

Measurement of Fatigue Damage in Metallic Micro-Materials by an A.C. Potential Method

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Abstract: Fatigue test systems with electrolytic-polishing apparatus were developed to study fracture strength and to investigate fatigue damage in metallic micro-materials. This system has an electro-dynamic actuator or an audio speaker as a loading device. Fatigue tests were conducted after manufacturing small cross-sectional specimens by the electrolytic-polishing apparatus. In both materials, scattering of fatigue lives were very large compared with conventional size specimens. Two types of fracture morphologies were observed. A.C. potential method was applied to clarify the fatigue mechanisms and monitoring fatigue damage in micro-materials. For iron, the value of potential were almost constant during fatigue process except for just before final fracture, while they continuously increased up to final unstable fracture in aluminum.

Key words: *Metallic micro-materials, Fatigue life, Fracture morphology, A.C. potential method*

1. INTRODUCTION

It is believed that the materialization of micro-machines will bring revolutionary new ways of inspections of structures and machine components. Micro-machines are now attracting a great deal of interest in practical use of medical care equipments, space satellites, engineering, etc. Right now, most of studies on micro-machines are conducted on its manufacturing. The next stage of the study on the micro-machines is to ensure the integrity of those and those components. To realize this integrity, clarification of mechanisms and monitoring damage for fatigue and fracture of micro-materials should be conducted. In present study, fatigue tests of micro-materials were conducted, and their fatigue damages were monitored with A.C. potential method.

2. EXPERIMENTAL METHOD

The materials employed for the present study were commercially pure iron and aluminum wires of 1 mm in diameter. To remove residual stress, iron was annealed in 893 K for 10.8 ks (3 hr) and aluminum was in 473 K for 10.8 ks (3 hr). The grain size of iron was 20 μm and 25 μm for aluminum.

In the present study, fatigue test systems with electrolytic-polishing apparatus were developed, and two kinds of test systems were constructed. One system was consisted of electro-dynamic actuator, and this system was controlled by a personal computer. The loading capacity of this actuator was 200 N. The other

test system was employed an audio speaker as an actuator, and this system was controlled by analog electronic circuits. The loading capacity of this system was 10 N. Fatigue tests were conducted after manufacturing small cross-sectional specimens with an electrolytic-polishing apparatus that is shown in Fig. 1. The counter electrode had a hole, and specimen was passing through the hole. Mixture of acetic anhydride and perchloric acid was used for the electrolytic solution. Since the corrosion chamber was made of thin rubber sheet, the fatigue test can be conducted without removing it. Geometry of specimens is shown in Fig. 2. The minimum diameter, d , of each specimen was 200, 300 or 600 μm . Cyclic axial force was applied, where

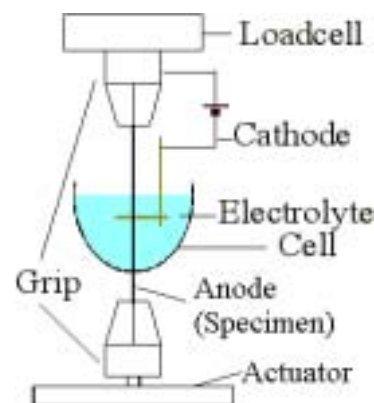


Fig.1. Fatigue test system with electrolytic-polishing apparatus

stress ratio, R , was 0.1 and loading frequency, f , was 50 Hz. To investigate the fracture morphologies, specimen's geometry after fracture was observed by using SEM. To monitor the changes in specimen's deformation during fatigue test, electric potential changes were measured by applying constant alternating current (0.03 A, 47.1 Hz) [1,2]. The A.C. potential measurement system is shown in Fig. 3.

3. EXPERIMENTAL RESULTS

3.1. Fatigue life

$S-N$ curves are shown in Fig. 4. In aluminum, fatigue tests were conducted for specimens of 200 or 300 μm in diameter, and in iron, 200,300 or 600 μm in diameter.

As seen in the figures, scatters of fatigue life were very large compared with conventional size specimens

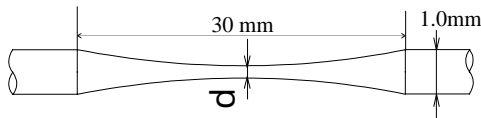


Fig. 2. Configuration of specimen.

