Evaluation of Cyclic Plastic Deformation by Nano -Indentation

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ABSTRACT

Using Dynamic Ultra-Micro Hardness Tester, the change of mechanical property at stress concentration parts under cyclic loading was measured and the cyclic hardening/softening phenomena at early stage of fatigue around crack tip were made clear. The effect of the stress concentration, the strain amplitudes and the number of cycles on the micro Vickers hardness by conventional method and the dynamic hardness evaluated by indentation depth were examined. Furthermore, it is shown that the cyclic local plastic behavior good agree with the change of surface micro dynamic hardness and this micro indentation test is effective measuring method of the change of mechanical property in metals.

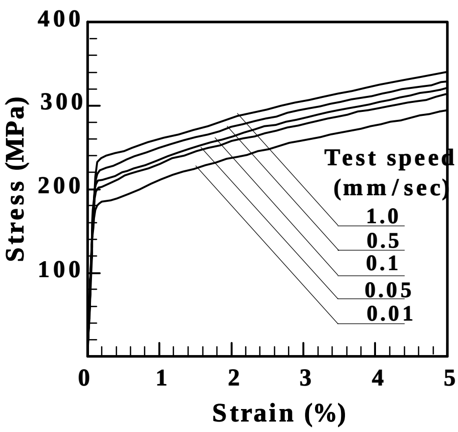
1. INTRODUCTION

As the evaluation method of the mechanical properties of material surface layer, the super-micro hardness testing machine are paid attention to micro-electron manufacturing industries[1-4]. The change of material properties under cyclic loading does play an important role in fatigue process. So, in this study, the change of material property, that is, the cyclic hardening/softening phenomena at early stage of fatigue around the crack tip was measured by using Dynamic Ultra-Micro Hardness Tester (DHU-201S)[5] and the effect of the stress concentration, the strain amplitudes and the number of cycles on the surface micro hardness were examined. The conventional method of micro Vickers hardness demand the measurement of the diagonal length of indentation and lot of time are need. But, in this study, as the hardness value is evaluated by the indentation depth which is electrically detected by the differential transformer, the measurement time is shortened substantially. The hardness value obtained by this method was named “dynamic hardness” in this paper and the propriety of this evaluation method was shown.

2. EXPERIMENT

2.1 Material and specimen

The material used is austenite stainless steel plate (thickness 6mm), SUS304 in JIS. The crystal grain sizes were 50~200μm. The material properties were obtained by monotonic tensile test and cyclic strain test. Figures 1 and 2 show the monotonic stress-strain curves and the cyclic stress-strain curves by joining tip of stabilized hysteresis loops[6]. This material cyclically soften in small strain region (< 0.4%) and cyclically harden in larger strain than that and this material shows the strain rate dependence at room temperature.



