

## EVOLUTION OF $\gamma$ - $\gamma'$ MICROSTRUCTURE IN TERNARY Co-Al-W ALLOYS

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### Extended Abstract

The discovery of a two-phase  $\gamma$  (FCC)- $\gamma'$  ( $L1_2$ ) field in the ternary Co-Al-W phase has sparked significant research interest into possible Co-based analogs to traditional Ni-based superalloys used in turbine engine applications [1]. Much of this work has focused on creep and mechanical properties of ternary alloys and the effects of quaternary additions on microstructure and mechanical behavior. Despite its paramount importance to future alloy development, only a few reports have been published experimentally studying microstructural evolution and long-term phase stability in the ternary system [2-8]. Atom probe tomography (APT) has demonstrated that a ternary alloy quenched to room temperature from above the  $\gamma'$  solvus temperature results in a microstructure containing  $L1_2$  ordered regions 2 nm to 10 nm in diameter within the parent FCC matrix [4]. A similar microstructure was recently reported in rapidly solidified melt-spun ribbons, suggesting  $\gamma'$  nucleation cannot be suppressed in ternary Co-Al-W alloys [5]. The same work also demonstrated that the  $\gamma'$  phase is a nonequilibrium one in the ternary Co-Al-W system, as first suggested by Kobayashi et al., but questioned within the community due to contradictions in reported results and its long-term persistence in annealed microstructures [6-8].

Clearly, the ternary Co-Al-W system is rich with scientific interest in addition to being of utmost importance for potential engineering applications of Co-based  $\gamma$ - $\gamma'$  alloys. This work experimentally investigates microstructural evolution ternary in Co-Al-W alloys. As reported, nucleation of  $\gamma'$  cannot be suppressed even under rapid solidification conditions. Upon subsequent annealing at 900 °C, the growth of  $\gamma'$  is very rapid, reaching the metastable equilibrium volume fraction between  $\gamma/\gamma'$  in a matter of minutes. As annealing time increases, coarsening of  $\gamma'$  occurs from initially irregularly shaped precipitates 20 nm to 50 nm in size to the highly faceted cuboids 200 nm 500 nm in size typical of Ni-based counterparts. For alloy compositions within the metastable  $\gamma$ - $\gamma'$  phase region (a mole fraction of Al between about 9 % and 10 % and a mole fraction of W between about 7 % and 12 %) no additional phases are observed in the microstructure for annealing times of 2000 h and greater at 900 °C. The equilibrium phases B2 (CoAl) and  $D0_{19}$  ( $Co_3W$ ) finally nucleate between 2000 h to 4000 h, in conjunction with an observable decrease in the  $\gamma'$  volume fraction. In Al-rich alloys (a mole fraction of Al greater than 10 %), B2 is observed to readily nucleate for annealing times of 168 h or less, followed by nucleation and growth of  $D0_{19}$ . Conversely, for Al-poor compositions, although  $D0_{19}$  readily nucleates after relatively short annealing times, B2 is not observed to form until times of 2000 h or greater. This apparent difficulty in B2 nucleation likely explains discrepancies in the stability of  $\gamma'$  reported in literature. For all compositions, equilibrium is not reached even after annealing for 8000 h at 900 °C, and the  $\gamma'$  phase is present in the microstructure with a volume fraction of up to 20 % in some alloys. At a temperature of 850 °C

evolution toward equilibrium occurs more rapidly with  $\gamma'$  almost completely gone after annealing for 4000 h, suggesting kinetics is not the reason for the slow dissolution of  $\gamma'$ . The persistence of the nonequilibrium  $\gamma'$  phase is discussed in terms of its thermodynamic competitiveness with the three-phase equilibrium and the existing metastable coherent equilibrium between  $\gamma$  and  $\gamma'$  which results in a very low excess (interfacial) free energy microstructure compared to one in which D0<sub>19</sub> or B2 have nucleated, resulting in a high activation barrier for nucleation, growth, and evolution toward true equilibrium consisting of the three phases  $\gamma$ , D0<sub>19</sub>, and B2.

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