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Definition of Loading for Hardness Blocks

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Abstract – In a previous report, the authors investigated changes in hardness measurements when load rise time (***LRT***) was changed over a broad range in Vickers harness tests with loads of between 15 kgf and 150 kgf. As a result, we reported that hardness measurements varied according to the ***LRT*** value for every test load, while they remained almost constant between 15 kgf to 150 kgf if ***LRT*** was the same, although the indentation velocity of the indenter differed by more than three times between the two loads. It is very interesting that the considerable difference in indentation velocity due to varied test loads was not reflected much in hardness measurements. We, therefore, verified the effects of loading speed on hardness measurements theoretically from the strain rates of indentation deformation under the indenter and obtained some findings as follows.

(1) It is necessary to define loading conditions to ensure the reliability of hardness blocks.
(2) The loading condition, namely the strain rate under indentation could be determined by the equation which was newly introduced by the authors.
(3) According to this equation, loading conditions for general harness tests could be defined by loading time (***LRT***) regardless of load values.
(4) Also considering that hardness measurements can vary according to load holding time, we may say that testing conditions can be "defined by time,".
(5) Consequently, from the viewpoint of industrial practice, it would be reasonable to have rough criteria, that is, for how many seconds the test should be conducted, rather than to have scrutinized discussions on indentation velocity.

Keywords: Standard blocks, Loading speed, Indentation velocity, Strain rate

1. INTRODUCTION

In tensile tests, as a general rule, the greater the test velocity is, the greater is the measured strength of the tested material. Every material shows a rate effect to same extent, so the effect is considered to appear even with hardness blocks having ideal uniformity. Extended test load values have come to be used, for example, from 3,000 kgf for a 10 mm Brinell ball indenter to 1 gf and smaller values for a Micro Vickers scale and nano-indentaion test. Accordingly, the depths of indentations vary considerably as indicated in Table 1. However, the indentation velocity of the indenter must vary considerably as the load rise time is almost the same for the test loads.

Table 1 Calculated values of Vickers indentation dimensions for a sample hardness of 300 ***HV***

Test load ***P*** (kgf)	Diagonal length ***d*** of indentation (μm)	Indentation depth ***d/7*** (μm)
3,000	4,310	616
150	963	138
30	431	62
3	136	20
0.003 (3 gf)	4.31	0.6
0.0003 (0.3 gf)	1.36	0.2

In a previous report, the authors measured changes in hardness measurements when load rise time (***LRT***) was changed over a broad range in Vickers harness tests with loads of between 15 kgf and 150 kgf. As a result, we reported that hardness measurements varied according to the ***LRT*** value for every test load, while they remained almost constant between 15 kgf to 150 kgf if ***LRT*** was the same, although the indentation velocity of the indenter differed by more than three times between the two loads.$^{1)}$ It is very interesting that the considerable difference in indentation velocity due to varied test loads was not reflected much in hardness measurements. We, therefore, verified the effects of loading speed on hardness measurements theoretically from the strain rates of indentation deformation under the indenter.

2. CALCULATIONS AND CONSIDERATIONS OF STRAIN RATE CONCERNING VICKERS HARDNESS

Indentation deformation of a wedge-shaped indenter such as a Vickers shows similarities in the sizes of indentations. The strain rate $\dot{\varepsilon}(t)$ of indentation deformation under the Vickers indenter has already been minutely examined as an indentation expansion rate $^{2)}$ in research on dynamic hardness tests by Nakayama et. al., and can be determined by the following equation.

$$\dot{\varepsilon}(t) = \alpha \frac{V(t)}{x(t)} \qquad (1)$$

,where

t : time
$V(t)$: Indentation velocity
$x(t)$: Depth of indenter's indentation
α : Constant (0.2 ～ 0.3)

In this equation, if the hardness H is assumed to be

$$H = \frac{P(t)}{x^2(t)} = Const.$$

from equation (1) with the increase of load, $\dot{\varepsilon}(t)$ can be expressed as follows.

$$\dot{\varepsilon}(t) = \frac{1}{2}\alpha \frac{\frac{dP(t)}{dt}}{P(t)} \qquad (2)$$

This introduces the definitional equation of Oliver et al. for nano-scale indentation.$^{3)}$ Furthermore, if the increase of load is expressed by $P = at^n$ (a: constant related to load size, n: constant related to loading method), equation (2) is then expressed by the following equation:

$$\dot{\varepsilon}(t) = \frac{1}{2}\alpha \frac{n}{t} \qquad (3)$$

,where

n=1 : If the load-increasing velocity (kgf/s) is constant; (conventional testing machines fall under this category)
n=2 : If the indenter's indentation velocity is kept constant

From equation (3), $\dot{\varepsilon}(t)$ can be determined only by time (t) values and constant (n) related to loading method. Also equation (3) could be drawn from equation (1) in the same manner as mentioned above.

