Fatigue Behaviors near Endurance Limit of Copper

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This paper describes the result of observations on fatigue cracks and induced substructures of polycrystalline copper (99.9 %) near the endurance limit. After machined in size and polished, specimens were annealed at 850°C for 1 hr. The resulting grain diameter was of the order of 400 μ. At first, a S-N curve was obtained, in which three test pieces were stressed more than 10^{10} cycles (Fig.1). For economy of the testing time, an ultrasonic fatigue machine operating at 17.7 kc/s was used. The temperature rise in the specimens resulting from such a high frequency of cyclic stress was suppressed by cooled water. Fig.2 shows the vibration unit of this machine.(1) As seen in the S-N curve, a knee did not observed, but the endurance limit seemed to appear at σ=4.9 kg/mm^2 and N=9.6x10^9 cycles. Even in such a limit, the specimens revealed a few marks looking like micro-cracks in the slip-band, especially in the vicinity of grain boundaries (Fig.3). Some of them, by polishing, were made sure to be micro-cracks. There were three types of crack, (1) along a grain boundary (especially a twin boundary), (2) arrested by a grain boundary and (3) running into a grain off a grain boundary. The third type of crack is interesting for the study in this paper (Fig.4). This crack appeared as shown in Fig.5 when etched so as to exhibit grain boundaries.

To check up whether the point obtained above was the endurance limit or not, the specimen showing the above crack was further stressed for 3.2×10^9 cycles (about one-third the number of cycles at the endurance limit) at the same stress, but the crack as well as others did not extend and very few slip-markings were observed. The aspect of the crack in this stage is given in Fig.6.

Then, the specimen was annealed at 500°C (1 hr), and stressed for the same number of cycles (3.2×10^9 cycles), but all the cracks showed no changes. Hence, the annealing temperature was elevated up to 600°C (1 hr) and the same stressing as above was again repeated. Although other cracks did not extend in this treatment, the above crack showed a considerable extension, with the slip-markings as seen in Fig.7. Polishing of a slight amount of the specimen surface could reveal the progress of the crack during this treatment (Fig.8).

Forrest and Tate[2] demonstrated on α-brass that the endurance limit is not the stress to start a crack, and the stress required to propagate a crack across a grain boundary. However, the present work revealed that at the endurance limit there were a few cracks which deviated from a grain boundary and run into a grain. When annealed,

such cracks could propagate on further cyclic stressing, although other cracks remained unchanged. And so, non-propagation of this type of crack seems to be due to the substructures induced in the course of the fatigue test. Thus, fatigue-induced substructures would be responsible for the endurance limit of fatigue as well as the grain boundary. By means of the fatigue test in which polishing and annealing were cyclically performed, the present authors[3][4] showed that the initial cracks of fatigue would be formed by the motion of dislocations such as dipoles of vacancy type and their motion was impeded in the forest of dislocations like patches, but relatively free in the cell structure induced by fatigue stress. The substructures formed in the specimens cycled up to the endurance limit will be shown in the meeting.

References;

(1) Awatani, J. & Katagiri, K., Bull. JSME. 12 (1969), 10.

(2) Forrest, P. G. & Tate, A. E. L., J. Inst. Metals, 93 (1964 65), 438.

(3) Awatani, J. & Fukuda, Y., Bull. JSME, 14 (1971), 307.

(4) Awatani, J. et al., Bull. JSME, 16 (1973) in press.

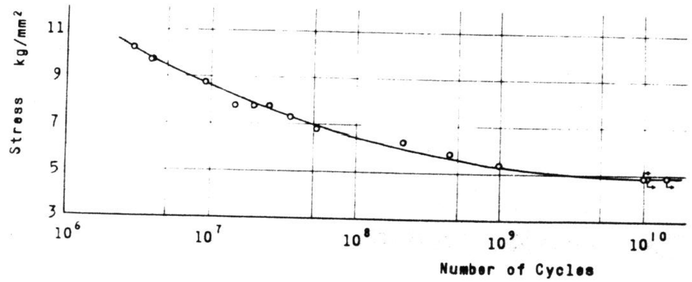

Fig.1

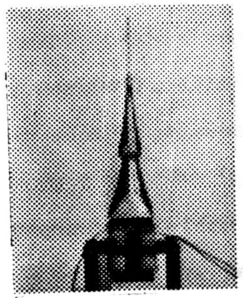

Fig.2 Ultrasonic fatigue testing machine

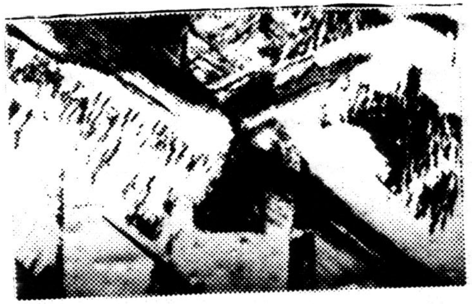

Fig.3 A mark like a micro-crack observed in a slip band

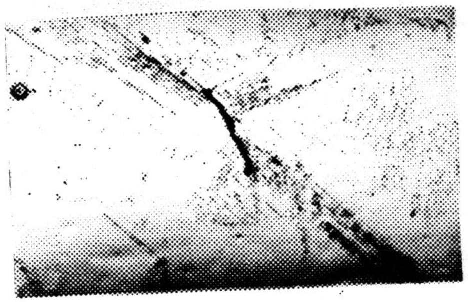

Fig.4 The surface aspect after removal of a layer of about 3 μ, showing a micro-crack, the same area as Fig.3

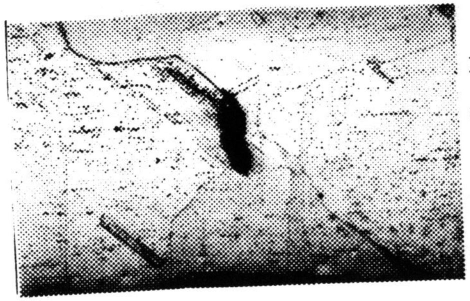

Fig.5 The micro-crack after polishing and etching, the same area as Fig.4

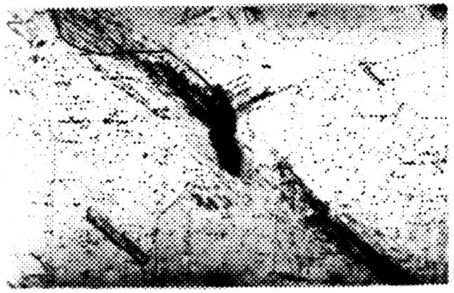

Fig.6 The micro-crack after further stressing for 3.2×10^9 cycles, showing non-propagation of the crack

Fig.7 The micro-crack after annealing and stressing for 1.6×10^9 cycles, showing propagation of the crack

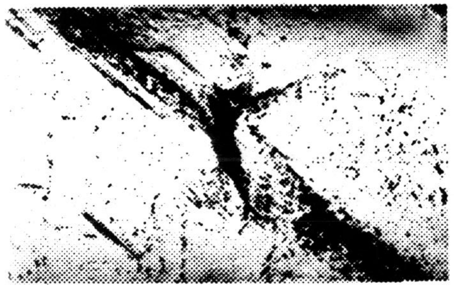

Fig.8 The aspect of the crack after a slight polishing