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EFFECT OF LOADING RATE AND DURATION TIME ON INDENTATION HARDNESS MEASUREMENTS

G. Aggag[1], *A. Abu-Elezz*[2]

[1] National Institute for standards (NIS), Cairo, Egypt, aggag95@hotmail.com
[2] National Institute for standards (NIS), Cairo, Egypt, aabuelezz@yahoo.com

Abstract: Previews studies on the effect of loading rate on the micro and nano indentation hardness showed that both of them affect hardness measurements. Such effect has been included in micro and nano hardness measurements. ISO/FDIS 14577-1 standard determine the loading rate of the indenter for micro hardness showed not exceed 2 μm/sec and for nano hardness should be less then 10 nm/sec. The present study is a trial to reveal the effect of both loading rate and duration time on the macro indentation hardness applied on standard hardness test blocks. A modern Zwick hardness tester that could vary loading rates and duration time over a broad range was used to preform this study. The study showed that a safe loading rate should not exceed 10 μm/sec. It also showed an obvious effect of duration time on the hardness value. It is recommended that the duration value should be stated clearly in such hardness measurement.

Keywords: Indentation hardness, loading rate, duration time.

1. INTRODUCTION

Hardness has conventionally been defined as the resistance of a material to permanent penetration by another harder material with measurement being made after the test load has been removed, such that elastic deformation is ignored. Recently, instrumented indentation hardness [1] provides the ability to measured the indenter penetration under the applied load throughout the testing cycle and is therefore capable of measuring both the plastic and elastic deformation of the material under test. Newly, ISO 14577-1,-2,-3 are addresses the macro, micro and nano-range of the indentation test [2]. As modern standards methods for hardness measurement, the rate of load application is limited with considerable variability in the requirements. The requirements are limitations to the rate of indenter motion, the loading cycle time or a vague statement to avoid impact.

Indentation loading rate was found to be one of the main influence quantities for Rockwell and Vickers scales [3-5]. In metals, the extent of strain hardening is affected by the loading rate [6]. Also, the extent of plastic deformation and dislocation movement, densification, micro fissuring, shear faulting, twinning or crushing may be rate sensitive. The aim of this study is a trial to reveal the effect of both loading rate and duration time on the macro indentation hardness. For these study, hardness block with a high uniformity of hardness values were used as specimens [7].

2. EXPERIMENTAL PROCEDURE

A modern Zwick hardness tester that could very loading rates and duration time over a broad range was employed [8].The hardness tester is shown in figure 1. As shown in figure 2, two measurement systems, both with high resolution, one for load and one for indentation depth, the indenter and a sensor are integrated in shell. Load was applied by a screw-driven crosshead that was controlled by a closed-loop feedback circuit connected to a built-in the load cell. The indenter was mounted directly on the load cell.

The duration time are varying from 1 to 300 sec, and loading rate are 0.0001, 0.001, 0.01, 0.1, 0.5 and 1 mm/sec. The load indentation curves are recorded by universal software designed by Zwick thought personal computer. Hardness standard blocks with a high uniformity of hardness values of 301HV10, 306HV1 and 702HV10 are used to perform this study. 301HV10 means hardness values is 301 kg/mm^2 with applying load 10 kg. Therefore the hardness block are chosen in two cases: case one with the same hardness number and different applying load, 301HV10 and 306HV1. The second with the same applying load and different hardness values, 301HV10 and 702HV10.

Figure 1: Zwick universal hardness testing machine.

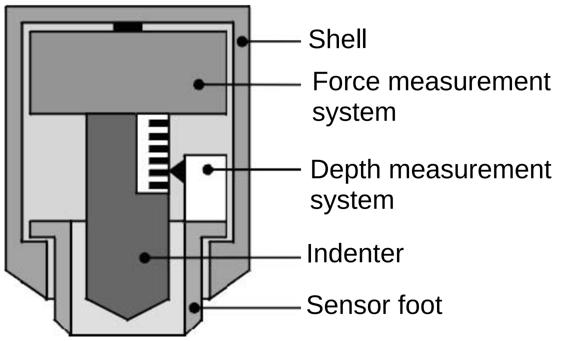

Figure 2: Schematic construction of hardness measurement head of Zwick.

3. ANALYSIS OF LOAD PENETRATION DEPTH INDENTATION CURVES.

Instrument indentation hardness provides the ability to measure the indenter penetration *h* under the applied force *F* throughout the testing cycle and is therefore capable of measuring both the plastic and elastic deformation of the material under test. Figure 3 is a typical load displacement hysteresis curve obtained from standard block 301HV10 specimen. During indenter loading, the material undergoes both elastic and plastic deformation. This loading part of the curve, with the subtraction of the elastic deformation is used to determine the hardness of the material. The unloading part of the curve is essentially elastic and with some analysis gives information about the elastic material properties. The indentation hardness value is calculated by dividing the test force by the surface area of the indenter penetrating beyond the original surface of the test piece A_c as in the equation (1).

$$HM = \frac{F_{\max}}{A_c} \quad (1)$$

Where F_{max} is the maximum applied load and A_c is the projected area of the impression under load. In a conventional Vickers hardness test the area of the residual impression is measured optically and used in place of the area of the impression under load. Stilwell et al [9] showed that this is acceptable since when an indentation is unloaded there is little elastic recovery of the impression sides, although the depth recovers substantially.