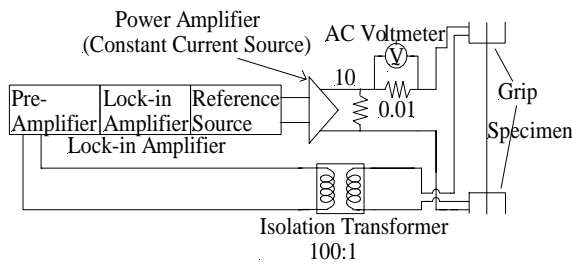
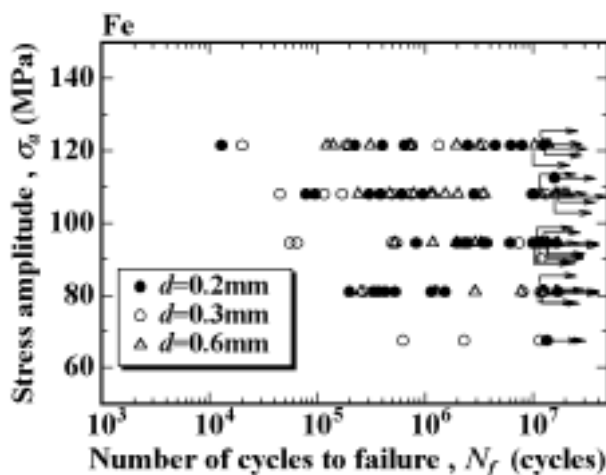


Fig. 3. System of A.C. potential technique method.

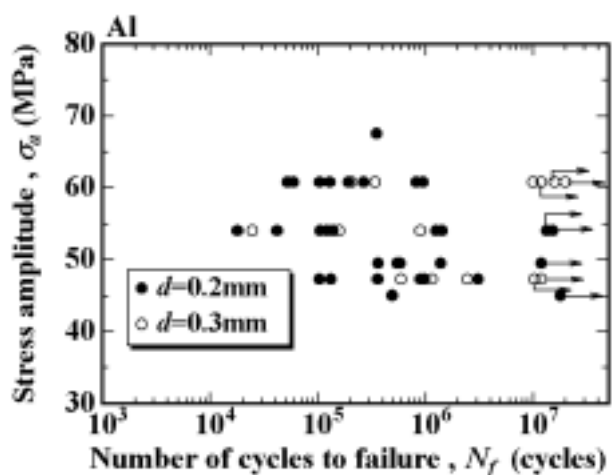
[3]. In the range of diameter employed in present study, fatigue strength was independent on specimen size.

3.2. Fracture morphology

Fractographic observations were made to clarify fracture mechanisms. As seen in Figs 5 and 6, two kinds of fracture morphologies were observed. In Fig. 5 (a) and 6 (a), the cross-sectional area after final fracture was much smaller than that before the fatigue test. Dimples are observed in the surfaces of final unstable fracture. On the other hand, in the fracture surface, which is shown in Fig.5 (b) and 6 (b), the cross-sectional area after the final fracture was almost the same as that before the fatigue test, and fracture morphologies shows the appearance of brittle-fracture. The difference is considered to have come from the crack initiation mechanism. In the case of Figs 5 (a) and 6 (a), single crack may have been initiated, and it propagated up to critical size for the final unstable fracture. In the case of Figs 5 (b) and 6 (b), however, many cracks may have been formed at specimen surface, and they were propagated to the center of specimen. In iron, the fracture morphologies like Fig. 5 (a) were often observed in specimen whose diameter was 600 μm , and those was not almost observed in specimen with diameter smaller than 600 μm . As shown in Fig. 6 (a) the fracture morphology like Fig.5 (a) was also observed in aluminum specimen with diameter of 200 or 300 μm , but it was rare. In aluminum, this kind of fracture morphology may also appear for larger specimen. There were no correlation between fracture morphologies and the stress amplitude in both materials.

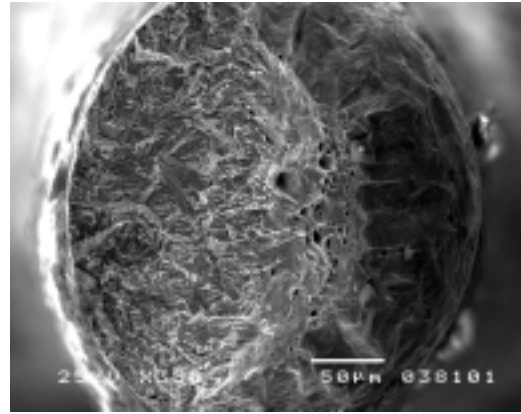
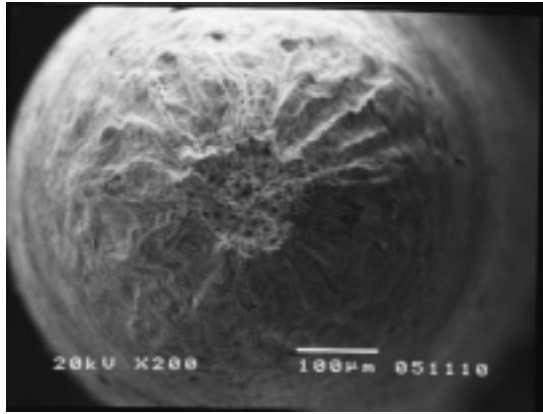


