DOE/ER/10570--1

DOE/ER/10570--T1

DE83 000993

MECHANISMS OF DAMAGE ACCUMULATION IN
TIME-DEPENDENT CYCLIC DEFORMATION

Progress Report

January 1, 1982 to December 31, 1982

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August 1982

Prepared for

The U.S. Department of Energy

under Contract No. DE-AC02-80ER 10570-A000

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Abstract

Problems of cyclic creep and time-dependent cyclic deformation are being increasingly recognized in machines used for energy conversion and storage, but few studies have been done in exploration of the relevant damage phenomena. Accordingly, the proposal called for the parallel study of two kinds of damage produced in cyclic creep: 1) change in dislocation density and arrangement, to be studied in copper and 2) damage phenomena perhaps involving precipitates in Cr-Mo-V rotor steel. Progress in studying both types of damage has been encouraging. In copper tested at low temperatures, strain bursts were recognized for the first time in polycrystals of a pure metal in both cyclic and static creep and a paper reporting these results was published. Since then we have defined cyclic stress-strain response in cyclic creep, and carried out a study of single crystals in order to study better the dislocation structures associated with bursts. For the study of rotor steel, three batches of materials were obtained and characterized and a new high temperature apparatus built to do tests. Because of its superior quality, a Westinghouse rotor steel was eventually chosen for detailed study. Much effort was directed this year to improving both the environmental and heating aspects of the high temperature testing apparatus because of reliability problems with the heating cartridges. High temperature tests have been extended to lower amplitudes but unfortunately the variations in diametral strain response reported last year for high amplitudes were not observed.

Introduction

The proposal on which this contract is based briefly described some of the main factors that enter into the design evaluation process of energy converting machines (1). These factors had previously been considered by a consortium of well-known creep-fatigue investigators who had prepared a report strongly calling for further investigation of creep-fatigue damage mechanisms (2). A review of the literature indicated (1) that means were especially lacking for a qualitative determination of "damage" based on measures of the change in the state of a material due to loading-history. Accordingly, we proposed to do parallel studies of cyclic creep in copper and of microstructural changes due to complex loading of Cr-Mo-V rotor steel. The studies envisaged: 1) analysing hysteresis loops produced by various forms of cyclic loading to uncover the friction and back stresses acting on the dislocations, 2) examining slip line behavior to check strain localization and 3) observing changes in dislocation structure and/or precipitates by electron microscopy.

An extensive review of the literature was presented as Appendix A of the originating proposal but this emphasized pure metals (1). From the time that work on the contract began in March 1980, we learnt a considerable amount about the literature of Cr-Mo-V steel. Such learning modified our plans for this material. An up-dated review of the steel literature was presented in last year's report and a refined version of this was offered for publication in the Dearborn Conference (May 1982) (3). No further reviews will therefore be given here. Rather, descriptions of progress in both the steel and copper studies follow.

Research Progress - Steel

Last year, details of three batches of rotor steel were given. Because of the superior quality of the Westinghouse steel, our studies have focused on specimens prepared from two locations of that rotor. Although the batches of specimens differed in their content of upper bainite the differences in their cyclic response have not been significant.

During the year we completed tests at a strain range of 1.5% with and without hold times and offered a paper for publication. This paper contained a report of the structure of the as-cycled and virgin steel, and considerable STEM observations have been made on these structures. Observations are continuing. Preliminary results indicate the following: a) the carbides are remarkably stable for the testing conditions applied although we note some changes in density amongst the smallest alloy carbides; 2) the dislocation structures after regular push-pull cycling are little modified from the virgin state; 3) considerable modifications are caused by cycling with holds in tension, the main change being in the formation and size of cell structures. New observations are now being made on the steel cycled at lower strain amplitude.

Development work on the high temperature testing apparatus has continued. One change has been to spot weld thermocouples to the samples rather than to use spring-loaded contact probes. It may be this improvement that has caused the flow stresses observed for a strain range of 0.8% to match those of Ellison and Patterson. Our previous results indicated lower flow stresses than theirs and it may have been that our temperature was too high because of poor heat

transport between sample and probe. The new environmental chamber has been mainly successful, but we nevertheless still observe a slight-oxidation of the samples, perhaps through residual impurities in the Argon. The main recent result, which has caused us much concern, is the different behavior observed in the diametral strain range. Previously we observed, in the initial cycles, exactly the behavior expected of well-behaved elasto-plastic metal; subsequently the diametral strain range increased to a peak (because of strain localization, we presumed) and in the remainder of the test, declined steadily. This type of observation was interpreted to indicate a gradual decrease of ductility. At the lower amplitude now studied, the final decline has not occurred, but rather the value saturates at the point where major cyclic-softening saturates. At present, we do not understand this behavior.

Research Progress - Copper

To investigate the mechanism of cyclic creep in pure copper, careful experiments using sawtooth cycling in load control and 100% unloading and partial unloading have been done on polycrystalline material at room temperature. As reported last year, we discovered the phenomenon of strain bursts in cyclic creep and in other forms of static and periodic loading and a publication was prepared (4). We have now studied and documented:- 1) the stress range over which bursts occur; 2) the stress range over which cyclic creep occurs; 3) the cyclic creep cyclic stress-strain curve (CCCSSC) and its relation to the regular cyclic stress-strain curve; 4) the effect of partial unloading on the CCCSSC; and 5) the threshold for cyclic and static creep at ambient temperature. A report of some of this work has been offered for publication (5).

Much effort has been directed to understanding the dislocation structures produced during strain bursts. Initially these studies were done in polycrystals and structures were documented as a function of orientation. However, the differences between burst and unburst structures were too subtle to distinguish with confidence in polycrystals and resort was therefore made to single crystal studies. Monocrystals of different orientations were tested in cyclic creep and the cyclic stress-strain curves for cyclic creep were established at room temperature. Bursts were found very pronounced in single crystals and they generally occurred by producing slip bands which then spread throughout the specimen. These slip lines were studied by replicas and interferometry. Thus, during a burst, the specimens contained burst and unburst volumes. TEM specimens were prepared from these different volumes and studied by regular contrast methods. Typically, the dislocation structures consisted of dipolar walls dominated by primary dislocations in unburst material. Volumes of metal undergoing a strain burst were found more cellular and bursts are associated with slip on other slip systems -- sometimes even on other slip planes. We anticipate that all the structural information required from monocrystals will be gathered by the end of August, 1982, and a thesis emphasizing bursts can be prepared by December.

References

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