ABSTRACT

Cyclic loading tests, under four different strainrange partitioning modes, on PWA 1422 (MAR-M-200+Hf) alloy at 975°C were conducted to gain understanding of the microstructural features of failure responsible for observed deviations from theoretical predictions. Time-independent plasticity and time-dependent creep deformations were obtained by means of different strain-rates controlled through different cyclic loading frequencies. Scanning electron metallography and fractography revealed the important role of the heterogeneous microstructural features of the dendritic unidirectionally solidified material, the importance of relaxation phenomena such as the Ostwald ripening of the gamma-prime particles, and of oxidation, on the low-cycle fatigue crack propagation. The cyclic response was compared to the monotonic response of the material through a material hodograph presentation.

INTRODUCTION

High-temperature low-cycle fatigue life of nickel-base superalloys can be predicted by the strainrange partitioning procedure[1]. It involves the determination of four basic cyclic hysteresis loops which combine two types of inelastic strains with two loading directions within a predetermined strainrange value, namely: PP-plastic tension and plastic compression, CC-tensile creep and compression creep, PC-plastic tension and compression creep, and CP-tensile creep and plastic compression. The different modes can be achieved by controlling
either temperature or strain-rate. High strain-rate and/or relatively low temperature induce the mode of plasticity (time-independent loading), whereas low strain-rate at high temperature induces the creep mode (time-dependent loading).

The strain-rate within a given strain-range dictates the maximum attainable stress in the strength test mode, whereas the stress level in the creep mode controls the creep duration. The cyclic response of the material is therefore a function of the inelastic strain-range, the strain-rate and the cyclic stress, controlled by the wave-form and the frequency of cyclic straining\(^{(2)}\).

MATERIAL CHARACTERISTICS

The study concentrates on a dendritic unidirectional solidified MAR-M-200(+Hf) nickel-base superalloy known as PWA 1422. According to Manson\(^{(3)}\) the fatigue life of this material is insensitive to the mode of applied strain-range. However, in the present work some deviations in life were observed, probably due to nonuniform microstructural features. The commonly used dendritic unidirectionally solidified material differs from idealized cellular unidirectionally solidified material by having dendritic-arm protrusions along the longitudinal grain-boundaries, so that segments of grain-boundaries are normal to the solidification direction, which is the loading direction in service (Fig. 1).

The microstructure within the dendritic arm shows fine eutectic-like nodular structure of γ'-phase, which coarsen towards the arm periphery with the appearance of a more condensed grainy form (Fig. 2). It differs from the usually observed very fine modulated square γ'-particles coherent with the γ-phase matrix, which appear in the grain bulk material (Fig. 3). The grain-boundaries are heavily decorated with a mixture of γ'-particles and M\(_{23}C_6\) carbides. Occasionally, large MC carbides or TiN-nitrides appear adjacent to the dendritic-arm tips.

EXPERIMENTAL PROGRAM

Mechanical tests\(^{(4)}\) were conducted in a 25-ton closed-loop electrodydraulic MTS machine, controlled by integral function generator. Differentiation between loading and reversal rates was obtained with an Interstate Electronic function generator equipped with suitable dual-ramp facility. Strain was measured with an extensometer having two strain transfer rods, each attached at one end to gage-length collars on the specimen, and at the other to an LVDT outside the furnace. The averaged signal