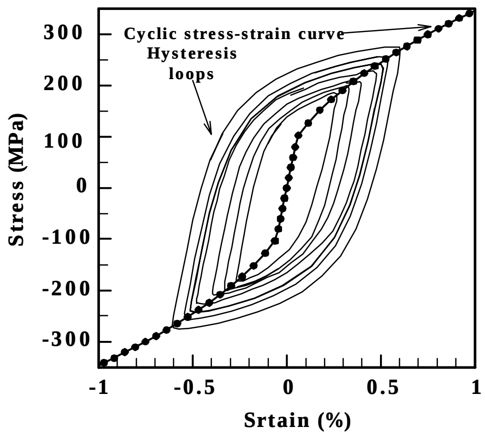


Fig.1 Monotonic stress-strain curves   Fig.2 Cyclic stress-strain curves

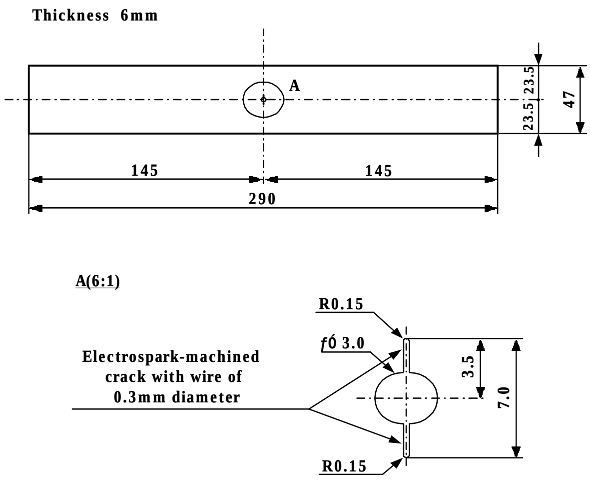


Fig. 3 Test specimen

Figure 3 shows the geometry and dimensions of hardness measuring specimen. The center pre-crack was made by electro spark machine with wire of 0.03 mm diameter as stress concentration parts. All specimen were annealed(in vacuum, 800℃ 3.0 hr hold, furnace cooling) and the solution heat treatment (in vacuum, 1030℃ 2.0hr hold, rapid cooling) was made.

2.2 Experimental procedure

2.2.1 Cyclic loading test

In order to examine the change of material property under cyclic loading, the low cycle fatigue tests were carried out by displacement control; the displacement amplitudes, 0.25mm, 0.3mm, 0.35mm and the subjected number of cycles are 10, 50, 100, 1000 cycles at each amplitude.

The strain behaviors were measured by strain gauges which were pasted at 1.5mm distance from the crack tip. In this cyclic loading test, an electro-hydraulic servo-type fatigue testing machine was used.

2.2.2 Dynamic micro hardness test

The surface of specimens obtained by cyclic loading test were treated by electrolytic polishing. Surface roughness is about 0.04μm in Ra. In this hardness test of the material surface, Dynamic Ultra-Micro Hardness Tester (DHU-201S, Shimadzu co. shown in Fig.4) was used. Figure 5 shows the effect of loading speed and subjected weight on the Hv hardness in raw material. In the light weight, surface hardness shows high value as comparison with heavy weight, but each measurement value in the same weight is in a narrow band. In this study, we the hardness tests were carried out for each specimen in the load 294 mN and 10 sec holding time, and Vickers indenter was used in order to compare with conventional Vickers hardness

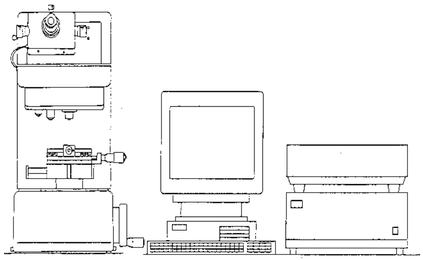


Fig. 4 Appearance of nano-indentatation testing machine

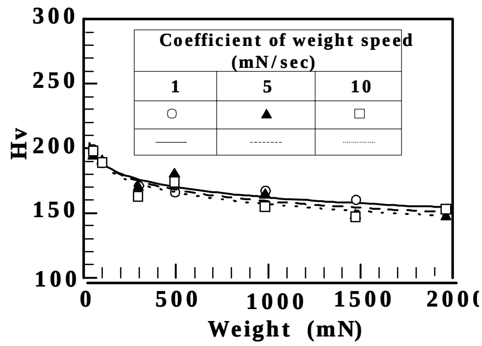


Fig. 5 Effect of loading speed

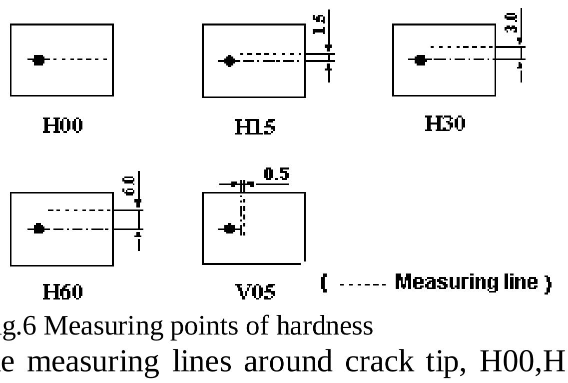
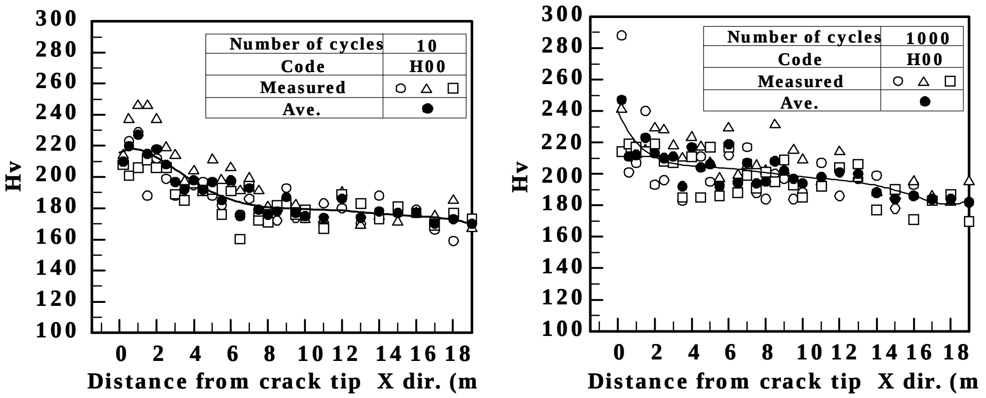


