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Variation in internal friction and ultrasonic attenuation in aluminium during the early stage of fatigue loading*

Zhengang Zhu and Guangtao Fei
Laboratory of Internal Friction and Defects in Solids, Institute of Solid State Physics, Academia Sinica, Hefei 230031 (China)

Abstract

The variations in internal friction Q^{-1} and ultrasonic attenuation $\Delta\alpha$ *vs.* cycle number N of push–pull fatigue loading with various strain amplitudes ϵ_a for 99.999 wt.% Al polycrystalline specimens were measured. The corresponding dislocation configuration in the specimen was observed by transmission electron microscopy. Experimental results showed that the dislocation configuration corresponding to the $\Delta\alpha$ maximum on the $\Delta\alpha$–N curve consists of bands of tangled dislocations accompanied by single dislocation segments located between the tangle bands. The σ maximum on the σ–N curve corresponds to an incomplete dislocation cell structure. The change in the internal friction Q^{-1} *vs.* cycle number N was found to be synchronous with that of the stress σ.

1. Introduction

It is common knowledge that dislocations in deformed f.c.c. metals at room temperature are frequently distributed heterogeneously. The most commonly encountered type of heterogeneous dislocation distribution is the three-dimensional cell structure. Because the heterogeneity of dislocation distribution in deformed metals is a general feature, the study of the evolution of the dislocation configuration is important.

In the work reported in this paper we measured the variation in stress σ, strain ϵ, internal friction Q^{-1} and ultrasonic attenuation $\Delta\alpha$ in 99.999% aluminium during the early stage of fatigue loading, and we observed the dislocation configuration with the emphasis on the relation between the variation in physical parameters and the evolution of the dislocation configuration.

2. Experimental details

The metal used were Al (99.999%) produced by Fushun Aluminium Plant, China. The specimens were cut to size (9 mm in diameter and 34 mm in length) and annealed at 450 °C for 3 h. The grain size obtained is about 3 mm. Measurements were taken at room temperature on the fatigue ultrasonic meter developed by a French cooperation with China [1]. The shape of the strain wave is triangular with a period of 6 s controlled by a microcomputer (IBM PC-286). An ultrasonic longitudinal pulsed wave with a frequency of 15 MHz was sent periodically through the specimen with propagation direction parallel to the push–pull axis. The time of propagation through the sample is 11 μs.

The controlling system of the ultrasonic meter has been improved in China [2]. In the new controlling system, the PDP-11/23 computer has been substituted by the IBM PC-286 microcomputer. The MS-1214A interface has 12 bit A/D and 12 bit D/A converters, a pulse signal generator with a period of 1 μs and a counter. One D/A channel gives the controlling signal and the other D/A channel is used as a digital amplifier. The controlling program has been rewritten in Turbo Basic and assembler language. In the experiment, we acquire the physical parameters at 512 points and give 1024 controlling signals within one fatigue cycle, no matter how short one period is, so that it is possible to compare precisely the physical parameters acquired at different fatigue periods. In our program, triangular, sinusoidal and rectangular waveforms can be used to control the ultrasonic meter.

3. Results and discussion

Figures 1, 2 and 3 show the variations in σ, Q^{-1} and $\Delta\alpha$ respectively *vs.* N. They were obtained for different ϵ_a. It is clear from Figs. 1, 2 and 3 that σ, Q^{-1} and $\Delta\alpha$ do not change with increasing N at low strain amplitude (lower than 10×10^{-5}). A typical dis-

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*Dedicated to Professor T.S. Kê on the occasion of his 80th birthday.

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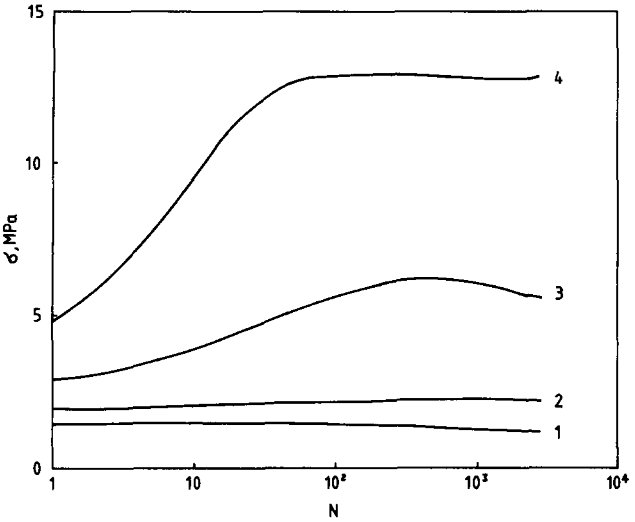

Fig. 1. Variation in the stress σ *vs.* cycle number N: curve 1, $\epsilon_a=25\times10^{-6}$; curve 2, $\epsilon_a=50\times10^{-6}$; curve 3, $\epsilon_a=200\times10^{-6}$; curve 4, $\epsilon_a=800\times10^{-6}$.