Oliver et al [1] showed that the A_c is determined from the so-called area function of the indenter tip, $A_c = f(h_c)$ where h_c is the contact depth, i.e the distance along the indenter axis that the indenter is in contact with the sample. The indentation depth is related to the maximum indentation depth, h_{max},by the equation (2) [1]:

$$h_c = h_{max} - \varepsilon * F_{max} / S \quad (2)$$

Where ε is constant depends on the geometry of the indenter (ε=0.75 for Vickers indenter [9]), and S is the contact stiffness, defined as an incremental in load divided by the resulting increment in displacement in the absence of plastic deformation. In the present study, the contact stiffness S is determined in two steps:

1-Unloading indentation curve data from 40-95% of maximum load is fitted with $F = f\,(h-h_f)^m$, where h_f is the residual imprint depth (see fig 1) and *f* and *m* are fitting parameters [10].

2-the unloading curve fit is differentiated analytically to determine the slope at maximum load: S=dF/dh at F=Fmax.

Once the contact depth has been determined the contact area is readily obtained from the geometry of the diamond pyramid (which is assumed to remain unreformed). For a prefect Vickers indenter the contact area Ac as in the equation (3) :

$$A_c = 26.43 * h_c^2 \quad (3)$$

Eight testing point at least were taken for each hardness values.

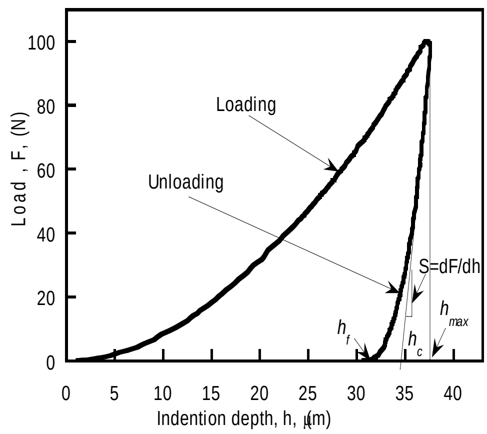

Fig 3 Load indentation curve of standard block 301HV10 specimen, at loading rate 0.001 mm/sec.

4. RESULTS AND DISCUSSION.

4.1 Effect of duration time on HV and HM

Figures 4, 5 and 6 shows the effect of duration time on Vickers and Martens hardness values with steel hardness test blocks for 301 HV, 306 HV and 702 HV. The plotted data represent the measurements of each test. For these results it is apparent that, the hardness values measured by Vickers and Martens method, have a certain tendency depending on duration time. HV values tended to get slighter higher then HM values for these experiments. There was no significant variation in the hardness measurements at each duration time, which indicates the good uniformity of the test block used.

