DISLOCATION DISTRIBUTION IN PLASTICALLY DEFORMED METALS

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ABSTRACT

The distribution of dislocations in the surface layer $\rho_s$ and in the interior $\rho_i$ and its affect on work hardening and fatigue fracture has been described. In fatigue $\rho_s$ is always greater than $\rho_i$ but both increase with the number of stress cycles. The dislocation structure in the interior is, however, unstable without the presence of the surface layer. It is shown that fatigue damage can be measured when a sufficiently penetrating X-ray source is used.

INTRODUCTION

It is often mistakenly assumed that the work hardening is uniform throughout the cross-section of specimens strained axially. This view is often tacitly accepted contrary to the evidence presented in a large number of papers published over the past 20 years. However, when uniform work hardening is not assumed it appears much easier to understand the phenomena involved in fatigue, stress corrosion, creep and the influence of environmental effects on the mechanical behavior of metals. Apparently a too simplistic model leads to difficulties in explaining phenomena that occur in real materials. One of the purposes of this paper is to provide evidence for the important role of the surface layer in plastic deformation and fracture processes. The discovery in 1928 by A. F. Jaffe' (1) that the ductility of rock salt crystals which are normally brittle could be greatly enhanced when they were deformed in water is perhaps the first indication of the possibility of altering the mechanical behavior of solids by influencing the surface. Later Gough (2) reported that the fatigue behavior of various metals

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was enhanced when the tests were conducted at reduced pressures. Rehbinder found in 1928 that surface active agents decreased the hardness and increased the drilling rate of rocks and minerals. Later it was reported that the plastic flow properties of metals also were altered by solutions containing surface active substances (3). The influence of solid films also was found to have a very large effect on the mechanical behavior of single and polycrystalline metals. A review of the earlier work conducted prior to 1960 is given in reference (4). The early explanations for the influences of the surface on mechanical behavior were usually in terms of the dissolution of microcracks or in terms of a decrease in surface energy. The concept of a Griffith crack arose because of the Jaffe' effect. However, electron microscopic as well as other investigative techniques failed to reveal the presence of such cracks. Yet, the concept of the existence of Griffith cracks as a real entity is still assumed in some quarters.

Starting in 1961, a systematic investigation of surface effects was initiated. The earlier research was an investigation to determine the effect of chemically removing the surface during plastic deformation on the mechanical behavior of metals (Al, Cu, Au, Fe, Mo, and Zn (5-8). It was established that the removal of the surface layers of metals during tensile deformation decreased the slopes of Stages I, II and decreased the flow stress in Stage III. The extent of the first two stages increased with increasing rate of removal of the surface layers. These effects were not small, for example for Al single crystals at a dissolution rate of 13 \( \mu \text{m} \) per minute, the slope of Stage I decreased by a factor of 2 while the extent increased 2.5 times. Similarly for polycrystalline metals the flow stress was decreased with increasing removal rate. From these latter observations it was clear that grain boundaries did not eliminate the influence of the surface layer on mechanical behavior as might have been assumed on intuitive grounds. Other parameters such as activation energy, activation volume, dislocation velocity stress exponent and the relaxation rate are known to be affected by the surface. Of interest is the observation that the mechanical behavior of gold, which is believed not to have an oxide layer, was influenced by the surface. Apparently, the changes in the mechanical behavior are not due only to the removal of an oxide film but also associated with the formation of a surface layer that influences the behavior of the entire specimen.

From the changes in the mechanical properties, the activation energy, activation volume and hardness, it was concluded that the surface layer formed during plastic deformation was "hard" and contained a higher percentage of dislocations than the interior (7,9). This conclusion was based primarily on the changes produced in the mechanical behavior when the surface layer was removed from