Fig.6 Measuring points of hardness

Figure 6 shows the measuring lines around crack tip, H00,H15,H30,V05 and the measuring points of each line is 90 points. The hardness of each point was evaluated by mean value of 3 points and the dynamic Vickers hardness was calculated from the load and the indentation depth.

3. RESULTS AND DISCYSSION

The hardness distribution after 10 cycles and 1000 cycles at line H00 are shown in Figs.7(a) and (b), respectively. Figure 8 shows the change of hardness distribution at each measured line. The hardness along the crack line increase at the vicinity of the crack tip due to the cyclic plastic deformation by the stress concentration shown in Fig.7(a). Increasing the number of cycles, the tendency become remarkable by development of cyclic plastic deformation. Figure 8 shows the change of hardness distributions at each measured line. From this figure, it is found that the hardness largely increase in the early stage of fatigue.



(a) 10 cycles (b)1000 cycles

Fig.7 Example of hardness distribution at line H00

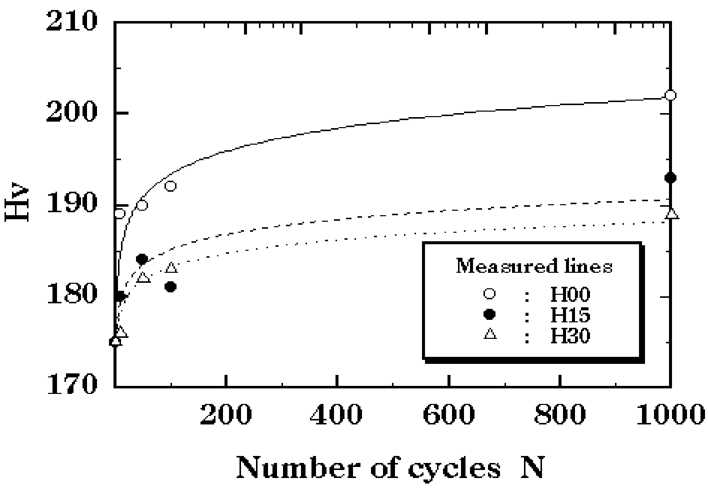
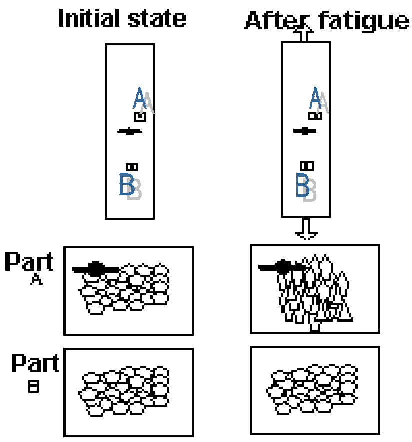