Fig. 1 shows the loading curve when ***LRT*** (t_0) = 3 s at the test load of 150 kgf. Fig. 2 shows the result of $\dot{\varepsilon}(t)$ calculated at time t point in this case. According to Fig. 2, strain rate values are higher for the example of constant indentation velocity of n=2 than for the example of constant loading speed of n=1, although they decline with the passage of loading time t for both examples.

To keep the strain rate constant during the load rise time, which is ideal for material tests, it is necessary to apply the load (dotted line; $P=b^t$) as shown in Fig.1

Fig. 3 shows the relationship between test load P_0 and strain rate at ***LRT*** t_0 based on equation (3). If ***LRT*** t_0 remains constant, the strain rate is constant regardless of the values of test load P_0. This theoretically supports the test results indicated in a previous report of the authors. Namely, because the strain rate remains constant, even with varying

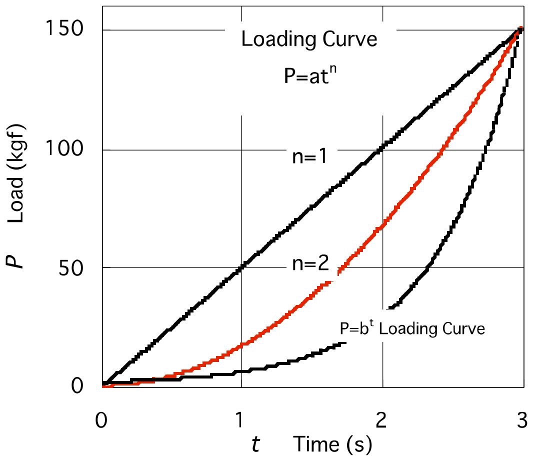

Fig.1: Example of loading curve

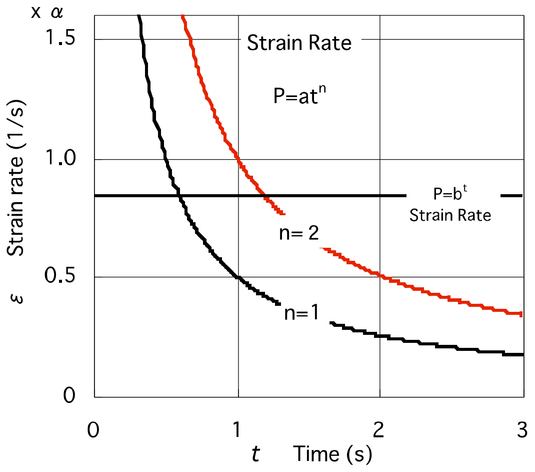

Fig.2: Example of strain rates ($\dot{\varepsilon}$) calculated

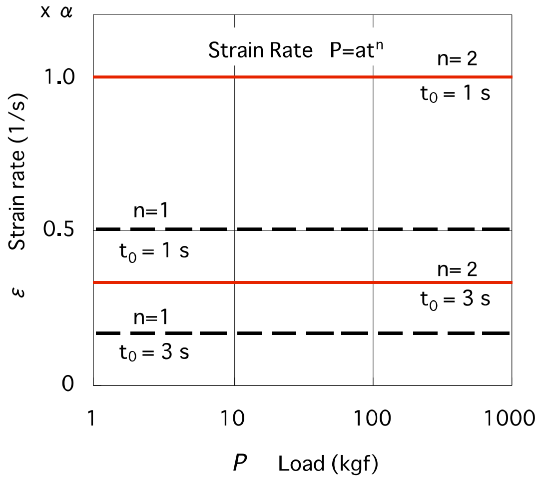

Fig. 3: Effect of test load on strain rate, with ***LRT*** kept constant

test loads, if t_0 is defined with the loading method (n) kept identical, hardness measurements are considered to be constant despite any rate effect that may exist with the tested material.

Consequently, when defining ***LRT*** to be constant regardless of load values, as in the ISO standards for harness tests, the tests can be conducted at the same strain rate $\dot{\varepsilon}(t)$ even if the load varies widely from the ultra-micro to the macro field in hardness scales such as ***HV*** and ***HM***. This is also convenient from a practical viewpoint. The idea of defining ***LRT***, which has been empirically used until now, is therefore proved to be excellent from an industrial viewpoint.

3. CONCLUSION

The hardness test values of materials depend on the accuracy of the load. Even if loading is done precisely, every test is affected by loading conditions. Therefore, it is necessary to define loading conditions to ensure the reliability of hardness blocks, although they are mainly affected by the uniformity of the blocks. As international unification of loading conditions is underway for general hardness tests and determining reference hardness values, a method of defining testing time regardless of load values would be rational. Also considering that hardness measurements can vary according to load holding time, we may say that loading conditions can be "defined by time," as is the case with tensile tests. Consequently, from the viewpoint of industrial practice, it would be reasonable to have rough criteria, that is, for how many seconds the test should be conducted, rather than to have scrutinized discussions on indentation velocity.

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