardness at the 1000 HV level



**Figure 9.** Effect of force duration time



## 5 CONCLUSION

In this paper, we propose the effectiveness of using Vickers indenters to study the loading mechanism of a Rockwell hardness machine, Rockwell loading conditions, and the structure of Rockwell diamond indenters. The results of the experiments presented in this paper can be summarized as follows.

- (1) Active attention is needed to the rigidity of a Rockwell diamond indenter, or the diamond-tip embedding structure, as well as the geometry of its spherical tip.
- (2) More careful study of the accuracy of reference indentation depth for Rockwell testing, or the loading mechanism of its initial test force, is required.
- (3) In indentation hardness testing, such as Rockwell and Vickers, true values differ with loading conditions, but the dispersion and reliability of hardness measurements basically remain unchanged.
- (4) Because various advanced loading control systems and testing methods, such as load cells, are now available, the dead-weight-type loading mechanism may now only impair dynamic accuracy and be unable to meet the industrial need for rapid testing.
- (5) Rapidity is important for industrial hardness testing. Therefore, we find it very reasonable to unify Rockwell loading conditions according to ISO 6508 Part 1 and Part 3. This kind of international unification of hardness standard driven by the field-oriented selection of the rapid loading conditions should also be followed for Vickers and Brinell standards.
- (6) Hardness test blocks are used to control the accuracy of hardness testers on a daily basis. Hardness measurements obtained with normally operating hardness testers should almost agree with the hardness values of applicable test blocks. Therefore, it should be avoided to apply as standard such testing conditions that might produce different hardness values than those obtained with the testing conditions generally applied in the industrial world.

The authors will continue more detailed studies of Rockwell hardness testing and indentation hardness as a whole using a range of high-precision hardness test blocks, testing machines, indenters, and load cells. Finally, We thank Akashi Corporation and INSTRON Japan Co., Ltd. for their valuable advice and cooperation throughout the experiments.

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