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Al-Cu-Ni (Aluminum-Copper-Nickel)

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The review by [1991Pri] of this system presented a reaction sequence, a full liquidus projection, a solidus surface for Al-poor alloys, full isothermal sections at 900, 700, 600, and 500 °C from [1948Kos] and at 900, 800, 700, 600, and 500 °C for Al-poor alloys from [1938Ale] and four vertical sections at 4 and 10 wt.% Al and at 6 and 60 wt.% Ni, respectively. The compilation by [1995Vil] includes a liquidus projection, isothermal sections at 900, 800, 700, 600, 500, and 25 °C and 18 vertical sections (all from pre-1950 work). Recent work reviewed here includes an experimental isothermal section at 800 °C by [2003Wan], computed isothermal and vertical sections by [2005Mie], and the identification of a miscibility gap in the *B*2 phase by [2005Kai].

Binary Systems

The Al-Cu phase diagram [Massalski2] depicts a number of intermediate phases and invariant reactions. The *C*16 tetragonal phase $CuAl_2$ (θ) is well known, due to its presence in age-hardening Al alloys. CuAl (η) has two crystal modifications, the high-temperature orthorhombic and the low-temperature monoclinic forms. The two forms of the ζ phase have a composition range of 55.2 to 59.8 at.% Cu and are stable below 590 °C. Two modifications of the ε phase occur around the composition Cu_3Al_2 and are stable above 560 °C. The ε_2 phase has the $D8_1$, NiAs-type hexagonal structure. The δ phase (59.3-61.9 at.% Cu) has rhombohedral symmetry. The γ_1 phase (Cu_9Al_4) has the $D8_3$-type cubic structure. The β (Cu_3Al) phase (70.6-82.0 at.% Cu) is body-centered-cubic (bcc). The Al-Ni phase diagram [1993Oka] shows five intermediate phases: $NiAl_3$ (Fe_3C-type orthorhombic), Ni_2Al_3 ($D5_{13}$-type hexagonal), NiAl (*B*2, CsCl-type cubic, also denoted β), Ni_5Al_3 (Ga_3Pt_5-type orthorhombic), and Ni_3Al ($L1_2$, $AuCu_3$-type cubic; also denoted γ′). The Cu-Ni phase diagram depicts a continuous solid solution between Cu and Ni. Below 354 °C, a miscibility gap occurs in this face-centered-cubic (fcc) solid solution.

Ternary Compounds

A number of ternary phases have been reported in this system [1991Pri, 1995Vil]. Some of them are based on extensions of binary phases into the ternary region. A few of them are phases resulting from a martensitic transformation. One Al-rich ternary compound Al_7Cu_4Ni forms through a

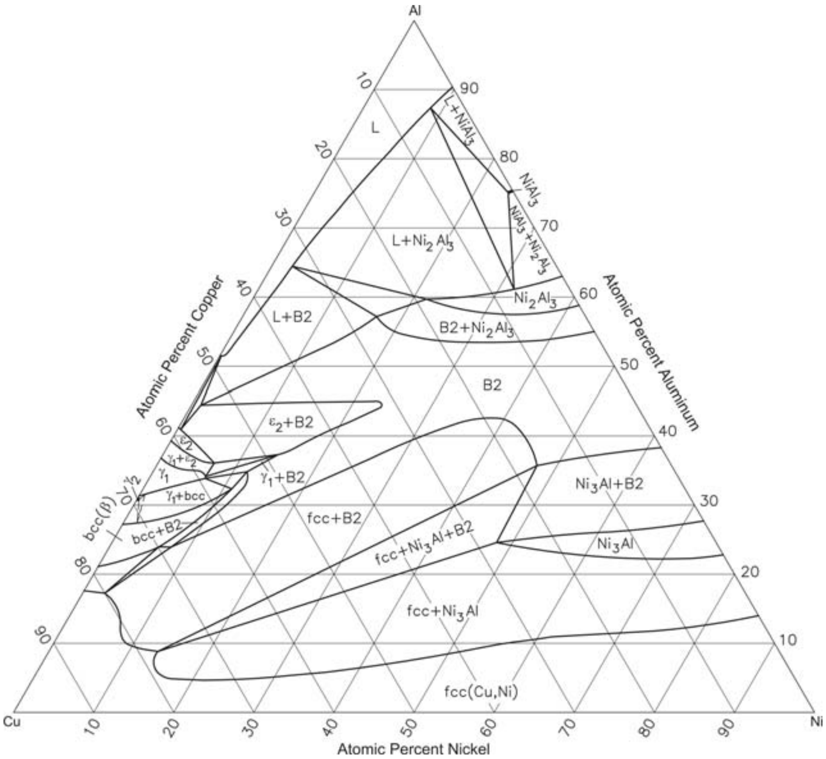

Fig. 1 Al-Cu-Ni isothermal section at 800 °C [2003Wan]

