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Al-Cr-Mo-Ni (Aluminum-Chromium-Molybdenum-Nickel)

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Isothermal sections of this quaternary system at 1250, 1000, and 800 °C and at 75, 60, and 50 at.% Ni, respectively, were investigated by [1984Cha], [1986Cha], and [1987Cha]. [2001Hav] obtained new experimental data at 900 °C at 70 at.% Ni and compared the same with a computed isothermal section using the binary and ternary interaction parameters from the literature.

Binary Systems

For brief descriptions of the Al-Cr, Al-Ni, and Cr-Ni systems, see the Al-Cr-Ni update in this issue. For Al-Mo and Mo-Ni descriptions, see the Al-Mo-Ni update in this issue. The Cr-Mo phase diagram [Massalski2] depicts a continuous body-centered-cubic (bcc) solid solution between Cr and Mo. A miscibility gap appears in this solution below 880 °C.

Ternary Systems

Updates of the Al-Cr-Ni and Al-Mo-Ni systems appear in this issue. [1974Kau] computed four isothermal sections at 2227, 2027, 1227, and 727 °C for the Al-Cr-Mo system. The Cr-Mo-Ni system reviewed by [1990Gup] presented a reaction sequence, a schematic liquidus projection and isothermal sections at 1250, 1200, 850, and 600 °C. A primitive orthorhombic phase denoted P is present in the above temperature range at the composition $Cr_{18}Mo_{42}Ni_{40}$, with space group *Pnma* and lattice parameters $a = 1.6983$ nm, $b = 0.4752$ nm, and $c = 0.9070$ nm [Pearson3].

Quaternary Phase Equilibria

With starting metals of Al (99.99 wt.%), Cr (~99.9 wt.%), Mo (~99.9 wt.%), and Ni (99.99 wt.%), [1984Cha] arc melted under Ar atmosphere three quaternary and two ternary alloys, all containing 75 at.% Ni. The quaternary alloys contained 10 to 20 at.% Al and 2.5 to 7.5 at.% each Cr and Mo and the ternary alloys contained 15 at.% Al and 10 at.% Cr or Mo. The samples were given a final anneal at 1250, 1000, or 800 °C for 1 week and quenched in ice water. The phase equilibria were studied by optical and electron metallography, x-ray diffraction, and electron probe microanalysis (EPMA). The partial isothermal sections constructed by [1984Cha] at 75 at.% Ni and at 1250, 1000, and 800 °C are redrawn in Fig. 1. The sections show essentially the γ-γ′ equilibrium at these temperatures.

In continuation of the above work, [1986Cha] studied the phase equilibria at 1250 °C in alloys with a constant Ni content of 60 or 50 at.%. The P phase appeared in alloys with 60 at.% Ni, while, in addition, the σ phase was present in alloys with 50 at.% Ni. In further studies, [1987Cha] investigated five quaternary alloys with 60 or 50 at.% Ni at 1000 and 800 °C. The alloy composition, the phase constitution and the composition of the phases as measured by EPMA in the annealed alloys were listed. However, they could not construct isothermal sections at 1000 and 800 °C, due to the limited number of alloys used and the difficulty of attaining equilibrium at these temperatures. However, they improved the two isothermal sections of [1986Cha] at 1250 °C and at a constant Ni content of 60 and 50 at.%, respectively. These are redrawn in Fig. 2 and 3.

Starting with metals of purity of 99.9 to 99.99 wt.%, [2001Hav] prepared five quaternary alloys by vacuum and induction melting. The alloys contained Al, Cr, and Mo up to 13 to 15 at.% each, with Ni content between 70 and 72 at.%. The homogenized alloys were annealed at 900 °C for 300 h and quenched in water. This annealing time may not have been long enough for attaining equilibrium. The phase constitution was studied by a scanning electron

