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FATIGUE CRACKS UNDER PLANE STRESS IN ELECTRODEPOSITED COPPER SINGLE CRYSTALS—PART II

平面応力下における電着銅単結晶の疲れき裂（2）

By Masahisa MATSUNAGA* and Yoshiaki HAGIUDA*
松永正久・萩生田善明

3. Experimental results and discussions

2) Electron microscopic observations

It has been reported that the extrusion and the intrusion are observed at the initial stage of cracks, using optical microscopy with the taper section method[4], electronmicroscopy with the replica method[4] and scanning electronmicroscopy. However, it is difficult to observe these by electronmicroscopy with taper section method, because a bulk specimen is difficult to cut into thin films at the extrusion and the intrusion. Since the film was used in this experiment, it could be cut into thin films to observe the section of the fatigued specimen.

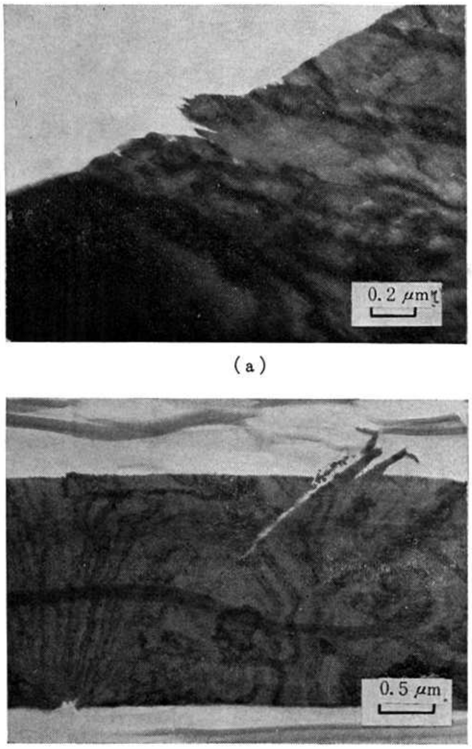

Fig. 9 Extrusions and intrusions observed on the sections.

Fig. 9 (a) and 9 (b) indicates pairs of the extrusions and the intrusions. Fig. 10 shows a pair of the extrusion and the intrusion formed separately but connected each other. This coincides with the Cottrell's model[5].

Fig. 11 indicates a pair of the extrusion and the intrusion formed on each side of the film, and Fig. 12 shows a process of formation of such extrusion and intrusion. In the tensile stroke, a

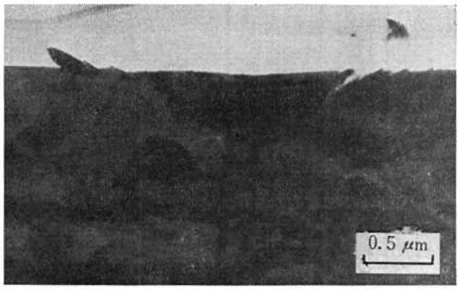

Fig. 10 Extrusion and intrusion corresponding Cottrell's model.

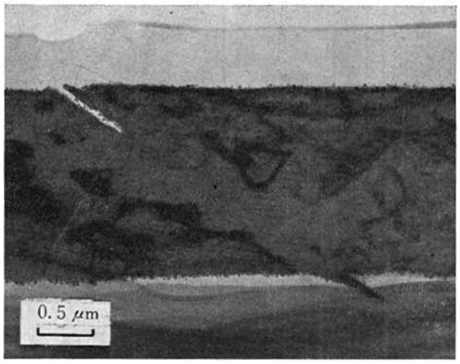

Fig. 11 Electronmicrograph of extrusion and intrusions formed on each side of a film.

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* Dept. of Mechanical Engineering and Naval Architecture, Inst. of Industrial Science, Univ. of Tokyo.

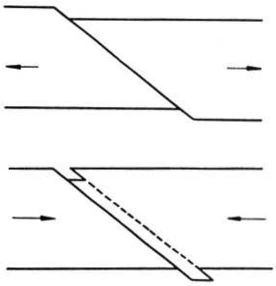
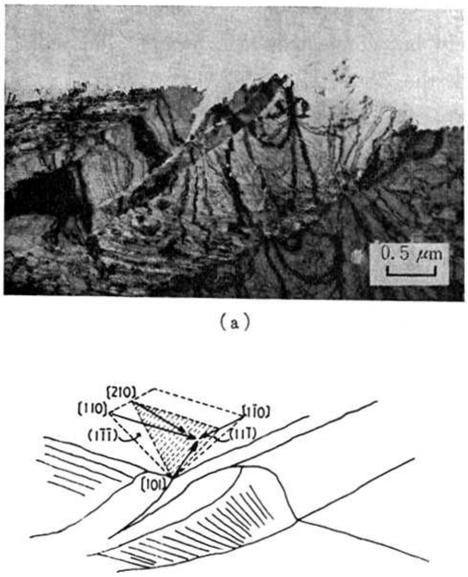