ternary peritectic reaction at ~820 °C [1948Kos]. It has rhombohedral symmetry, space group $R32$, hexagonal parameters $a = 0.4105$ nm and $c = 3.997$ nm [Pearson3]. See [1991Pri] for a listing of a number of phases in this region with stacking variants. [2003Wan], however, did not find this ternary phase at 800 °C. Since the existence of a ternary phase with stacking variants appears established in several earlier reports, it is possible that its formation temperature is close to 800 °C, either a little below or above this temperature.

Ternary Isothermal Sections

With starting metals of Al (99.98 wt.%), Cu (99.99 wt.%), and Ni (99.98 wt.%), [2003Wan] arc melted 112 alloy compositions. The samples were annealed at 800 °C for 30 days followed by quenching in ice water. The phase equilibria were studied by backscattered electron imaging, x-ray powder diffraction, and electron probe microanalysis. Diffusion couples were also prepared, annealed, and examined. The isothermal section at 800 °C constructed by [2003Wan] is redrawn in Fig. 1. No ternary phase was found at this temperature. No continuous solid solution was found between any Al-Cu and Al-Ni binary phases. The NiAl-based $B2$ phase shows extensive solubility of Cu. Near the Al-Cu side, NiAl forms a two-phase field with the bcc phase Cu_3Al. [2003Wan] pointed out the complex nature of the phase relationships in this region and the difficulty of complying with the Schreinemaker's rule (as can be seen in Fig. 1). Significant Cu solubility occurs in Ni_2Al_3 and Ni_3Al (γ') phases.

[2005Mie] made a thermodynamic analysis of this ternary system in the Al-poor region. In this treatment, the Cu_3Al-based bcc solid solution is clubbed together with NiAl ($B2$) as one entity and modeled as a substitutional solid solution (single lattice). Several computed isothermal and vertical sections were presented on a weight present basis using a semilog scale. Tie-triangles in isothermal sections appear with curved boundaries as a result of the use of log scale for the Cu-Ni axis, thus making direct comparison with recent experimental data difficult. The isothermal section of [2005Mie] at 800 °C is replotted in Fig. 2 on a linear atomic percent scale. As the copper-rich Cu-Al compounds were not modeled, this region cannot be compared with the section of [2003Wan] in Fig. 1. In other regions, the agreement with the superposed section of [2003Wan] shown in Fig. 2 is reasonable. However, the locations of the two right-side corners of the tie-triangle differ significantly between the experimental and the computed results. The continuous solid solution between Cu_3Al ($A2$) and NiAl ($B2$) computed by [2005Mie] was not found by [2003Wan]. The clubbing of $A2$ and $B2$ phases as a single entity without separating the ordering contribution to the energy is a drawback in the thermodynamic description of [2005Mie].

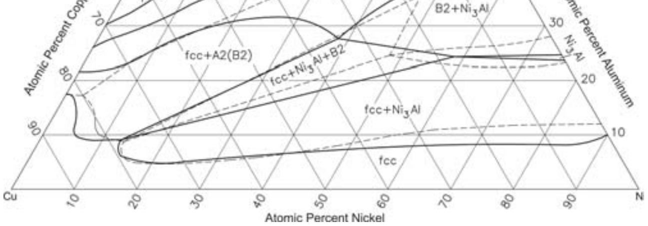

Fig. 2 Al-Cu-Ni computed isothermal section at 800 °C [2005Mie]

With starting metals of Al (99.7 wt.%), Cu (99.9 wt.%), and Ni (99.9 wt.%), [2005Kai] induction melted about eight alloy compositions that lie approximately on the Cu_3Al-NiAl join. The alloys were annealed at 750 to 600 °C for 336 to 720 h. The phase equilibria were studied by optical microscopy, energy dispersive x-ray spectroscopy, and transmission electron microscopy (at room temperature and 700 °C). The isothermal section at 700 °C constructed by [2005Kai] in the region of the bcc-$B2$ stability region is redrawn in Fig. 3. The small miscibility gap seen occurs entirely in the $B2$ region with $B2'$ and $B2''$ coexisting here.

