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BIAXIAL CREEP-FATIGUE BEHAVIOR OF MATERIALS FOR SOLAR THERMAL SYSTEMS

by

S. Majumdar

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ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

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Materials Science Division

May 1980

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ABSTRACT

Biaxial creep-fatigue data for Incoloy 800 and Type 316H stainless steel at elevated temperature are presented. Tubular specimens were subjected to constant internal pressure and strain-controlled axial cycling with and without hold times in tension as well as in compression. The results show that the internal pressure affects diametral ratchetting and axial stress range significantly. However, the effect of a relatively small and steady hoop stress on the cyclic life of the materials is minimal. A 1-min compressive hold per cycle does not seriously reduce the fatigue life of either material; a tensile hold of equal duration causes a significant reduction in life for Type 316H stainless steel, but none for Incoloy 800. Fracture surfaces of specimens made of both materials were studied by scanning electron microscopy to determine the reason for the difference in behavior.

I. INTRODUCTION

A general feature of solar thermal systems that is distinctly different from the operating conditions associated with fossil and nuclear power plants is the highly cyclic nature of the thermal loading experienced by critical components. Solar thermal systems will undergo at least one major start-up and shutdown cycle per day, with additional cycles likely to be imposed by intermittent cloud cover and unscheduled maintenance and repair. Thus, critical components may be expected to accumulate of the order of tens of thousands of cycles over their design lifetime. In many cases, such as the solar central receiver, the temperatures and stresses will be sufficiently high to introduce creep-fatigue-environment interaction as a major life-limiting factor. A further complicating factor in many solar thermal systems is the highly asymmetric nature of the thermal load, which together with the pressure load often results in the creation of a multiaxial state of stress in critical components of a solar system. Unfortunately, virtually no multiaxial creep-fatigue data are currently available for any material.

The present program was initiated in order to address the problem of creep-fatigue under a biaxial state of stress. The materials chosen were Type 316H stainless steel and Incoloy 800, both of which are candidate materials for use in solar thermal systems. Tubular specimens were subjected to a constant internal pressure and strain-controlled axial cycling with and without hold time at elevated temperature. The data generated for Type 316H stainless steel have been published in detail in a previous report.[1] The present report summarizes the results obtained for Incoloy 800 and compares the observed behavior with that of Type 316H stainless steel.

II. EXPERIMENTAL DETAILS

Details of the specimen design and test equipment were described in Ref. 1. Specimens were fabricated from 1-in.-diameter seamless tubing supplied by Pacific Tube Company of Los Angeles, California; tube dimensions were 1-in. OD x 0.109-in. (min) wall for Type 316H stainless steel and 1-in. OD x 0.125-in. wall for Incoloy 800. Chemical analysis of the Type 316H stainless steel was described in Ref. 1; similar data for Incoloy 800 are given in Table I. The Incoloy 800 tubing was given an annealed and pickled finish by the vendor and satisfied ASME specification SB-163. All the specimens were tested in the as-received condition. Nominal room-temperature mechanical properties of both the materials, as supplied by the vendor, are given in Table II. Micrographs of the as-received materials, shown in Fig. 1, indicate that the grain structures are generally equiaxed with average ASTM grain sizes of 6.5 and 6.3 in transverse section and 6.4 and 5.9 in longitudinal section for Type 316H stainless steel and Incoloy 800, respectively. Note that the grain size for the Incoloy 800 material is rather large and consequently the present heat may not be representative of an average heat of Incoloy 800.

The biaxial fatigue testing was carried out in a closed-loop servo-controlled MTS testing machine using constant internal pressure and axial strain control. The internal pressure was provided by commercially available pressurized air bottles. Axial and diametral strains were measured by means of high-temperature extensometers and the axial load was measured by a 40-kips load cell. The specimen was heated by a Lepel induction heater operating at a frequency of 455 kHz. The maximum temperature variation in the central 0.5-in. gauge length of the specimen was ±10°F.

The test procedure consisted of first heating the specimen to the desired temperature with zero axial load, and holding the temperature steady until the whole system came to thermal equilibrium. The internal pressure, if any, was then applied and the specimen kept at the temperature for sufficient time to allow the new temperature distribution to reach equilibrium. The specimen was then cycled axially under axial strain control. Hysteresis loops of axial stress versus axial strain and axial strain versus diametral strain were recorded on x-y plotters at regular intervals. Each individual signal was also plotted on a strip-chart recorder. For the internally pressurized specimens, the test was shut down automatically when a crack penetrated through the wall. For the unpressurized specimens, the test was shut