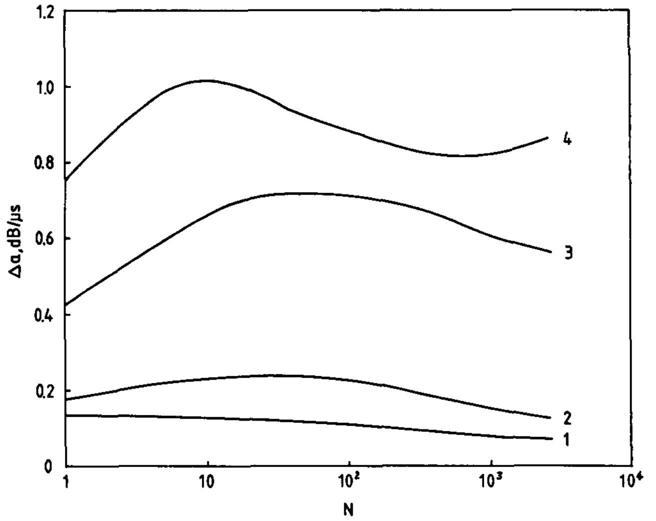

Fig. 3. Variation in the ultrasonic attenuation $\Delta\alpha$ *vs.* cycle number N: curve 1, $\epsilon_a=25\times10^{-6}$; curve 2, $\epsilon_a=50\times10^{-6}$; curve 3, $\epsilon_a=200\times10^{-6}$; curve 4, $\epsilon_a=800\times10^{-6}$.

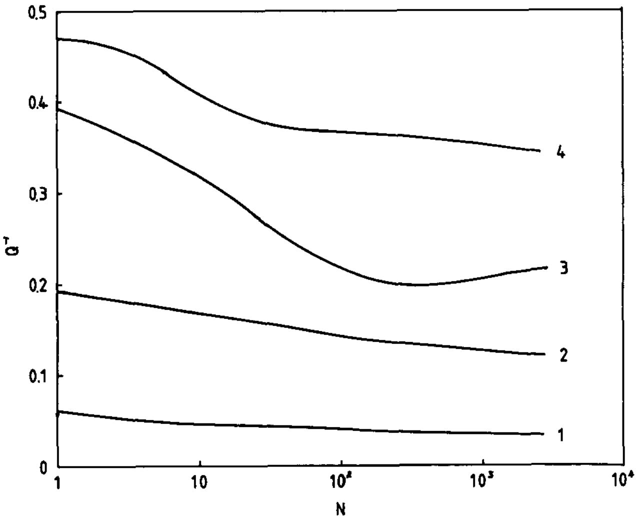

Fig. 2. Variation in the internal friction Q^{-1} *vs.* cycle number N: curve 1, $\epsilon_a=25\times10^{-6}$; curve 2, $\epsilon_a=50\times10^{-6}$; curve 3, $\epsilon_a=200\times10^{-6}$; curve 4, $\epsilon_a=800\times10^{-6}$.

location configuration in the initial annealed state is shown in Fig. 4(a), which mostly exhibits a network structure. Figure 4(d) shows the dislocation configuration corresponding to the condition of low strain amplitude and cycle index 3000. We found that there is not much difference between Fig. 4(a) and Fig. 4(d). It can be concluded that there is no obvious dislocation multiplication and variation in dislocation configuration in the whole fatigue process at low strain amplitude. Under the conditions of high strain amplitude, σ, Q^{-1} and $\Delta\alpha$ obviously varied with N. The observation by transmission electron microscopy (TEM) of this process reveals that the dislocation configuration changes markedly (Fig. 4(b) and Fig. 4(c)). Comparing the $\Delta\alpha$–N curve (Fig. 3) and the TEM observation, one can find

