Materials Science & Engineering Doctoral Defense

Thermo-mechanical behavior of hierarchical and nanocrystalline Ni-Y-Zr alloys

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Abstract

Microstructure refinement and alloy additions are considered potential routes to increase high temperature performance of existing metallic superalloys used under extreme conditions. Nanocrystalline (NC) Cu-10at%Ta exhibits such improvements over microstructurally unstable NC metals, leading to enhanced creep behavior compared to its coarse-grained (CG) counterparts. However, low melting point of Cu compared to other FCC metals, e.g., Ni, might lead to early onset of diffusional creep mechanisms. Thus, our research seeks to study the thermo-mechanical behavior and stability of hierarchical (prepared using arc-melting) and NC (prepared by collaborators through powder consolidation) Ni-Y-Zr alloys where Zr is expected to provide solid solution and grain boundary strengthening in hierarchical and NC alloys, respectively, while Ni-Y and Ni-Zr intermetallic precipitates (IMCs) would provide kinetic stability. Hierarchical alloys revealed microstructures stable up to 1100 °C with ultrafine eutectic of ~300 nm, dendritic arm spacing of ~10 µm, and grain size ~1-2 mm. Room temperature hardness tests along with uniaxial compression performed at 25 and 600 °C revealed that microhardness and yield strength of hierarchical alloys with small amounts of Y (0.5-1wt%) and Zr (1.5-3 wt%) were comparable to Ni-superalloys, due to the hierarchical microstructure and potential presence of nanoscale IMCs, whereas NC alloys of same composition were found twice as hard as the hierarchical alloys. Creep tests showed active Coble creep mechanisms in hierarchical alloys with creep rates being 1000 times slower than Ni superalloys at high stresses and 0.5 homologous temperature, whereas that of NC alloys at lower stresses were only 20 times faster than hierarchical alloys with the difference in grain size ranging from 103 to 106 times at the same temperature. Lastly, the in-situ wide angle x-ray scattering (WAXS) measurements during quasi-static and creep tests implied stresses being carried mostly by the matrix before yielding and in primary creep stage, respectively, while relaxation was observed in Ni5Zr for both hierarchical and NC alloys. Beyond yielding and in the secondary creep stage, lattice strains reach steady state, thereby an equilibrium between plastic strain rates is achieved across different phases, which reaches a saturation state where strain hardening effects are compensated by recovery mechanisms.

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Zoom Link: https://asu.zoom.us/j/81357553026