(a) Iron



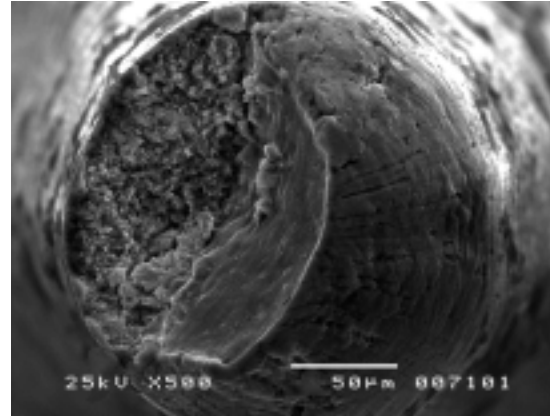
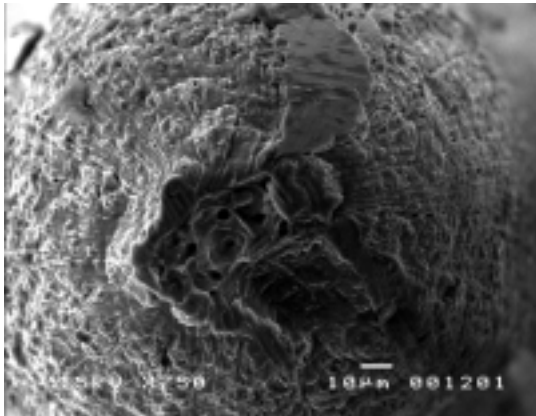
(b) aluminum

Fig. 4. $S-N$ curves.



(a) $d = 600\mu\text{m}$, $\sigma_a = 81.0 \text{ MPa}$, $N_f = 2.5 \times 10^5$ (b) $d = 300\mu\text{m}$, $\sigma_a = 67.5 \text{ MPa}$, $N_f = 2.3 \times 10^6$

Fig. 5. Fracture surface of commercially pure iron.



(a) $d = 200\mu\text{m}$, $\sigma_a = 54.0 \text{ MPa}$, $N_f = 1.1 \times 10^5$ (b) $d = 200\mu\text{m}$, $\sigma_a = 54.0 \text{ MPa}$, $N_f = 1.4 \times 10^6$

Fig. 6. Fracture surface of commercially pure aluminum.

3.3. Fatigue Damage Monitoring with A.C. potential Change

Changes of electric potential were measured at stress amplitude of 126 MPa for iron, and 54 MPa for aluminum. The values are plotted against relative number of cycles in Fig. 7 for iron, and in Fig. 8 for aluminum. In iron, the values of electric potential were almost constant except just before the final unstable fracture. At the final stage of fatigue, *i.e.*, just before the final unstable fracture, the values increased rapidly. In aluminum, however, the value continuously increased up to the final fracture.

To investigate the mechanism of the electrical potential change, specimen's geometry was observed by using CCD camera (the magnification was x300). Since there was no change of specimen geometry during fatigue process in both materials, the difference in the electric potential changes is considered to come from the difference in the crack initiation mechanism. It is

well known that the initial size of the fatigue cracks is about grain size in iron, while it is very small in aluminum. In the micro-materials, it is considered that the effect of initial crack size on the fatigue strength is very large. In iron, since the crack length at the initiation is about the grain size, and the cross section area was the same order as the grain size, crack initiation life may have been short. Another words, most of the fatigue life is considered to be the crack initiation life. In aluminum, on the other hands, since the initial crack size may have been very small, final fracture may have not occurred just after the crack initiation. The propagation of small cracks may have occupied most of the fatigue life.

4. CONCLUSION

In present study, fatigue test system with electro dynamic actuator and electrolytic polishing apparatus were developed to study the fatigue strength and