Fig. 12 A model of forming process of Fig. 11.

step originated by slip was formed on the surface. In the compression stroke, the step again recovered its flatness leaving a small distance, and thus the extrusion and the intrusion were formed.



(a)

(b)

Fig. 13 Extrusion and intrusion and their orientations when the axis of stress is (210).

Figs. 13(a) and 13(b) indicate a photograph and an illustration of a crack when the axis of stress is (210) on the (100) surface. In the figure, direction of the crack is (1$\bar{1}$0) and parallel lines appeared are the intersection of secondary slip planes (1$\bar{1}\bar{1}$) and the cut surface.

3) Initiation process of uniformly distributed cracks on single crystals

Miyamoto and Chiba[5)] analyzed the initiation of cracks by the random walk theory of dislocation and expressed it by equation (1).

$$\nu = mF_N^{(x)} \tag{1}$$

where ν is a mean value of cracks produced on the specimen surface at the number of cycles N, m is the number of dislocations which are effective to form the intrusions and extrusions and x is z/rb (z is depth from the surface and rb is movement distance of dislocation leaving the surface in one cycle of stress).

$$F_N^{(x)} = 2\left\{1-\Phi\left(\frac{x}{\sqrt{N}}\right)\right\} \tag{2}$$

where Φ denotes the normal distribution function.

Table Calculated critical depth and dislocation density.

Axis of stress	x_c	Dislocation density/cm²	Critical depth z_c (μm)	Saturated number of cracks/0.1 m²
(100)	350	7.6×10^8	14	750
(110)	250	5.8×10^8	10	6500
(210)	200	7.8×10^8	8	8200

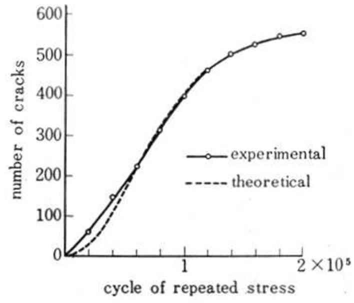


Fig. 14 Initiation process of the uniformly distributed cracks.
axis of stress: (100)
measured surface area: 0.078 mm²
$\varepsilon = 15\times10^{-4}$

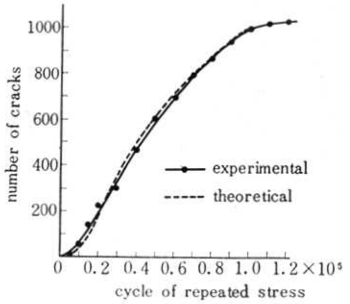


Fig. 15 The same as Fig. 14.
axis of stress: (110)
measured surface area: 0.016 mm²
$\varepsilon = 15\times10^{-4}$

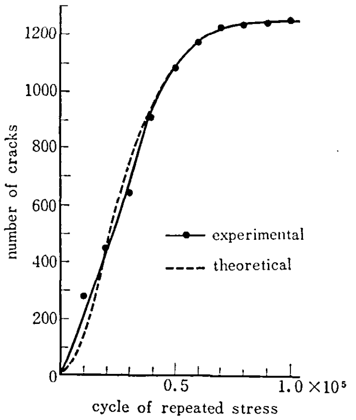


Fig. 16 The same as Fig. 14
axis of stress: (210)
measured surface area: 0.015 mm²
$\varepsilon = 15 \times 10^{-4}$

If x_c is chosen as shown in the Table, coincidence of the theoretical and experimental values are satisfactory as Figs. 13, 14 and 15. If $rb = 400$ Å is chosen, taking from the result by Avery et al⁽⁷⁾, critical depth and dislocation density are calculated as shown in the Table.

The dislocation density reported by Lukáš and Klesnil⁽⁸⁾ in a fatigued copper specimen was about 10^{10}/cm². Comparing with the calculated value of $6 \sim 8 \times 10^8$/cm², it is considered that 6 to 8 per cent of total dislocation are connected with the formation of the intrusion and the extrusion according to the model.

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