PRESSURE-CONTROL-TYPE HARDNESS TESTER

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This is the report for hardness tester which equips new force control system by pressure difference. A prototype of the hardness tester was fabricated in this study, and its performance was confirmed under fairly low vacuum conditions; the differential vacuum range relative to atmospheric pressure was 20–60 kPa. The variation of the cavity size was observed under each condition in the differential vacuum range. The distance between the vertices of the triangular pyramid was 4 μm, and the repeatability was considered to be within the accuracy of the vacuum gauge.

Key words: Hardness tester, Vacuum, Force control, Pressure difference, Vickers hardness test

1. Introduction

A conventional hardness testing machine uses a weight and complicated link mechanism as its load control system. This type of load control system has a limited load range, and the complicated link mechanism also increases the cost. To address these disadvantages, we propose an alternative load control system that utilizes pressure difference. The proposed system has a very wide load range and simple mechanism, and is also highly accurate if an appropriate vacuum gauge is used under high vacuum conditions.

2. Principles

2.1 Principle of hardness test

A hardness test is used to evaluate the hardness of a material based on the size of the indentation formed by applying a constant load to the material. There are several versions of the test with regard to the shape of the indentation. The Vickers hardness test uses a triangular pyramidal indenter. Fig. 1 is a schematic illustration of a Vickers hardness test. The indenter used for the test is shown in Fig. 1(a) and its impression is shown in Fig. 1 (b). The impression is created by pressing the indenter into the surface of the test piece. The Vickers hardness is calculated using the following equation, which is obtained from the relationship between the test load and the size of the indentation:

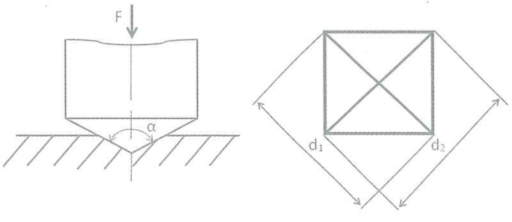
$$\text{Vickers hardness} = 0.102\frac{2F\sin\frac{\alpha}{2}}{d^2}$$

$$= 0.102\frac{2F\sin\frac{136^\circ}{2}}{\frac{d_1+d_2}{2}}$$

$$= 0.1891\frac{F}{d^2} \qquad (1)$$

Here, F is the test load (N); α is the face-to-face angle of the indenter; and d is the mean value of d_1 and d_2, which are the diagonal lengths of the indentation. The coefficient 0.102 is used to convert the test load to Newtons, if the original unit is kgf.

The test load F is predefined based on tests of different materials, and it is possible to obtain different values of the hardness using different test loads.



(a) Vickers indenter (b) indentation

Fig.1 Vickers hardness test

2.2 High accuracy principle

Theoretically, pressure control can be used to control a small force with the aid of a precision vacuum gauge. Moreover, a measurement accuracy of ±1% can be achieved by a vacuum gauge for a vacuum chamber pressure of 100000 Pa, implying a vacuum gauge error of ±1000Pa. Furthermore, the margin of error can be reduced to ±10, ±1, and ± 0.1 Pa using decompression pressures of 1000, 100, and 10 Pa, respectively. The gauge error reduces the pressure in a high-vacuum chamber, which makes precise control of the force possible by increasing

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the degree of the vacuum. The actual applied pressure is the pressure difference P given by Equation (2), where P′ is the pressure in the vacuum chamber and P″ is the atmospheric pressure. The area A is obtained using Equation (3), where d is the diameter of the circular area over which the pressure acts. The resultant force F is given by Equation (4).

$$P = P'' - P' \qquad (2)$$

$$A = \frac{\pi}{4} d^2 \qquad (3)$$

$$F = P \times A \qquad (4)$$

3. Experimental method

3.1 Experimental apparatus

We practically demonstrated the theoretical idea of using a vacuum to control the force of a hardness tester. The diameter of the vacuum chamber of the fabricated testing machine was 100 mm (see Fig. 2). Sufficient space was created for the placement of test pieces of diameter 10 mm diameter and depth 50 mm. In the interior of the one in about 20 mm, a 50mm diameter hole was drilled and the other thickness. We fabricated a structure for sandwiching the sheet to transmit the changes in the pressure difference. The structure was referred to as a flexure plate. The device can be made more compact if necessary. We used SUS304 because its surface can be easily smoothened and it exhibits excellent corrosion resistance in a vacuum. The SUS303 flexure plate was 0.3 mm thick and exhibited excellent strength and a corrosion resistance comparable to that of the vacuum chamber. We installed a gauge with a reading accuracy of 0.25% (M-341, Canon Anelva Ltd.) through the NW25 flange attached to the left side of the vacuum chamber. The right side, where a manual vacuum pump (NALGENE, Ltd.) was set up, had a similar structure. Fig. 2 and Fig. 3 shows the structure and principle of the device.