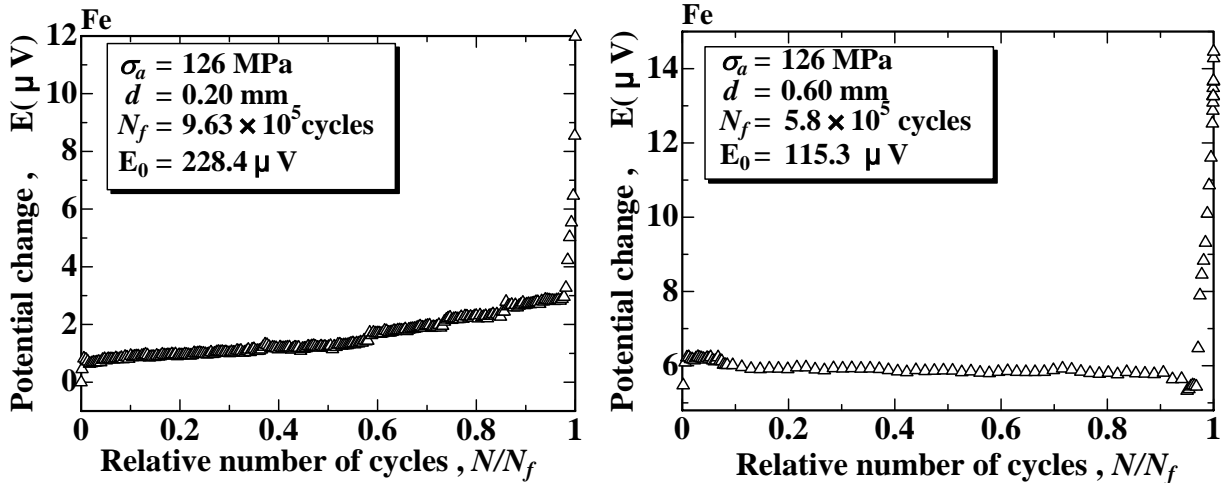


Fig.7. Changes of electric potential as a function of relative number of cycles in iron.

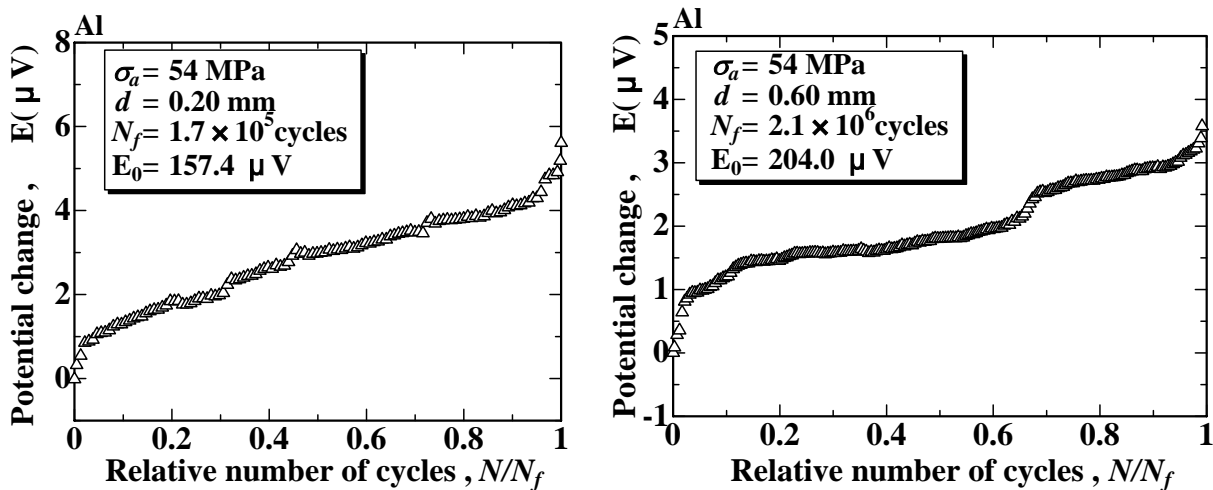


Fig.8. Changes of electric potential as a function of relative number of cycles in aluminum.

fracture morphology of micro-materials. And electro potential changes of specimen were measured during fatigue tests. Commercially pure aluminum and iron were employed for the fatigue tests. The following results were obtained:

- (1) In either material, scattering of fatigue lives were very large compared with the conventional size specimens. And in the range of diameter employed in present study, fatigue strength was independent on specimen size.
- (2) In either material, two kinds of fracture morphologies were observed. One type was that the cross-sectional area of specimen after the final fracture was much smaller than that before the fatigue test. The other type was that the area did not change during the fatigue test.
- (3) Two types of potential change were observed. For pure aluminum, the value of potential continuously

increased up to final unstable fracture. For pure iron, it was almost constant in most of the fatigue life, and it increased rapidly just before the final unstable fracture.

REFERENCES

1. Y. Nakai and R. P. Wei, Measurement of Short Crack Lengths by A.C.Potential Method, Engineering Fracture Mechanics, Vol. 32, pp.581-589 (1989).
2. Y. Nakai, H. Akagi, Y. Kitamura, and K. Ohji, Mesurement of Short Surface Crack Lengths by an A.C.Potential Method, Trans. Jpn. Soc. Mech. Eng., 55A, pp. 543-549 (1989).
3. Yoshikazu Nakai, Chiaki Hiwa, Takeshi Imanishi, And Akihisa Hashimoto, Size Effect on Fatigue Strength of Metallic Micro-materials, Proc. Asian-Pacific Conf. Fracture & Strength '99 (CD-ROM), SM22 (1999).