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STUDY ON METHODS FOR MEASURING VICKERS INDENTATIONS

Takashi Yamamoto[1], Masayuki Yamamoto[1] , Koichiro Hattori[2]

[1]Yamamoto Scientific Tool Lab.Co.,Ltd. ,Chiba, Japan
[2] National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

Abstract – The Vickers hardness test can cover an extensive range of test loads from several gram-force (gf) to 100 kilogram-force (kgf) with a single hardness scale. It is one of the most reliable strength tests because the simplicity of the testing theory and the indenter shape minimizes variances among hardness values obtained. The most vulnerable aspect of the Vickers method is an error when measuring the diagonal length of an indentation. In particular, an inexperienced operator tends to obtain smaller measurements than the actual length of the indentation. According to research by the authors, it is also revealed that the contrast of the microscopic image of an indentation varies with the angle of aperture of the objective lens. This report presents the results of an experiment on how measurer, measuring method, and aperture of objective lens (i.e., numerical aperture: N.A.) affect measurement of a Vickers indentation

Keywords: Vickers hardness test, numerical aperture

1. INTRODUCTION

The Vickers hardness test can cover an extensive range of test loads from several gram-force (gf) to 100 kilogram-force (kgf) with a single hardness scale. It is one of the most reliable strength tests because the simplicity of the testing theory and the indenter shape minimizes variances of hardness values obtained. The most vulnerable aspect of the Vickers method is an error when measuring the diagonal length d of an indentation. This study divides contributors to such error into three: (1) a personal error with variations among different measurers, (2) an error attributable to the method (device) of measuring an indentation, and (3) an error attributable to the objective lens used for the measurement. To explore how these elements affect measurement of a Vickers indentation, the following experiments were conducted.

2. PERSONAL ERROR WITH VARIATIONS AMONG DIFFERENT MEASURERS

The most significant issue as a contributor to an error when measuring a Vickers indentation is a personal error with variations among different operators when measuring the diagonal length of an indentation. In particular, an inexperienced operator tends to obtain smaller measurements than the actual length of the indentation. Over-measurement of an indentation is more easily noticed because this causes a slight gap between the marker line and the angular tip of the indentation. Conversely, as shown in Fig. 1, under-measurement occurs when the marker line is set inward from the angular tip, which is less likely to be noticed. This is supposedly a major cause of the under-measurement of the diagonal length of a Vickers indentation, which tends to occur with inexperienced operators.

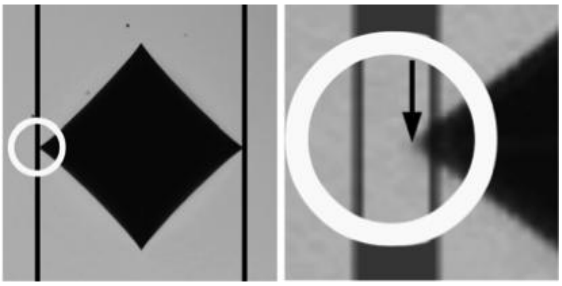

Fig. 1. Marker line set inward from the angular tip of an indentation.

Under the same test force, the Vickers hardness value, HV, is given as a function of d, or the diagonal length of an indentation, namely $HV = Cd^{-2}$ (C is a constant). Therefore, if an error when measuring the diagonal length is shown as Δd, the effort percentage of the hardness value attributable to Δd, or $\Delta HV / HV$ can be expressed as follows, using the partial derivative of the function HV.

$$\frac{\Delta HV}{HV} = \frac{\partial HV}{\partial d}\frac{\Delta d}{HV} = \frac{-2Cd^{-3}}{Cd^{-2}}\Delta d = -2\frac{\Delta d}{d}$$

This equation means that an error of 1% when measuring the diagonal length of a Vickers indentation produces an error of 2% in the Vickers hardness value. Therefore, it is essential to adjust the light axis, intensity for indentation-tip observation, in addition to ensure that the zero point of ocular microscope for diagonal-length measurement on a daily basis. The following experiment was conducted to quantify the personal error that could occur when indentation measurements were performed after the afore-mentioned adjustments and confirmations were done sufficiently..

