Precipitation behaviors in Co-Ni based alloys observed by transmission electron microscopy

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Co-based alloys are used in numerous commercial applications because of their excellent performance under severe environments, which require high-temperature strength, corrosion resistance, wear resistance, etc. In general, these alloys belong to a multi-component system, and the composition and heat and/or mechanical treatments to achieve a desired property are often complex. In this respect, understanding the microstructural changes during the processing is indispensable for the optimal selection of various processing parameters [1]. In particular, the identification of phases in the early stages of phase transformation, which necessitates atomic level observations, is critical to elucidate the origin of the mechanical properties of the alloys [2].

In the present study, we report the precipitation behavior of a Co-Ni-Cr-Mo-Nb alloy, heat-treated at 973-1073 K, which results in a mechanical strength suitable for high-temperature applications. For transmission electron microscopy (TEM) work, we used Titan 80-300 operating at 300kV, equipped with a Cs corrector for the objective lens; and employed a range of techniques available to clarify the crystallography and kinetics of the phase transformation. They include STEM-BF/HAADF imaging, EDS mapping and 3D tomography, in addition to conventional high-resolution microscopy (HRTEM).

Preliminary examination of a specimen heat-treated at 1073 K suggested that there are at least two different precipitates in the alloy system: the δ-phase that exists at grain boundaries as well as within grains, the latter showing lamellar morphology; and the μ-phase that exists only in grain boundaries, with a morphology indicative of discontinuous precipitation. The crystal structures of the both phase were investigated in the present study.

Figure 1 is a HRTEM micrograph of the interface region of coherent lamellar precipitates, the δ-phase, viewed from the [110] direction of the fcc Co matrix. The *c*-axis of the hexagonal precipitate is close to 2/3 a_{matrix} as expected from the simple ABAB... stacking sequence, whereas the *a*-axis is twice as much as the value expected from the sequence. This was also confirmed from the corresponding diffraction pattern and STEM images, taken along both the [110] and [111] axis. These results suggest that there are two phases involved in the present alloy system: one with $D0_{19}$ structure with the unit cell constants of a=0.50 nm and c=0.41 nm.

Figure 2 is a HRTEM micrograph of the interface region of the μ-phase viewed along the [111] direction of the fcc Co matrix. It can be noticed that the {220} planes of the matrix (0.12 nm) is resolved, and that the white dot contrasts of the precipitate exhibit the 6-fold symmetry. Our STEM-HAADF observations suggested that these correspond to the positions of heavy atoms, and we propose that the μ-phase belongs to a hexagonal system with a=0.45 nm.

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2. A. Chiba and M.S. Kim Mater. Trans. **42** (2001) p. 2112-2117.

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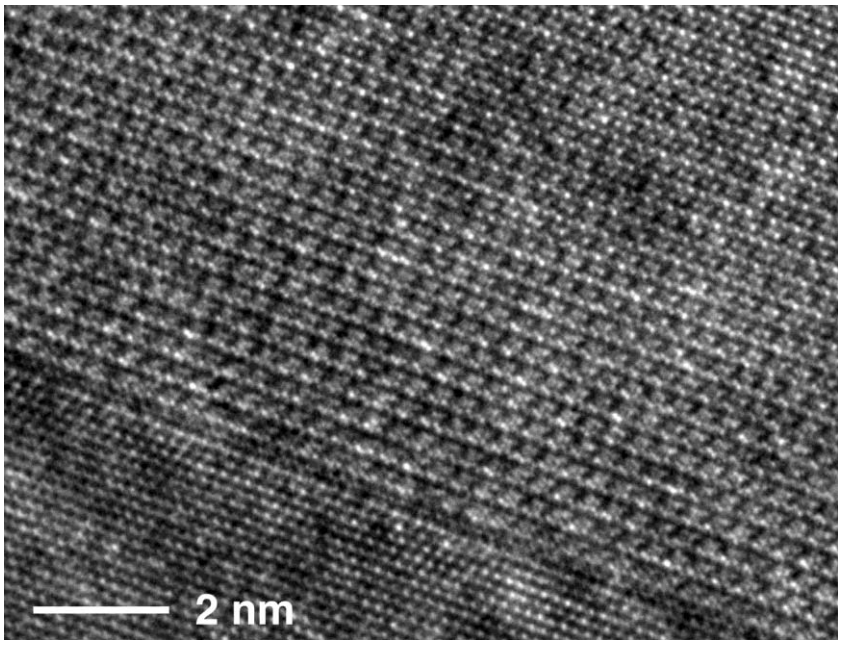

Figure 1. HRTEM micrograph of an interface region of a lamellar precipitate with $D0_{19}$ structure (δ-phase) and the fcc Co matrix, viewed along the [110] zone axis of the latter. Note the double periodicity in the direction parallel to the interface, *i.e.*, the [210] direction of the hexagonal precipitate.

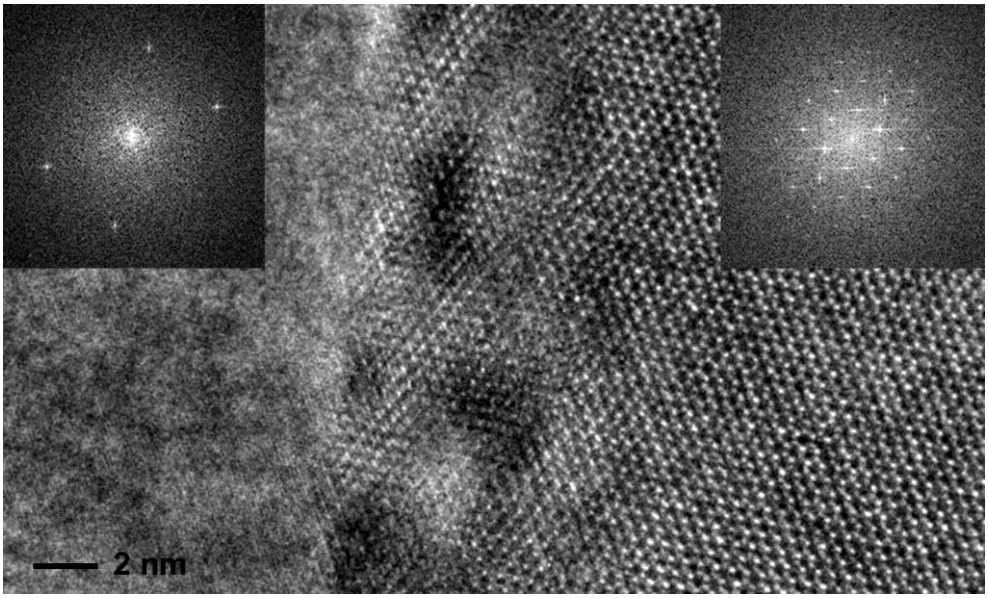

Figure 2. HRTEM micrograph of an interface region of a Mo-rich precipitate (μ-phase) and the fcc Co matrix, viewed along the [111] zone axis of the latter. The inset FFT diagrams indicate that the {220} planes of the fcc matrix (0.12 nm) is resolved, and that heavy atoms in the precipitate are located having 6-fold symmetry with the inter-atomic distance of $\sqrt{2}a_{\text{matrix}}$.

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