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The Creep Deformation Mechanisms of Nickel Base Superalloy René 104

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Abstract
The deformation substructures developed during creep of a newly developed polycrystalline Ni-based superalloy, René 104, consisting of a bimodal γ′ precipitate size distribution, was characterized using diffraction-contrast transmission electron microscopy (TEM). Increasing temperature and decreasing stress marked a transition in the deformation mechanism from microtwinning, through superlattice stacking fault formation, to dislocation climb/bypass.

Introduction

Nickel-based superalloys are an important class of engineering materials in that they were developed specifically for service conditions that require elevated-temperature strength and resistance to creep, thermal and mechanical fatigue, and oxidation [1-2]. The strength and creep resistance of these alloys are largely attributable to the ordered intermetallic γ′ phase, and to a lesser extent to solid-solution hardening in the γ matrix phase.

The purpose of this study was to evaluate the creep deformation behavior of Ni-based superalloy René 104 and to characterize the deformation structures that form during creep. Energy-filtered TEM (EFTEM) imaging was conducted for γ′ microstructural characterization. The deformation substructures that formed as a result of creep were characterized via diffraction-contrast TEM.

Materials and Experimental Procedure

Ni-based superalloy René 104, formerly known as ME3, was developed through NASA's (HSR/EPM) program through collaboration with GEAE and Pratt & Whitney [3]. Tensile creep specimens were machined from actual scaled up disk forgings about varying locations and given a supersolvus heat treatment in order to manipulate the γ′ precipitate morphology into a bimodal secondary and tertiary γ′ precipitate distribution. Constant load, uniaxial creep tests were then carried out at temperatures between 677 and 815°C and stress levels between 345 and 742 MPa.

Foils were prepared from the gauge length by sectioning the specimens at an angle of ~45° with respect to the tensile axis. TEM 3-mm disks were slurry drilled, ground to a thickness of ~100 μm, then electropolished in an electrolyte containing 10% $HClO_4$ and 90% Methanol at -40°C/15V. The deformation substructures that formed during creep experiments were characterized using a Philips CM200 TEM. EFTEM imaging (Fig. 1a) was performed on TEM foils to image and characterize the finer tertiary γ′ precipitates using a FEI Tecnai TF20 TEM [4].

Results and Discussion

A preliminary TEM investigation of the deformation substructures that formed during creep of René 104 was conducted. The microstructure consisted of a bimodal γ′ distribution. Distinct deformation mechanisms were identified for each temperature regime. The deformation mechanism of samples crept at 677ºC and 690 MPa was found to be that of microtwinning. Fig. 1b depicts the microtwins viewed in the edge-on orientation. The inset selected area diffraction pattern about the [011] zone axis yields strong evidence that the observed defect structures are microtwins with reflections that correspond to fundamental, superlattice, and twin reflection. Samples crept at 704ºC differed in mechanism. Fig 1c. depicts a shearing configuration in which γ′ precipitates and/or γ/γ′ are being sheared. These shearing configurations result in either a superlattice intrinsic (SISF) or superlattice extrinsic (SESF) stacking fault being formed in the matrix and/or γ′ precipitates. Additional work is in progress to identify the nature of the fault contrast and the partial dislocations that are responsible for the γ/γ′ shearing. In the temperature regime 760-815ºC, there appears to be a mixture of deformation mechanisms operating; however, climb/bypass appears to be activated in this regime (Fig. 1d). Characteristic of this dislocation climb/bypass mode are 1/2<110>-type matrix dislocations that bypass γ′ precipitates by thermally activated climb. This mechanism is presumed to be operative at these elevated temperatures during prolonged exposure where dissolution of the tertiary γ′ precipitates has occurred.

Summary

The creep deformation mechanisms in the newly developed René 104 superalloy were identified through TEM characterization. The observations show clear transitions in deformation mode as a function of stress and temperature. These dependencies must be considered and incorporated in the development of physically based models for creep of this and similar superalloys.

References

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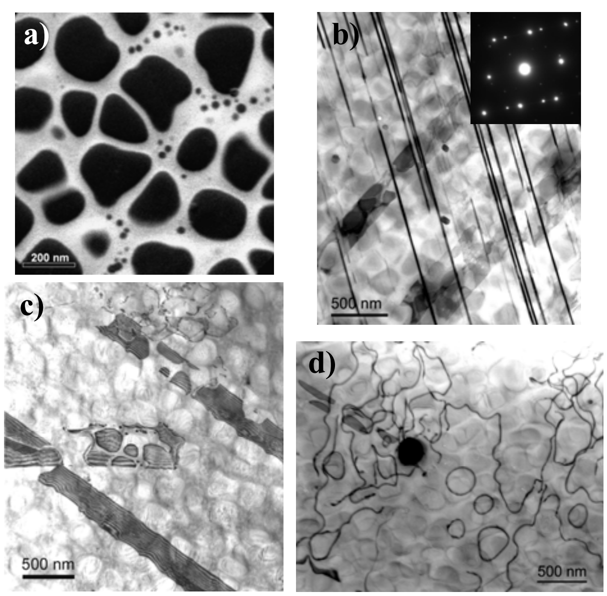

FIG 1. TEM images of René 104 Ni-based superalloy: a) EFTEM image depicting bimodal γ′ distribution; and b) microtwinning c) superlattice stacking fault shear and d) climb/bypass creep deformation substructures that form under different stress and temperature regimes. See text for details.

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