2.1. Experiment Method

To investigate personal errors when different operators take measurements of a Vickers indentation, we had six

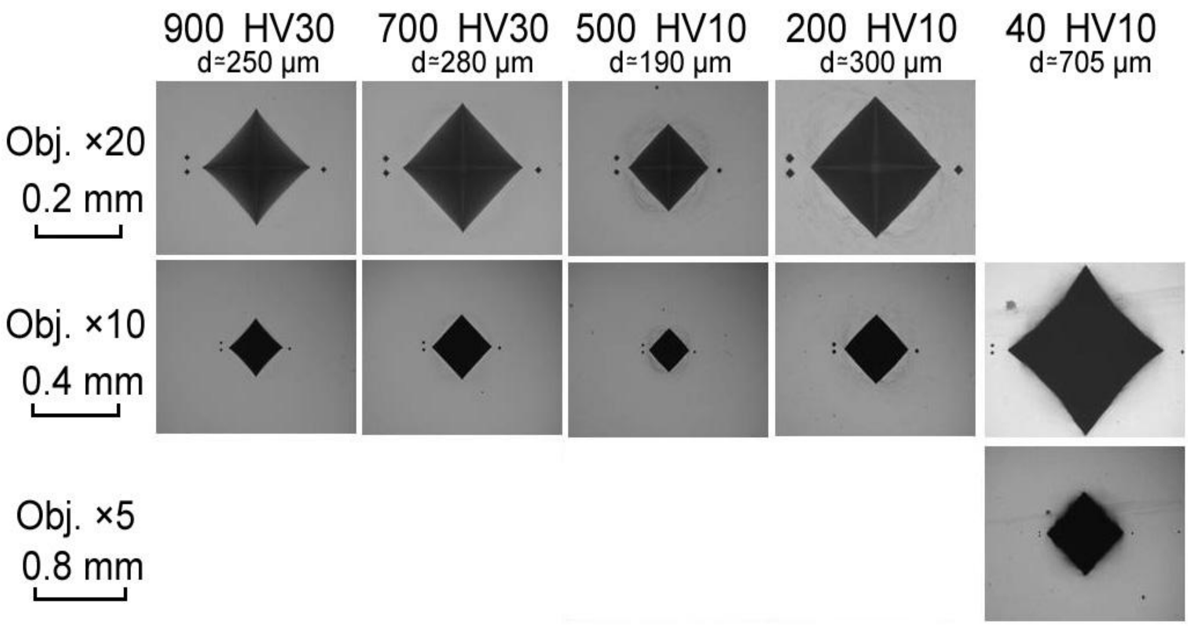

Fig. 2 Images of Vickers indentations observed for different objectives

hardness block testing operators measure indentations made on Micro Vickers hardness blocks under test loads of 30 kgf and 10 kgf (Fig. 2). The year of experience of the operators varied from six months to nearly 30 years, and the experiment was performed on a totally blind-test basis. The hardness blocks used included HMV900, 700, and 500 blocks (made of SK85), an HMV200 block (made of C1720P), and an HMV40 block (made of C1020P). The hardness tester used for measuring the indentations was MVK-ES manufactured by Akashi Co. shown in Fig. 3.

2.2. Experiment Results and Discussions

Table 1 shows the results of the personal error experiment. From these it was found that if the above-mentioned adjustments to visibility and optical system are sufficient, the variance of measurements among the six operators, including one with only six months experience, was as small as around 0.5% except for the HMV40 block made of C1020P. As can be seen from the comparative photos of the indentations in Fig. 2, the circumference of an indentation on the HMV40 block with a diagonal length of about 700 μm is somewhat blurred, unlike the other indentations compared. This blurring of the contour of the indentation may have led to larger errors, especially with less experienced operators, but the variance of measurements among the six operators less than 1%. This results suggests that the accuracy of measuring the diagonal length of Vickers indentations can be reliably high if the tester is well prepared with careful visibility adjustment and zero point confirmation.