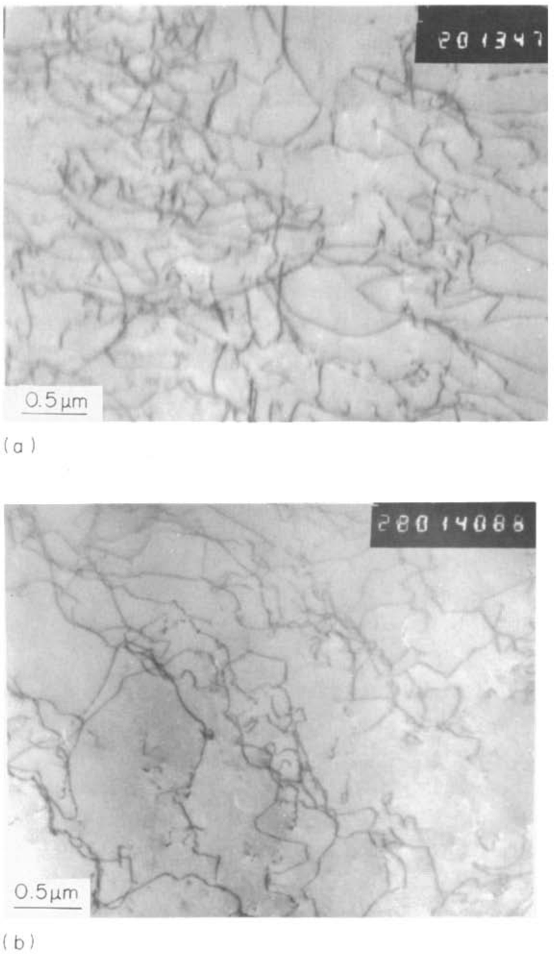

Fig. 4. (*continued*)

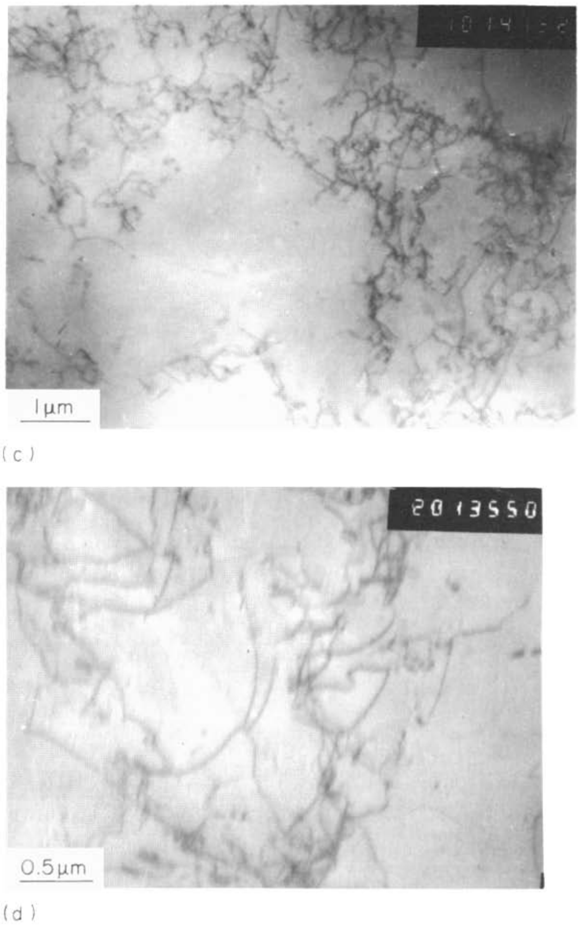

Fig. 4. Dislocation configurations: (a) annealed; (b) $\epsilon_a = 800 \times 10^{-6}$, $N = 10$ cycles; (c) $\epsilon_a = 800 \times 10^{-6}$, $N = 200$ cycles; (d) $\epsilon_a = 25 \times 10^{-6}$, $N = 3000$ cycles.

that the dislocation configuration corresponding to the $\Delta\alpha$ maximum on the $\Delta\alpha$–N curve consists of bands of tangled dislocations accompanying many single dislocation segments located between the tangled bands, whose two ends are pinned by the tangled bands.

The stress σ reaches the highest value after further fatigue cycling (Fig. 1, curve 4) while the relative dislocation configuration has evolved into an imperfect cell structure as shown in Fig. 4(c) and Q^{-1} exhibits a minimum on the Q^{-1}–N curves (Fig. 2, curve 3). This time $\Delta\alpha$ decreased, because the length of free dislocation segments evidently decreases owing to the formation of the cell structure.

The above results correspond to those of Vincent *et al.* [3]. They suggested that, at low amplitudes, $\Delta\alpha$ is caused by the interaction between point defects and dislocations, while, at high amplitudes, $\Delta\alpha$ is caused by the interaction between dislocations.

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