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Creep-induced microstructural evolution of the eutectic Mo-Si-Ti alloy by correlative electron microscopy

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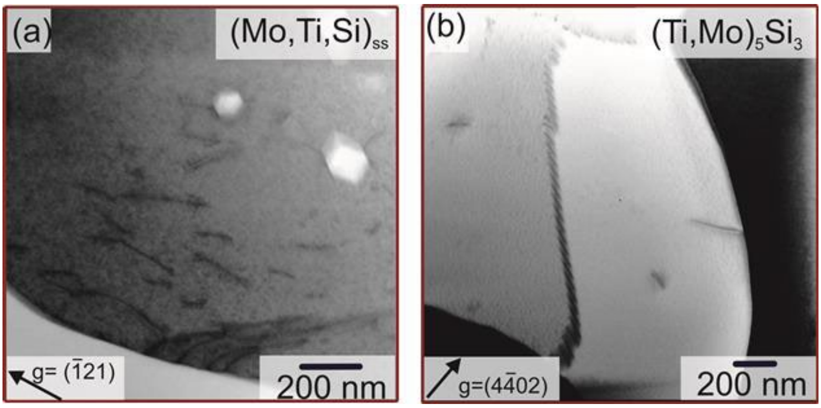
Turbine blades are critical parts of turbine engines because they experience the highest temperature in the combustion zone. The thermodynamic efficiency of the turbine engine directly depends on the turbine entry temperature (TET) of hot gases; the material's temperature capability dictates the operable temperature. The current state-of-the-art, single-crystal nickel-based superalloys operate close to 80 to 90 % of their melting temperatures. There is a continuous need to design newer high-temperature materials that can withstand higher operating temperatures above 1100 °C to improve efficiency and thus reduce CO2 emissions [1].

The Mo-Si-Ti system has been explored as a potential alternative to the existing high-temperature materials because of their lower density and high melting temperatures. The eutectic Mo-Si-Ti alloy showed pesting resistance and optimal creep behavior. It has a two-phase microstructure: a body-centered cubic (bcc), solid solution consisting of Mo, Ti and Si (Mo,Ti,Si)ss and hexagonal silicide (Ti,Mo)5Si3 [2]. The creep mechanism of this alloy is yet unknown and needs further investigation to understand how the creep strain accumulates in response to the applied stress and subsequent microstructural evolution at meso- and nano-scales in the two phases.

Compressive creep tests were performed under vacuum at 1200 °C and true stress of 100 MPa to understand the creep curve with characteristic minimum and creep rate acceleration after that. To understand the microstructural evolution, the samples were crept to true strains of 1.3, 10, 20, and 40 %. Electron backscatter diffraction (EBSD) was performed to study strain distribution in two phases and identify the region of interest for transmission electron microscopy (TEM) specimen preparation by focused ion beam (FIB). The dislocations were imaged using the diffraction contrast of the selected two-beam conditions in scanning transmission electron microscopy (STEM) mode. The invisibility criterion was used to determine the acting slip planes and the character of dislocations in both phases.

The deformation of silicide was observed in 0.2 % crept samples from EBSD-kernel average misorientation (KAM) maps. Both phases undergo deformation by dislocation plasticity. The following slip systems were identified: {110}, {-121} and {-213} planes with Burgers vector b = 1/2 <1-11> in the solid solution and basal slip {0001} or prismatic slip {1-1 00} both with Burgers vector b=1/3<-1-120> in the silicide [3]. During creep deformation, the growth and coarsening of (Ti,Mo)5Si3 precipitates in the solid solution, and the nucleation and growth of solid solution precipitates in the silicide occur [3]. STEM-energy dispersive spectroscopy (EDXS) was performed to determine the local chemical composition of the precipitates in the crept samples. Figure 1a shows numerous dislocations originating from the interface in the solid solution and the interaction of gliding dislocations with (Ti,Mo)5Si3 precipitates. Whereas Fig.1b shows the formation of low-angle grain boundaries in the silicide phase, confirming dynamic recovery. The microstructural findings were correlated with the creep curve, and the dominant creep deformation mechanisms (dislocation climb controlled creep and diffusional creep) were identified in the alloy.

Graphic:



Keywords:

Creep, dislocations, Mo-Si-Ti, (Ti,Mo)5Si3, precipitates

Reference:

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