A Study on Fatigue Damage by the Surface Observation of Electrodeposited Copper Crystals

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In the fatigue tests of electroplated ABS plastics1), small cracks uniformly distributed on the copper deposits are observed. The cracks, shown in Fig.1, are produced along the direction of the maximum shearing stress. Slip bands near a crack, shown in Fig.2, suggest that the crack is initiated as Stage I fatigue crack. In those specimens, it is easy to count the number of cracks formed on the surface, so that these cracks are useful for investigating the microscopic growth of Stage I cracks and the transition process from Stage I to Stage II. The crack initiation process is shown in Fig.3, in which the number of cracks was counted every 0.2×10^5 cycles. Fig.4 shows crack length distribution at each cycle, and indicates that those 10μ in length are most frequently observed. Although those cracks develop independently, the increases of their length and density bring about interaction of the number of cracks, as in Fig.3.

It is observed that similar cracks form on the electrodeposited copper single crystal, which is grown epitaxially on cleaved face $\{001\}$ of KCl after the method of Sard and Weil[2]. As shown in Fig.5, similar cracks to those in polycrystals are observed. In single crystal cracks are formed along the crystallographic direction of $<110>$. Fig.6 is the electron micrograph of the fatigue slip bands and intrusions, and Fig.7 shows the number of cracks against number of cycles for single crystals.

The fact that cracks are initiated randomly on the surface suggests that fatigue crack initiation process must be treated as a stochastic process. The authors postulate the following model based on the theory of probability by developing May's idea[3]. Following Mott[4], for example, the closed circuit motion of the screw dislocation, whose Burgers vector is at right angle with the specimen surface, is considered to be the elementary process. Fatigue cracks are formed as a result of numerous repetition of tne random surface movements caused by those dislocations. It is assumed that the block of the surface which once reached a critical depth is regarded as a fatigue crack. It can be shown by this model that the following expression

$$\varphi(N^{c}_{(\nu)}) = \nu \binom{m}{\nu} (F_N^{(x)})^{\nu-1} (R_N^{(x)})^{m-\nu} f_N^{(x)}.$$

gives the probability that ν th crack is initiated at the number of cycles $N^{c}_{(\nu)}$, where m denotes the number of those dislocations which behave due to this model, x the critical depth, N the number of cycles, $f_N^{(x)}$ the probability of the first passage through x, $F_N^{(x)}$ the distribution

function of $f_N^{(x)}$, and $R_N^{(x)} = 1 - F_N^{(x)}$. The mode of $N^{c}_{(\nu)}$, namely $N^{*}_{(\nu)}$ which might be regarded as the number of repetition up to the initiation of ν th crack, is obtained from the following equation.

$$\frac{\partial}{\partial N} \varphi(N^{c}_{(\nu)}) \Big|_{N=N^{*}_{(\nu)}} = 0 .$$

The number of repetition that the ν th crack appears shows a good coincidence with the experimental value for polycrystal, when parameters included in the model are suitably chosen. Using the values of m and area of observation, the density of dislocations which behave due to the model is calculated to be $1.7\times10^{6}\mathrm{cm}^{-2}$. The dislocation density for the fatigued copper polycrystals by means of transmission electron microscopy amounts to 10^{9}-$10^{10}\mathrm{cm}^{-2}$, after Lukáš and Klesnil[5]. It is concluded that the number of dislocations responsible for extrusions and intrusions in the model such as Mott's is thought to be $1/10^{3}$-$1/10^{4}$ of total dislocations.

References

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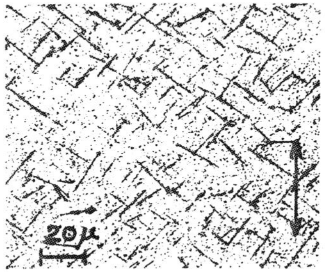

Fig.1. Uniformly distributed cracks (polycrystals). (Arrows indicate the direction of the loading.)

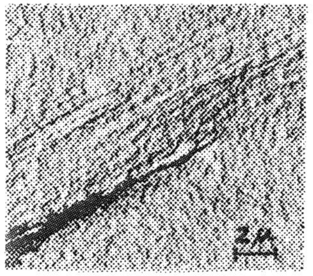

Fig.2. Edge of the crack with slip bands (polycrystals).

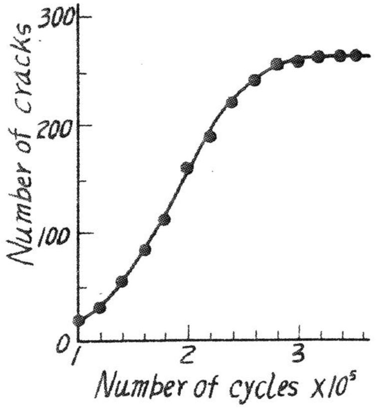

Fig.3. Crack initiation process (polycrystals).

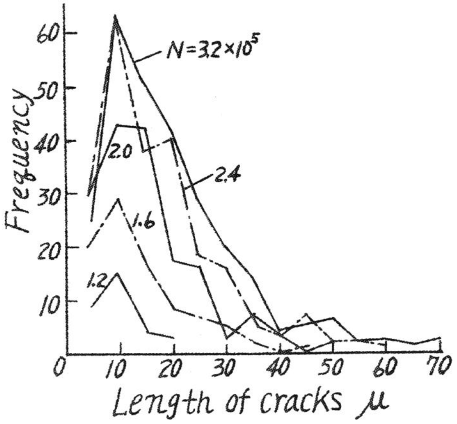

Fig.4. Crack length distribution (polycrystals).

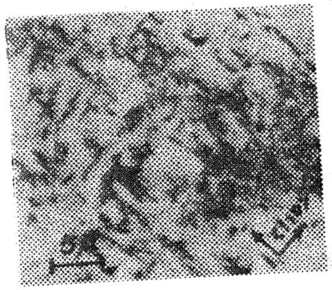

Fig.5. Uniformly distributed cracks (single crystal).

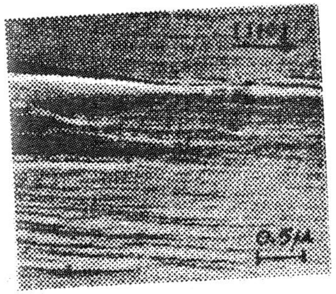

Fig.6. Slip bands and intrusions (single crystal).

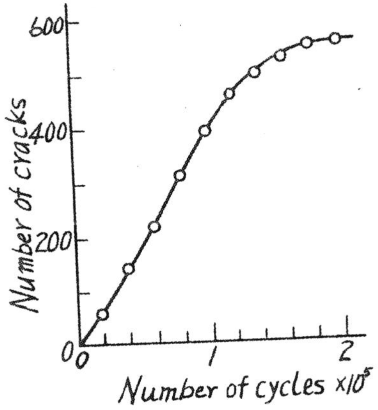

Fig.7. Crack initiation process (single crystal).