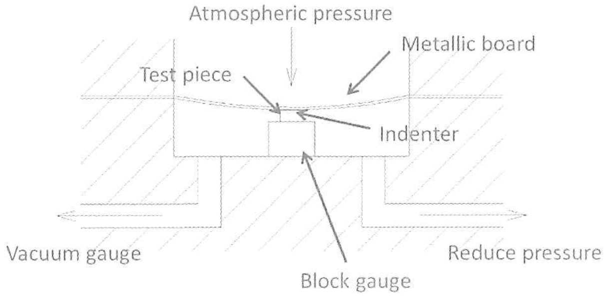

Fig.2 Principle of the hardness tester

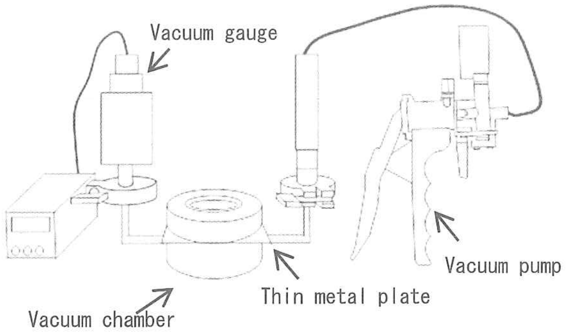

Fig.3 Experimental apparatus

3.2 Experimental procedure

The specimen was ultrasonically cleaned using pure water and a solvent, and subsequently cut to the required size. The experiments were performed in a resting state and care was taken to prevent the generation of unnecessary vibration during evacuation. After the test load was attained, it was maintained for a short period and then relaxed. The indentation in the test piece was then observed by a metal microscope and measured.

3.3 Experimental condition

The test piece was made from aluminum (A1050P) and measured 15 × 15 × 1 mm. The distance between the specimen and the indenter was adjusted to 0.3 mm and was not reduced by the pressure. The difference between the chamber and atmospheric pressures was increased in steps of 5 kPa from 15 to 60 kPa. The experiment was repeated 10 times for each pressure applied to the test piece. The indentations were observed by an optical microscope after the experiment.

4. Experimental results

Using the vacuum and atmospheric pressure to apply pressures of 20, 25, 30, 35, 40, 45, 50, 55, and 60 kPa, ten impressions were made in the aluminum test pieces for each pressure. A metal microscope (Nikon, Eclipse ME600) was used to observe the shape of the indentations and measure their diagonal lengths. Fig. 4 shows images of representative indentations for the different pressures, and Fig. 5 shows the relationship between the indentation size and the pressure difference. It can be seen that the indentation size increased with the degree of the vacuum, and by implication, with increasing pressing force.

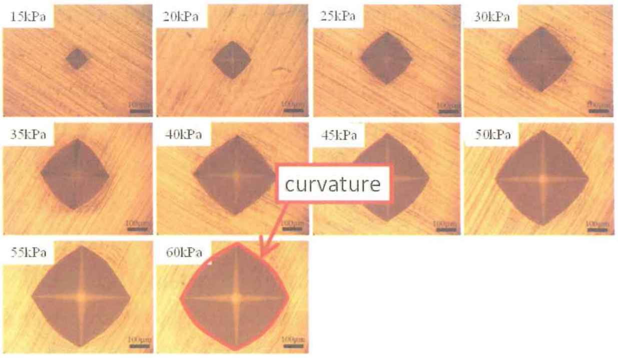

Fig. 4 Indentation for each pressure applied to the aluminum test piece

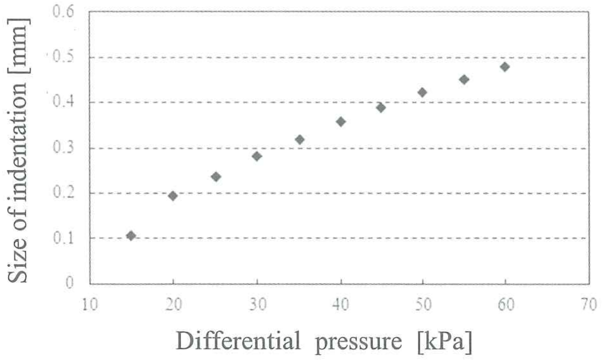

Fig. 5 Relationship between the size of indentation and the differential pressure

The variation of the indentation for each pressure is given in Table 1. The indentations ranged between 3 and 5 μm and were particularly large for a pressure of 60 kPa. The difficulty of maintaining constant pressure was observed to cause leakage of the vacuum chamber. This resulted in the tendency of the variation to reduce or remain constant with increasing degree of vacuum under the experimental conditions, resulting in the maintenance of approximately constant pressure. Both factors were considered to have their effects, and one of the variations was reduced, which, theoretically, resulted in a reduction of the pressing force by the high vacuum.

To investigate the variation of the pressing force and the increase in the vacuum, an experiment was performed in a low vacuum state in the test apparatus, which enabled easy maintenance of the pressure. A pressure of 1 kPa was applied by varying the pressure between 20 kPa and 15 kPa using the effects of the changes in the pressing force.