3. INFLUENCE OF MEASURING DEVICE AND NUMERICAL APERTURE (N.A.) OF OBJECTIVE LENS ON VICKERS INDENTATION MEASUREMENTS

An ocular micrometer (Fig. 3) is generally used to measure the diagonal lengths of Vickers indentations under a test load of 150 kgf. However, there are occasions when a stage micrometer is used, such as for comparative measurements between laboratories; in which case, a high-power objective lens is used to enlarge the indentation to a size that is bigger than the field of view, and measurements are based on the distance the stage micrometer travels. As

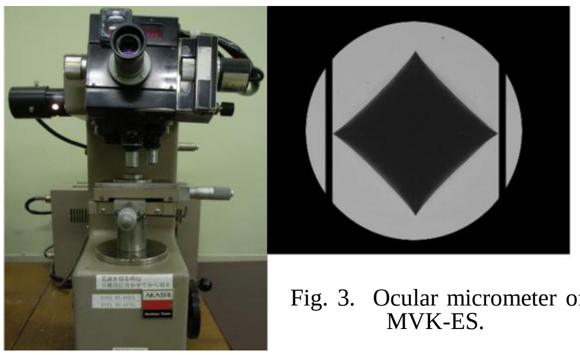

Fig. 3. Ocular micrometer of MVK-ES.

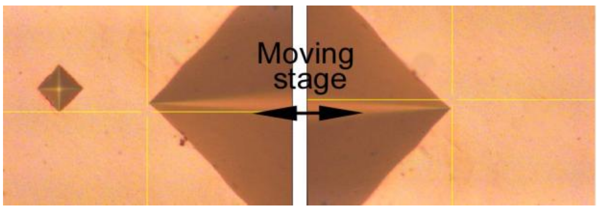

Fig. 4. Measurement of diagonal length by stage micrometer.

shown in Fig. 4, the marker line is set at one end of the diagonal line to zero the stage micrometer, and then the stage is moved until the other end of the diagonal arrives at the marker line. The distance the stage micrometer travels equals the diagonal length *d* of the Vickers indentation. With either micrometer, various objective lenses with different magnifications and angles of aperture are used. It is evident from the study by the authors that the contrast of the microscopic image of a Vickers indentation can vary significantly with the aperture of the objective lens used. Therefore, the following experiments were conducted to identify the influences of the measuring device and the angle of the aperture, or numerical aperture (N.A.), of an objective lens on the measurements of Vickers indentations.

Table 1. Comparison of HV indentation measurements by six measurers using an ocular micrometer.
(Unit: µm; MVK ES, ×20 N.A.0.44 objective lens used; Blind-test basis)

Specimens	Test load	Measurers						Avg.	Max. — Min.
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6		
		Expert level		Operator level		Trainee level			
		29 yrs.	12 yrs.	11 yrs.	3 yrs.	0.5 yr.	2 yrs.		
HMV 900	HV30	248.1	248.3	249.5	248.2	248.6	248.3	248.5	1.4 (0.56%)
HMV 700	HV30	280.1	280.4	281.6	280.5	280.2	279.9	280.5	1.7 (0.61%)
HMV 500	HV10	190.9	191.2	191.9	190.8	191.2	190.6	191.1	1.3 (0.68%)
HMV 200	HV10	298.6	299.1	299.5	299.0	298.8	299.6	299.1	1.0 (0.33%)
HMV 40	HV10	703.8	701.4	705.1	701.2	704.4	707.8	704.0	6.6 (0.94%)

Notice Results of HMV 40 were obtained using × 10 objective (N.A. 0.25).

3.1. Experiment Method

One experiment was conducted by having the operator No. 1 in Table 1 measure the diagonal lengths of the indentations made on the blocks used for the personal error experiment described in Paragraph 2, using two different models each of ocular (Akashi's MVK ES and AVK) and stage (Elionix ENT-2100 and Mitsutoyo MF, shown in Fig. 5 and Fig. 6, respectively) micrometers. Another experiment was performed to identify an error attributable to the aperture of an objective lens by comparing measurements taken with the Mitsutoyo MF stage micrometer mounted with objective lenses of seven different N.A. The experiments were conducted on a blind-test basis, as was the case with the personal error experiment. As a matter of course, these measurements were performed after carefully adjusting visibility and lighting to obtain a clear reflection of the angular tip of an indentation

3.2. Experiment Results and Discussions

As shown in Table 2, the results of indentation measurements agreed very well among the four measuring devices—two different models each of ocular and stage micrometers. The measurements performed with the Mitsutoyo MF stage micrometer by significantly changing the magnifying power and numerical aperture of the objective lens also agreed very well. As shown in Fig. 7, a change of aperture can bring about a change in the contrast of the reflection of an indentation, making it look like a barrel, not a spool, which is the way the reflection should originally look. However, this problem was resolved by adjusting the optical system, including the intensity of