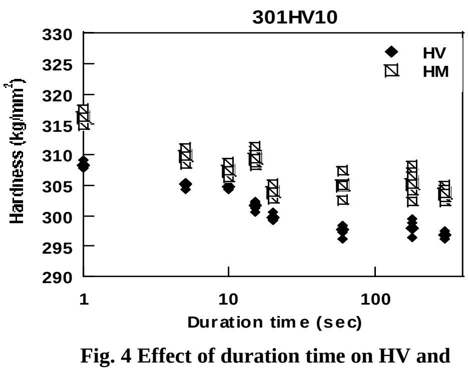

Fig. 4 Effect of duration time on HV and HM at the 301HV10 level

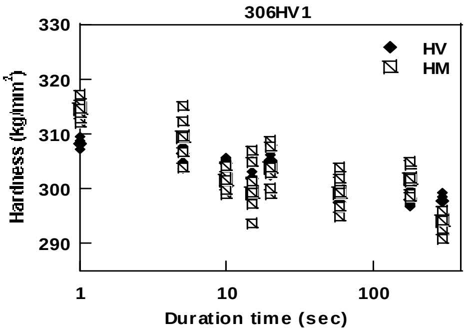

Fig. 5 Effect of duration time on HV and HM at the 306HV1 level

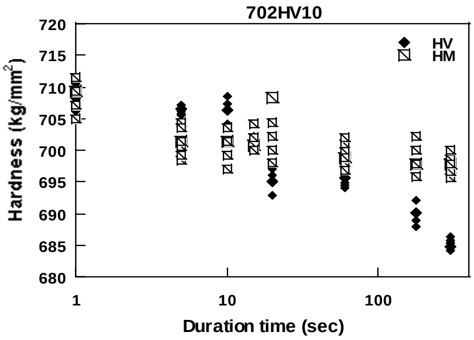

Fig. 6 Effect of duration time on HV and HM at the 702HV10 level

4.2 Effect of loading rate on HV and HM.

Figure 7 illustrates the test results on the reference test block with a value of 301 HV10, carried out with duration time of 10 sec and loading rates from 0.1 µm/sec to 500 µm/sec. The figure show the loading and unloading curves of loading rate 0.1, 1 and 10 µm/sec indicate an excellent congruent behaviour, which is only possible, if the test block are excellent uniformity. Also, the figure shows at loading rate lower then 10 µm/sec, the load indentation curve has no significant difference and the maximum applied load is about 10 kg. On the other hand, the loading and unloading curve of 100 µm/sec and 500 µm/sec showed different behaviour, due to dynamic effects. The maximum applied load at loading rate of 10 mm/sec and 500 mm/sec is different for each and also form lower loading rate. This means that the dynamic effects increase with increasing loading rate. Also the indentation size of 100, 500 µm/sec loading rate is greater then that occurring loading rate less then 10 µm/sec.

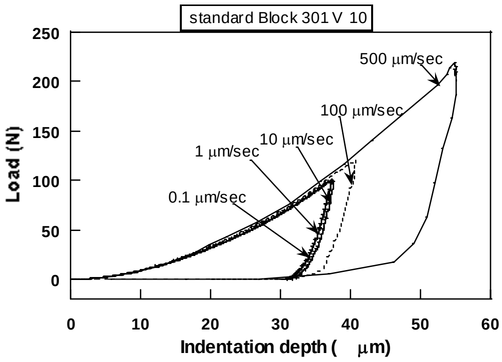

Fig.7 Load indentation curves at different loading rate.

Figures 8, 9 and 10 shows the effect of loading rate on Vickers and Martens hardness values with steel hardness test block for 301HV10, 306Hv1 and 702HV10. All the tests are carried out with constant duration time of 10 sec. The results shows HV and HM at loading rate less then 10 µm/esc have similar values. There is no significant difference between hardness measured by HV and HM at lower loading rate. By increasing loading rate the hardness measured by the two methods decreased. The scatter the measured hardness values increases with increasing loading rate. The

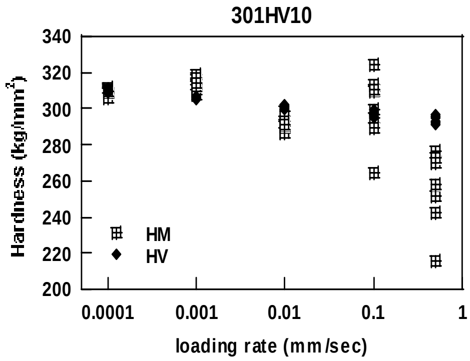

Fig. 8 Effect of loading rate on HV and HM at the 301HV10 level

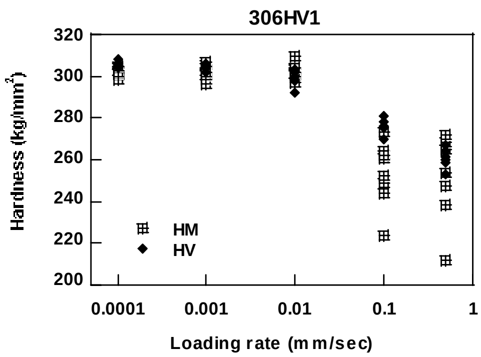

Fig. 9 Effect of loading rate on HV and HM at the 306HV1 level

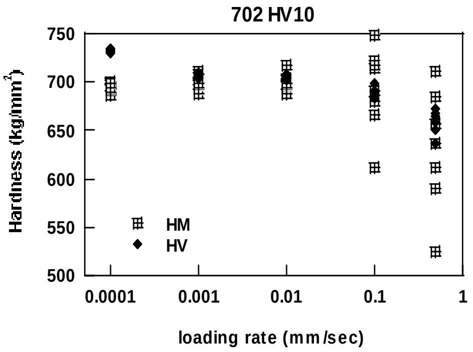

Fig. 10 Effect of loading rate on HV and HM at the 702HV10 level

5. CONCLUSIONS

The results of the experiments presented in this paper can be summarized as follows:
1- In indentation hardness the duration time showed obvious effect on the hardness values. It is recommended that the duration value should be stated clearly in such hardness measurement.
2- Indentation hardness value, such as Vickers and Martens hardness, showed the values differ with loading rate higher then 10 μm/sec.

More detailed study is needed to understand the effects of initial, final loading rate and rate of unloading on indentation hardness measurement.

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