Fig. 8 Change of hardness distributions at each measured line



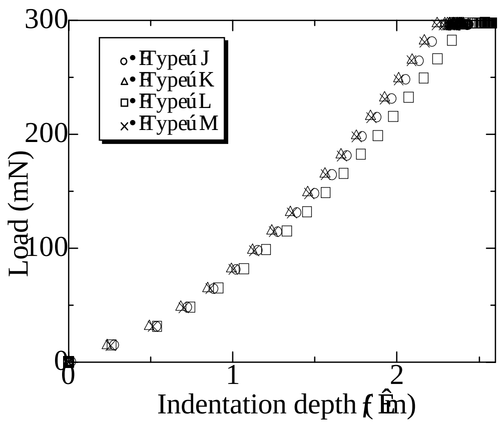
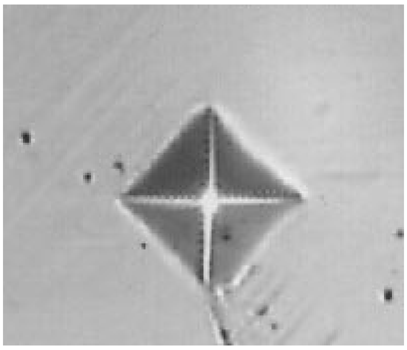
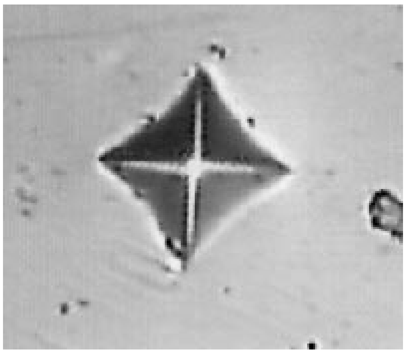


Fig. 9 Change of crystal size after fatigue

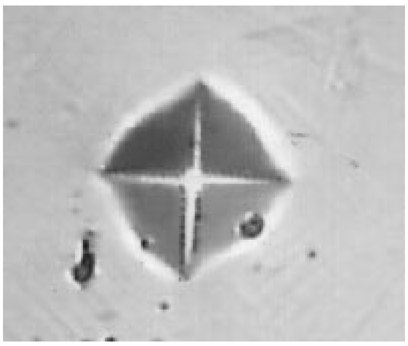
Fig. 10 Load-depth curves



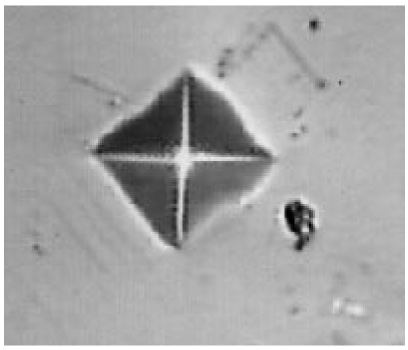
(a) Type I



(b) Type II

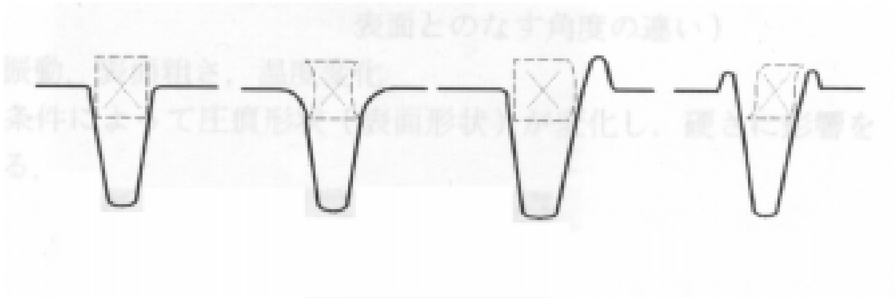


(c) Type III



(d) Type IV

Fig. 11 Configuration of indentation



Type I **Type II** **Type III** **Type IV**

Fig. 12 Configuration of cross section of indentation

Figure 9 shows the change of the crystal grain size which were obtained by etching schematically and the martensite texture was observed at this of cyclic plastic region around crack tip.

Next, we examined the relation between the load-indentation depth curve and the configuration of indentation. The configurations of indentation were classified into four type shown in Fig.11 and the load-indentation depth curves were shown in Fig.10. It become soft in the order of Type IV, type II, Type I, Type III. The corresponding configurations of the cross section of indentation are shown in Fig.12. From these figures, it is found that the change of mechanical properties were corresponded to the change of micro hardness.

4. CONCLUSIONS

The change of material property under cyclic load was evaluated by the change of dynamic micro hardness of material's surface and indentation shape. The results obtained are summarized as follows:

1) The hardness in vicinity of crack tip increase rapidly due to stress concentration and the hardness distribution correspond well to the strain distribution

2) Dynamic hardness measured by indentation depth is correspond well to conventional Micro Vickers hardness. So, the material property can be evaluated speedy by using Dynamic Ultra Micro Hardness Tester.

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