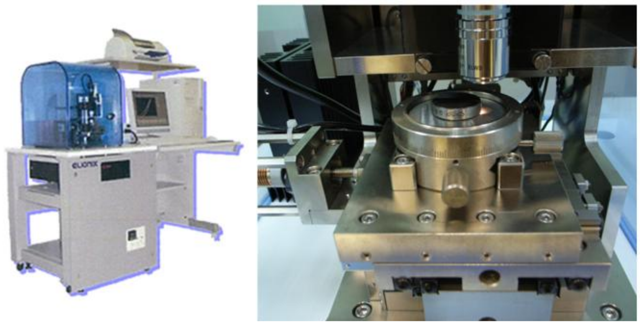

Fig.5 Stage micrometer of ENT-2100

Fig. 6 Stage micrometer of MF

lighting, leaving no effect on the measurement of indentations. From these results, it can be concluded that the difference in measuring device—ocular or stage—and

Table 2. Comparison of HV indentation measurements using four different measurement devices and seven different objective lenses.
(Unit: µm, Measurement results of the No.1 operator on a blind-test basis)

Specimens	Test load	Ocular micrometer		Stage micrometer					Avg.	Max. — Min.
		MVK ES	AVK	ENT	MF					
		× 20 N.A. 0.44	× 10 N.A. 0.25	× 50 N.A. 0.55	×10 N.A. 0.28	× 20 N.A. 0.42	× 50 N.A. 0.55	× 100 N.A. 0.7		
HMV 900	HV30	248.1	248.2	248.1					248.1	0.1 (0.04%)
HMV 700		280.1	280.0	280.2	280.3	279.2	279.0	279.0	279.7	1.3 (0.46%)
HMV 500	HV10	190.9	190.9	190.9					190.9	0.0 (0.00%)
HMV 200		298.6	298.8	298.9	297.8	297.1	298.1	297.8	298.2	1.8 (0.60%)
HMV 40		703.8	702.2	700.7					702.2	3.1 (0.44%)

Notice Results of HMV 40 by MVK ES were obtained using × 10 objective (N.A. 0.25).

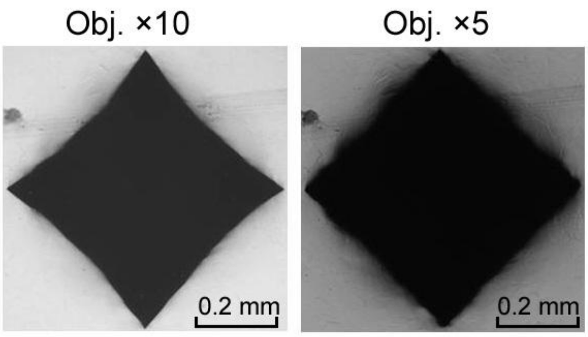

Fig. 7 Differences between images of the same indentation (40 HV10) by objectives

changes in the contrast of reflections due to varying aperture numbers of an objective lens did not affect measurements of Vickers indentations.

4. CONCLUSIONS

The results of this study can be summarized as follows.

(1)The results of measuring the diagonal length of Vickers indentations on standardized hardness blocks using ocular and stage micrometers agreed very well, with a measurement error of around 0.5%, except for the result obtained with the HMV40 block made of C1020P.

(2)The reflection of a large Vickers indentation on the HMV40 block with a diagonal length of around 700 µm is not sharply circumscribed. Therefore, less experienced operators tend to cause somewhat large errors, but they are still within 1%.

(3)Changes in the contrast of a Vickers indentation due to varying aperture numbers of an objective lens did not affect measurements, irrespective of whether they were taken with either ocular or stage micrometer.

From these results it can be concluded that, irrespective of differences in the measurement device used—ocular or stage micrometer—or the aperture number of an objective lens, the variance of measurements of the diagonal length of Vickers indentations is around 0.5% or less, as long as the tester's optical system and visibility are adjusted carefully and the correct measurement procedures are followed. Therefore, it is not necessary to make corrections for operator-to-operator differences using constant indentations or other measures.

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