Table1 Standard deviation for each differential pressure

Differential pressure [kPa]	Standard deviation [mm]
15	0.00288
20	0.00296
25	0.00306
30	0.00274
35	0.00280
40	0.00240
45	0.00284
50	0.00242
55	0.00233
60	0.00578

Fig. 6 illustrates the relationship between the variation of the indentation and the pressure difference. Because the accuracy of the gauge was 0.25% based on the reading, it can be seen that the variation of the accuracy of the gauge was 0.22 kPa, and the reading was assumed to be 86.3 kPa for an absolute pressure differential of 15 kPa. The straight line at the top of the figure indicates that the indentation size varies linearly with the pressure. Moreover, it was observed that the variation was less for a higher vacuum and within the range of the gauge accuracy. However, the data at other pressures were insufficient, although it was concluded that a decrease in the variation in the indentation size could not be produced. This implies the necessity to improve the precision of the gauge to enable the acquisition of more data.

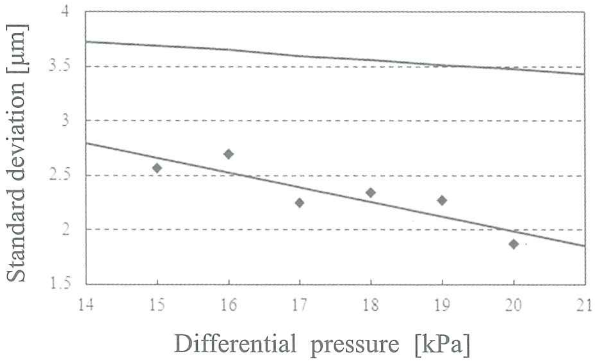

Fig.6 Reduction of the standard deviation by the pressure difference

5. Comparison of the performance of hardness testers

The performance of the proposed hardness tester was compared with those of testers available on the market. The models of the compared testers are not revealed here. The dispersions of the hardness values obtained by 10 tests for each load using multiple samples but the same pressure control method were examined. The results are presented in Table 2, and it can be observed that the sizes of the impressions ranged between 0.5 and 1 μm. Furthermore, Fig. 8 compares the load range of the proposed hardness tester under vacuum conditions with those of commercially available testers. It can be observed from the figure that the pressure control method was effective for a wide range of loads, and could take the form of a load applied at 1 atm. The generated force can be varied by changing the area of the plate deflection.

Table2 Performance of commercially available hardness testers

Load [N]	0.98	1.96	2.94	4.90
Average indentation diameter [mm]	0.07	0.10	0.12	0.16
Standard deviation of indentation [μm]	0.46	1.13	0.99	1.18
Average vickers hardness	35.7	36.1	36.1	36.0

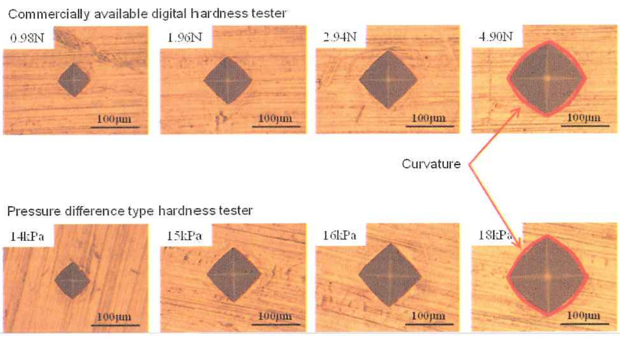

Fig.7 Comparison of the performances of commercially available hardness testers

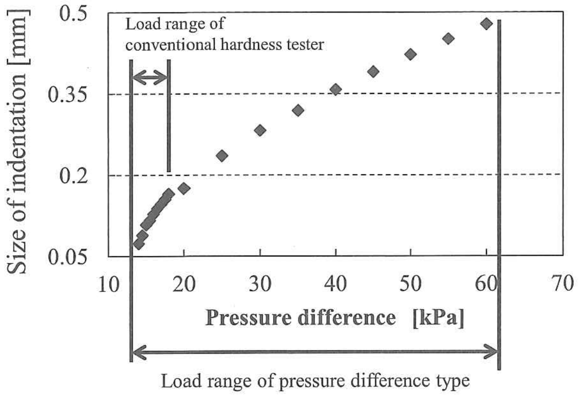

Fig.8 Wide load range of the hardness tester

6. Conclusions

In this study, we developed a hardness tester that uses a new load control method, and experimentally investigated its performance. A prototyping machine that utilizes the principle of the proposed tester is a compact and simple example of a hardness tester. The accuracy of the proposed tester was improved by the use of a vacuum, and the theoretical predictions were experimentally achieved. However, the effect of increasing the pressing force on the degree of vacuum could not be eliminated. An examination of the reproducibility of the indentation produced by the hardness tester revealed a standard deviation of about 4μm.

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