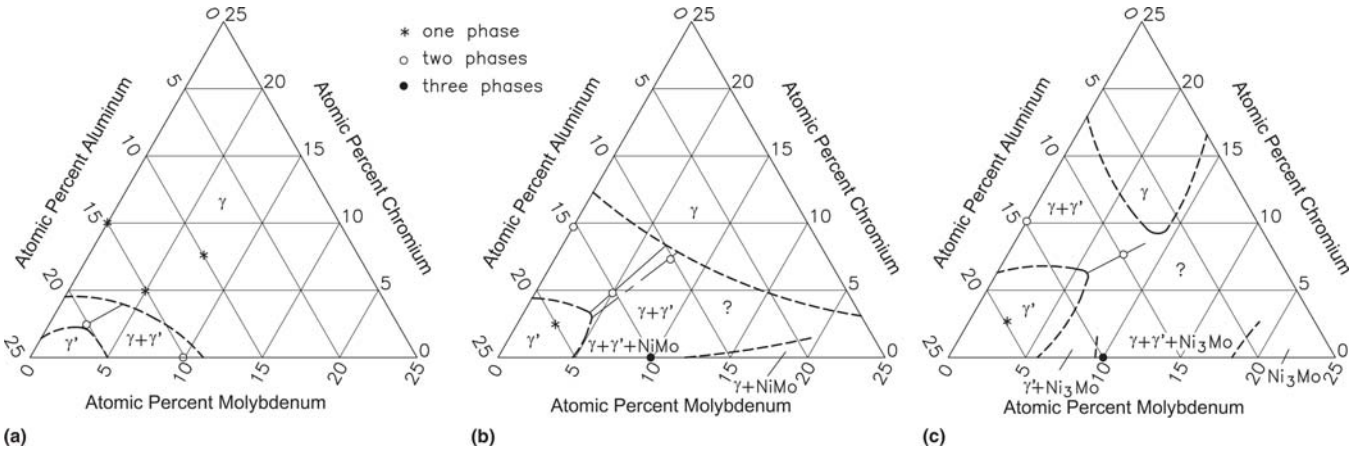

Fig. 1 Al-Cr-Mo-Ni partial isothermal sections at 75 at.% Ni and at (a) 1250, (b) 1000, and (c) 800 °C [1984Cha]

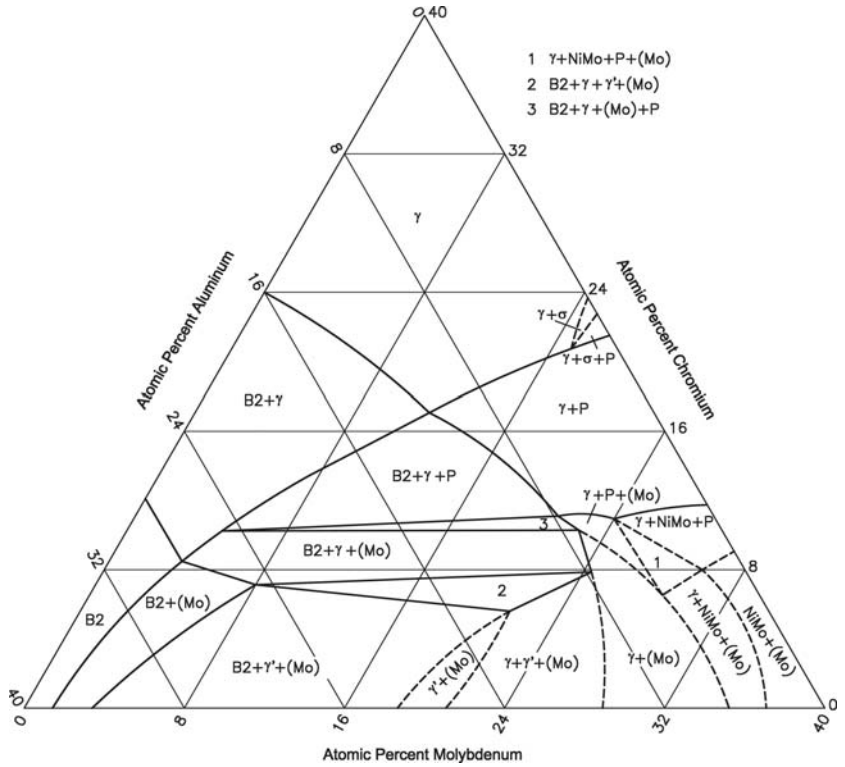

Fig. 2 Al-Cr-Mo-Ni partial isothermal sections at 60 at.% Ni and at 1250 °C [1984Cha]

