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Influence of alloying additions on $L1_2$ decomposition in γ-γ′ Co-9Al-9W-2X quaternary alloys

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ABSTRACT

The influence of alloying elements on the formation of the intermetallic phases B2 and $D0_{19}$ via $L1_2$ decomposition during long-time annealing was investigated in Co-9Al-9W-2X alloys using electron microscopy. It is found that the type, shape and location of these intermetallic phases strongly depend on the alloying elements, which could be mainly attributed to different formation energies. Ti promotes B2 phase formation contrary to Mo, Nb and Ta which stabilize three-phase $\gamma + D0_{19} + B2$ domains. Nb greatly destabilized the γ′ phase and is not suggested for alloy design in the Co-9Al-9W system.

Discovery of an ordered $L1_2$-γ′ precipitate phase in the ternary Co-Al-W system by Sato et al. [1] attracted significant interest because of the possibility to develop a new class of load bearing Co-base high-temperature alloys. The microstructure with coherent cuboidal γ′ precipitates embedded in a continuous γ matrix is morphologically identical to that of Ni-base superalloys suggesting that new Co-base superalloys may possess good high-temperature mechanical properties [2–5]. Such novel Co-base superalloys may offer a number of advantages with respect to corrosion resistance and castability when compared with Ni-base superalloys [6].

The γ′ solvus temperature in the Co-Al-W ternary system is quite low (~1263 K) [1] compared to that (~1620 K) of CMSX-10, a third generation single-crystal Ni-base superalloy [7]. The γ′ phase is not stable at all temperatures in the ternary system and co-exists with γ, B2 and $D0_{19}$ phases [8, 9]. In order to increase the γ′ solvus temperature and thus improve the microstructural stability, alloying elements, such as Ti, V, Ta, Nb, Mo and Ni have been added into the ternary system. Such elements increase the γ′ solvus temperature in the following order: Ta > Nb > Ti > V > Mo > Ni [10]. Other literature reports contradictory data on the effects of Nb and Ti, but actually the difference between ΔT_{Nb} and ΔT_{Ti} (for 2 at.% element addition) is only in the range of 10 °C or less [11, 12] which may explain the ambiguity of the results. However, after extended annealing other intermetallic phases, such as B2-CoAl and $D0_{19}$-Co_3W also occur and deteriorate the mechanical properties [13]. Unfortunately, in literature the studied alloys were often annealed for short times and thus limited details on the formation of these phases [10, 13–15] were reported. Additionally, investigations of the influence of alloy composition on these intermetallic phases and their formation mechanisms are rare [10, 13–15], although their morphology and distribution critically determine the mechanical properties. In the present study, phase transformations in Co-9Al-9W-2X alloys with different alloying elements were investigated. It is believed that this study can be instructive for alloy design and help understand phase transformations in these alloys.

The investigated Co-9Al-9W and Co-9Al-9W-2X (Ti, Mo, Nb and Ta) alloys (at.%) were prepared by arc-melting under argon atmosphere and re-melted at least eight times to obtain chemical homogeneity. The cast buttons were homogenized at 1300 °C for 12 h and subsequently annealed at 900 °C for 5000 h. Due to rapid decomposition of the γ′ phase in the Co-9Al-9W-2Nb alloy after annealing at 900 °C for 5000 h, this alloy was also annealed at 850 °C for 1000 h. It is reported by Lass et al. [16] that decreasing the temperature accelerates the dissolution of the γ′ phase in the ternary Co-Al-W system and after annealing at 850 °C for 4000 h only very little γ′ existed. Thus, here the annealing treatment at 850 °C was restricted to 1000 h to ensure that the γ′ phase has not completely decomposed. Scanning electron microscopy (SEM) investigations were performed using a LEO Gemini 1530. SEM specimens were prepared by electro-polishing with a solution of 26 ml perchloric acid (70%), 359 ml 2-butanol and 625 ml methanol at 30 V

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and − 30 °C. For electron back-scattered diffraction (EBSD) investigations a TSL analysis system fitted to the Gemini microscope was employed. EBSD specimens were prepared by vibration polishing. A Philips CM200 transmission electron microscope (TEM) operated at 200 kV and a FEI Titan 80–300 TEM with a Cs image corrector operated at 300 kV were used for TEM investigations. TEM foils with a diameter of 2.3 mm were ground to a thickness below 120 μm and thinned by twin-jet polishing at 25–35 V and a temperature of −40 °C with the same solution as for SEM specimen preparation. Elemental analysis was performed using EDS in the TEM mode and concentrations of the elements Co, Al and W were quantified with a Co-2Al-2W alloy standard.