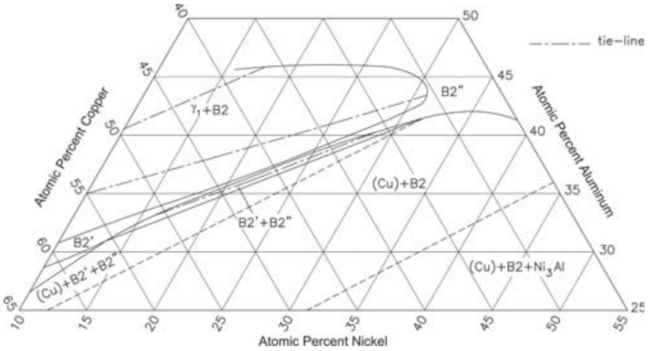

Fig. 3 Al-Cu-Ni isothermal section at 700 °C [2005Kai]

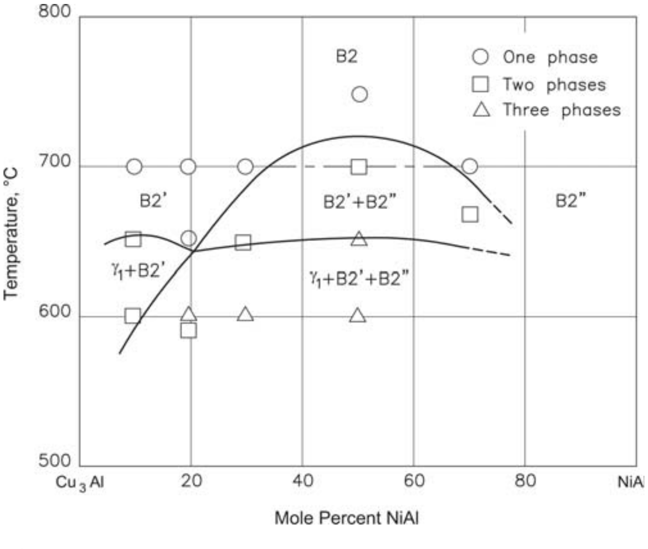

Fig. 4 Al-Cu-Ni vertical section along the Cu_3Al-NiAl join [2005Kai]

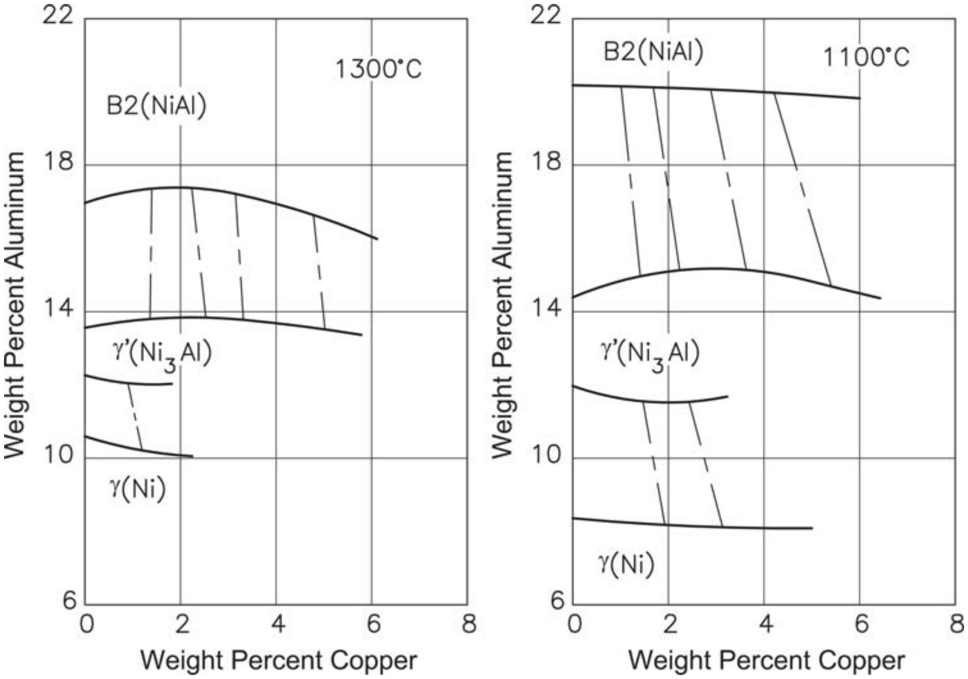

Fig. 5 Al-Cu-Ni partial isothermal sections at 1300 and 1100 °C [1994Jia]

The miscibility gap is not between *A*2 and *B*2 phases. A vertical section along the Cu_3Al-NiAl join determined by [2005Kai] is shown in Fig. 4.

[1994Jia] used the diffusion couple technique to study the γ/γ′ and γ′/*B*2 two-phase equilibria in Ni-rich alloys. The compositions of coexisting phases were determined by the electron probe microanalysis. The partial isothermal sections determined by [1994Jia] at 1300 and 1100 °C are shown in Fig. 5.

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