Segregation to Creep-induced Planar Faults in Ni-base Single Crystal Superalloys

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Nickel-base single crystal (SX) superalloys have long been served as indispensable materials for turbine blades in aerospace gas engines, owing to their outstanding creep properties. The unique mechanical resistance is attributed to the coherent γ/γ' microstructure in which the cuboidal γ' precipitates exhibit an ordered $L1_2$ crystal structure embedded in γ matrix channels, which is a solid solution with a face-centered cubic (FCC) structure [1]. In severely harsh operation environments, the mechanical properties of superalloys are primarily controlled by the precipitate shearing events associated with elemental segregation to and away from dislocations and planar faults within the γ' phases [2].

The present work focuses on understanding the alloying segregation to dislocations and planar defects. Some key aspects under investigation are: a) Do the nano defect phases, formed through elemental segregation, contribute to the stabilizing defect phases within the γ' precipitate? b) Does the elemental segregation to defects result in a reduction of defect energy, thereby facilitating the cutting of the γ' precipitate by the defects? To address these aspects, we designed double creep shear specimens [3] such that de-formation takes place along a specific loading direction $[11\bar{2}]$ to activate the slip system $[11\bar{2}](111)$ with Schmid factor of 1. Local high-resolution energy dispersive X-ray (EDX) is used in scanning transmission electron microscopy (STEM) mode to measure the elemental segregation to planar defects as a function of creep strains (1% and 2%). Both creep-deformed sample states allow us to differentiate whether a compositional steady state, and consequently a nanophase, has formed in the vicinity of the crystal de-fects[4], or if transient states are measured. Transient states would indicate ongoing diffusion processes that potentially control the kinetics of shear processes [5].

Microstructural characterization post creep deformation with the low magnification high-angle annular dark-field (HAADF) STEM micrograph of the 1% crept sample in Figure 1(A), and the conventional dark field two-beam condition image of the 2% crept sample in Figure 1(C) both depict the termination of planar fault motion inside the precipitate, indicating a leading partial dislocation shearing segment within the γ' phase. High-resolution HAADF images in Figure 1(B) and (D), elucidate that along these leading segments, the nature of the largest stacking fault is a superlattice extrinsic stacking fault (SESF), while at the very tip, in front of SESF we observe a short complex intrinsic stacking fault (CISF). Both faults show the same defect configuration: a closely spaced pair of Shockley partial dislocations with identical Burgers vector $\frac{1}{6}[11\bar{2}]$ glide on adjacent (111) planes. This process creates two energetically unfavourable CISFs, which are known to subsequently reshuffle Al-Al atom positions to convert the high-energy fault structure into a stable SESF with low planar fault energy [6].

The chemical distributions across the SESFs in Figure 2 illustrate almost identical segregation tendencies for 1% and 2% crept samples. The γ forming elements such as Cr, Co, W, or Re are enriched in the vicinity of the SESF, while γ' alloying elements Ni and Al are depleted. Quantitatively comparing the local alloying element concentration magnitudes at the SESFs show that the 1% crept sample exhibits the same local composition as the 2% crept sample, even though it experienced a longer creep time. This observation concludes that the segregation to the SESF has reached a steady state and establishes a stabilized nano-defect phase within the SESF after 1% creep strain. This result suggests that with a longer creep time, alloying elements do not further diffuse to the SESF [7].

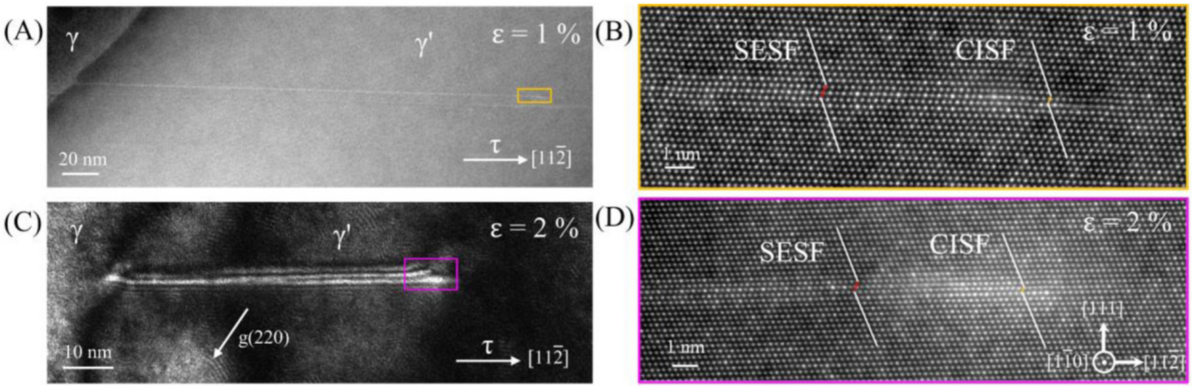

Fig. 1. Analysis of creep induced SESFs after ϵ = 1% and ϵ = 2% creep samples at 750°C and 250 MPa: (A) and (C) show lower magnification HAADF image and two beam condition conventional dark field image; (B) and (D) high resolution HAADF images.

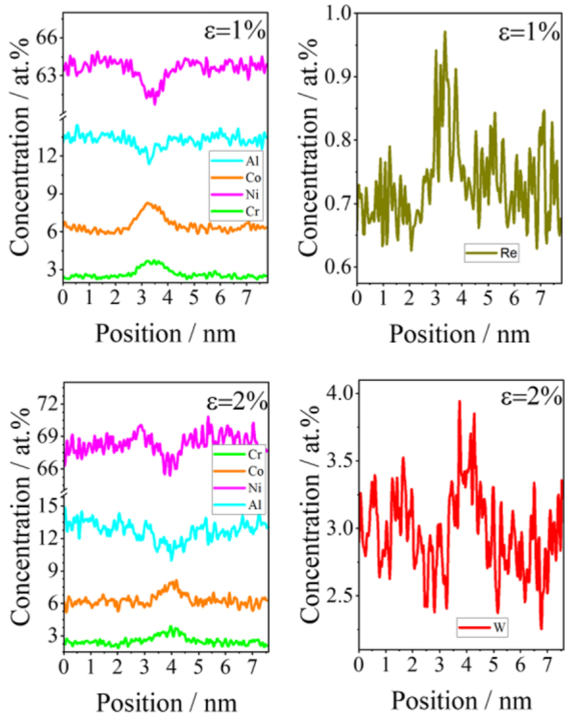

Fig. 2. Corresponding concentration line profiles across SESFs after ϵ = 1% and ϵ = 2% creep strains at 750°C and 250 MPa in superalloy samples.

References

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