Fig. 1 shows an overview of the microstructures of the Co-9Al-9W-2X alloys after heat-treatment. They have a similar $\gamma + \gamma'$ based microstructure (cuboidal γ' precipitates homogeneously distributed in a γ matrix) together with other intermetallic phases, such as B2-CoAl and $D0_{19}$-Co_3W. The amount, shape and location of these intermetallic phases depend strongly on the alloy composition. Although it is found in this study that the alloying elements increase the γ' solvus temperature by the order of Ta > Nb > Ti > Mo, they lead to a faster formation and higher fraction of the intermetallic phases compared to the microstructure of the Co-9Al-9W alloy. In the Co-9Al-9W-2Ti alloy, after annealing at 900 °C for 5000 h the B2 phase is observed to exist at grain boundaries and in the grain interior, easily recognizable by its darker appearance in

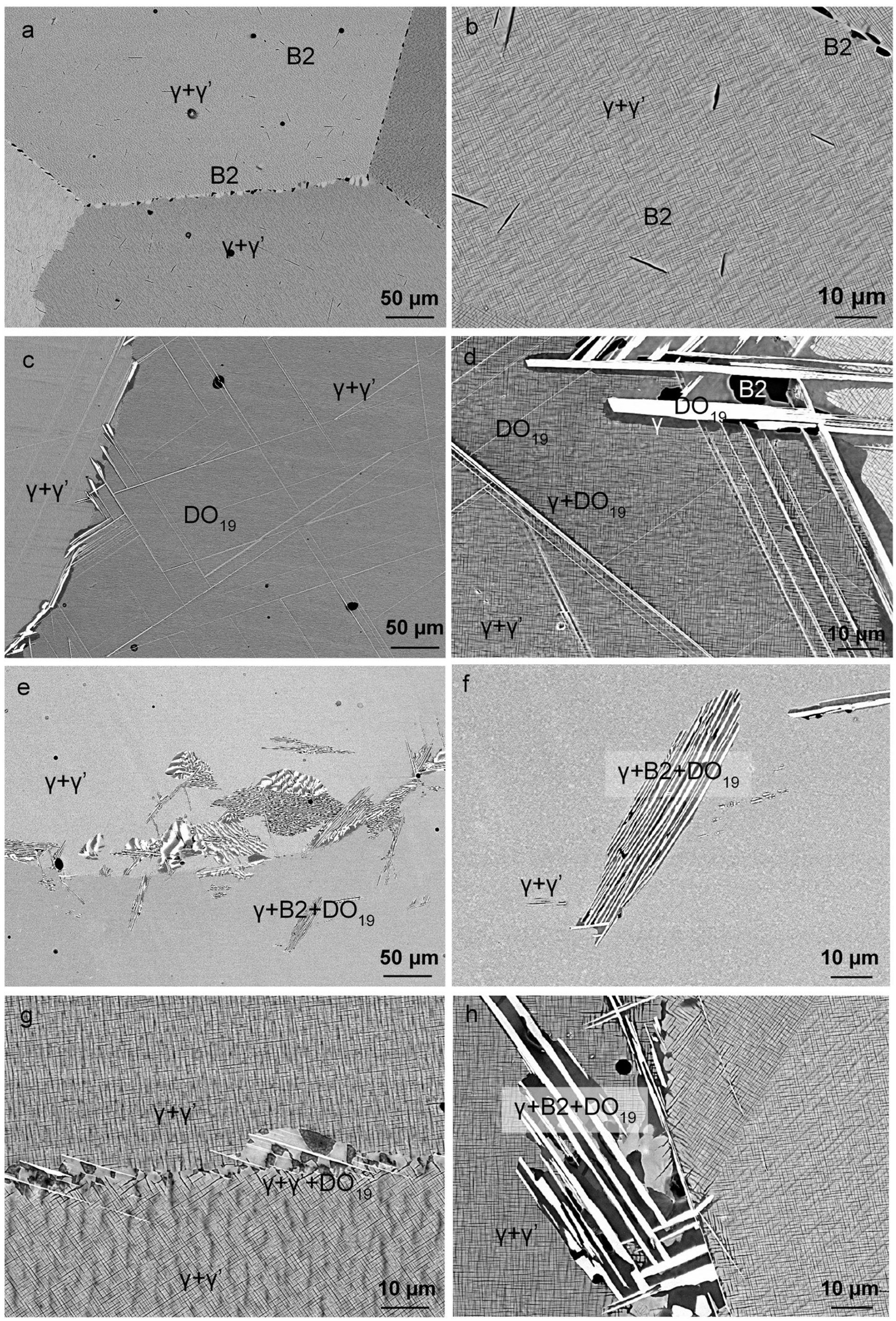

Fig. 1. SEM images of the alloys (a, b) Co-9Al-9W-2Ti at 900 °C for 5000 h, (c, d) Co-9Al-9W-2Mo at 900 °C for 5000 h, (e, f) Co-9Al-9W-2Nb at 850 °C for 1000 h, (g, h) Co-9Al-9W-2Ta at 900 °C for 5000 h under back-scattered electron mode.