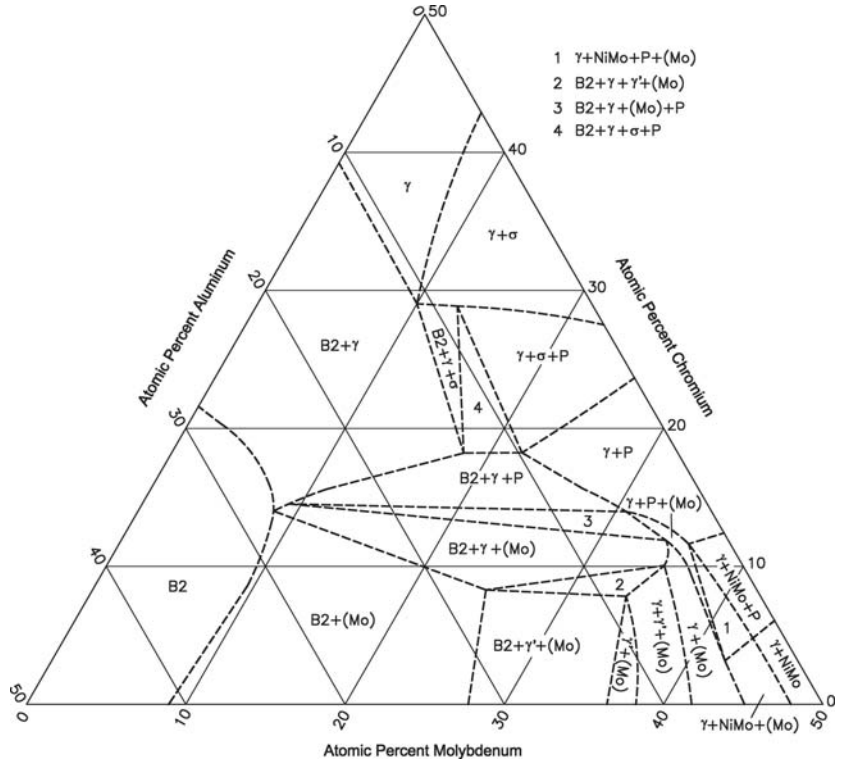

Fig. 3 Al-Cr-Mo-Ni partial isothermal section at 50 at.% Ni and at 1250 °C [1987Cha]

microscope equipped with the energy dispersive x-ray analyzer. The crystal structure was identified by selected area diffraction in a transmission electron microscope.

In the thermodynamic calculations using the CALPHAD approach, [2001Hav] used the literature values of the binary and ternary interaction parameters. Quaternary interactions

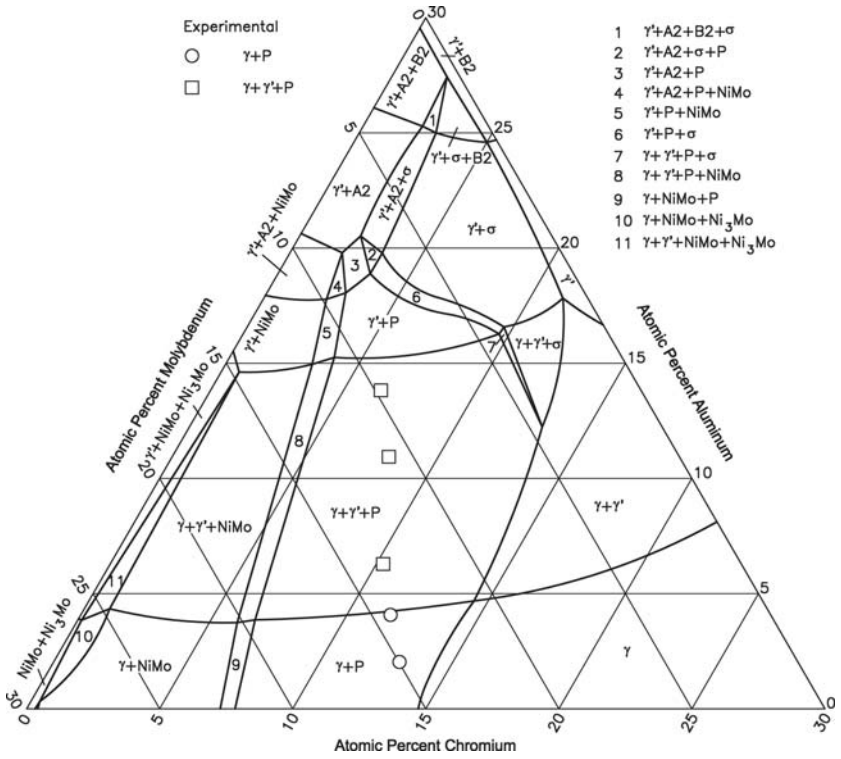

Fig. 4 Al-Cr-Mo-Ni partial isothermal section at 70 at.% Ni and at 900 °C [2001Hav]

were ignored. The third and fourth element solubility in NiMo and Ni_3Mo binary phases was taken into consideration. The Cr-Mo-Ni ternary compound P was found experimentally in the alloys investigated and was included in the calculation. The measured compositions of the phases in the five alloys were compared with the corresponding computed values. The isothermal section computed by [2001Hav] at 70 at.% Ni and at 900 °C is redrawn in Fig. 4. The location of the experimental alloys and their phase constitution are indicated in Fig. 4.

Among the earlier studies of this quaternary system, [1972Loo] determined the effect of Mo on the γ' solvus in a Ni-14at.%Cr-12at.%Al alloy. [1978Mac] evolved a procedure for predicting quantitatively the tendency for σ phase precipitation in Ni-based superalloys.

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