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

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The earlier reviews of this ternary system were those of [1984Mer], [1991Rog], and [1995Vil]. [2004Vel] updated the data reviewed by [1991Rog]. An update by [2006Rag] presented a computed liquidus projection, compared several isothermal sections of [1999Hua] and [2001Dup] and gave vertical sections along the NiAl-Cr and Ni_3Al-'Ni_3Cr' joins. An isothermal section at 1150 °C for Al-lean alloys determined by [2006Kit] was reviewed briefly by [2008Rag]. The ternary phases in the Al-rich region were recently investigated by [2008Gru1], who presented isothermal sections at 1000 and 900 °C. At 1000 °C, two ternary phases labeled ζ and ε were found; at 900 °C, only ζ was found. Very recently, for the Al-rich region, [2008Wei] determined a liquidus projection and an isothermal section at 700 °C. In addition to ζ, two other ternary phases of unresolved structure were identified at 700 °C.

Binary Systems

The Al-rich end of the Al-Cr phase diagram investigated recently by [2008Gru2] is shown in Fig. 1. The intermediate phases in the system are: $CrAl_7$ (V_7Al_{45}-type monoclinic, denoted θ), Cr_2Al_{11} ($CrAl_5$-type monoclinic, denoted η), $CrAl_4$ (hexagonal, $P6_3/mmc$, denoted μ), $CrAl_3$ (ν), Cr_2Al ($MoSi_2$-type tetragonal) and an unconfirmed low-temperature phase X at 75 at.% Cr. Between 30 and 41 at.% Cr, five phases were reported earlier: αCr_4A_9, βCr_4Al_9, γCr_4Al_9, αCr_5Al_8 and βCr_5Al_8, with no well-established phase boundaries between them. The work of [2008Gru2] shows only two phases in this region. The high-temperature phase denoted γ_1 is cubic (Cu_5Zn_8-type) and transforms on cooling via a second-order transition to γ_2, the transition temperature decreasing from 1140 to 1060 °C with increasing Al content. The γ_2 phase is rhombohedral (Cr_5Al_8-type). The Al-Ni phase diagram [1993Oka] shows five intermediate phases: $NiAl_3$ (Fe_3C-type orthorhombic), Ni_2Al_3 ($D5_{13}$-type hexagonal, denoted δ), NiAl ($B2$, CsCl-type cubic, denoted β), Ni_5Al_3 (Ga_3Pt_5-type orthorhombic), and Ni_3Al ($L1_2$, $AuCu_3$-type cubic, denoted γ′). The Cr-Ni phase diagram is of the simple eutectic type, with Ni dissolving up to ~50 at.% Cr and Cr dissolving up to ~32 at.% Ni.

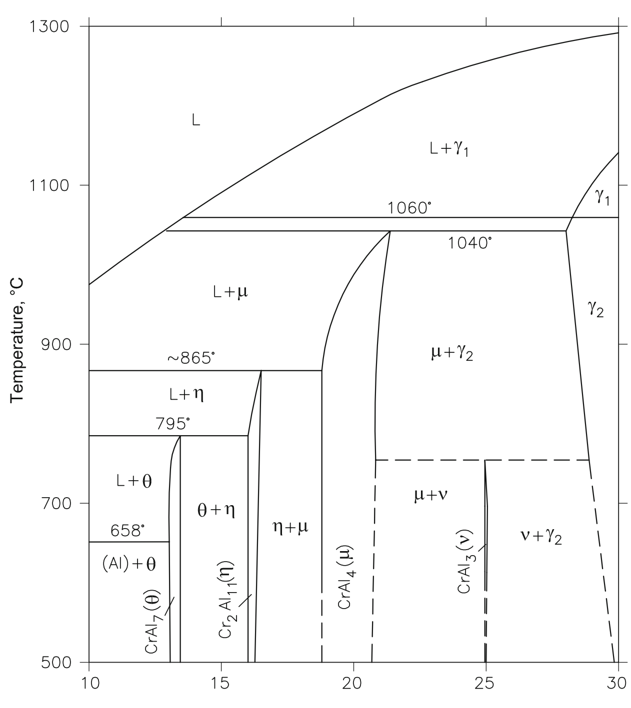

Fig. 1 Al-Cr Phase diagram in the Al-rich region [2008Gru2]

Ternary Phase Equilibria

About 20 alloys were induction-melted under Ar atm by [2008Gru1]. Alloys containing >60 at.% Al were annealed at 1000 °C for 90-120 h or at 900 °C for 110-142 h. Alloys with <60 at.% Al were annealed at 1150 °C for 49 h, at 1025 °C for 400 h or at 1000 °C for 382-686 h. All alloys were quenched in water after annealing. The phase equilibria were studied by x-ray powder diffraction, scanning and transmission electron microscopy and differential thermal analysis (DTA) at heating and cooling rates of 10-50 °C per min. The local phase composition was determined by the energy dispersive x-ray analysis.

The isothermal sections constructed by [2008Gru1] for Al-rich alloys at 1150 and 1025 °C (Fig. 2 and 3) are in broad agreement with earlier results reviewed by [2006Rag]. The isothermal sections of [2008Gru1] at 1000 and 900 °C are redrawn in Fig. 4 and 5. At 1000 °C (Fig. 4), two ternary phases were found. A hexagonal phase labeled ζ by [2008Gru1] (called κ or ρ_2 in earlier literature) was found to have a composition range between $Al_{79.0}Ni_{3.0}Cr_{18.0}$ and $Al_{71.5}Ni_{9.0}Cr_{19.5}$ [2008Gru1], with lattice parameters of $a = 1.7674$ nm, and $c = 1.2516$ nm. The DTA experiments indicated its formation at ~1030 °C. The second ternary phase at 1000 °C labeled ε (see Fig. 4) has orthorhombic symmetry with $a \approx 1.26$ nm, $b \approx 3.48$ nm, and $c \approx 2.02$ nm and occurs around the composition $Al_{76.5}Ni_{2.0}Cr_{21.5}$. Interpretation in the earlier literature of ε as the binary phase $CrAl_4$ (μ) was discounted by [2008Gru1]. The third component solubility in the binary phases μ, γ_2, and δ phases was found to be about 1 at.% Ni, 3 at.% Ni, and 2.5 at.% Cr respectively. At 900 °C (Fig. 5),

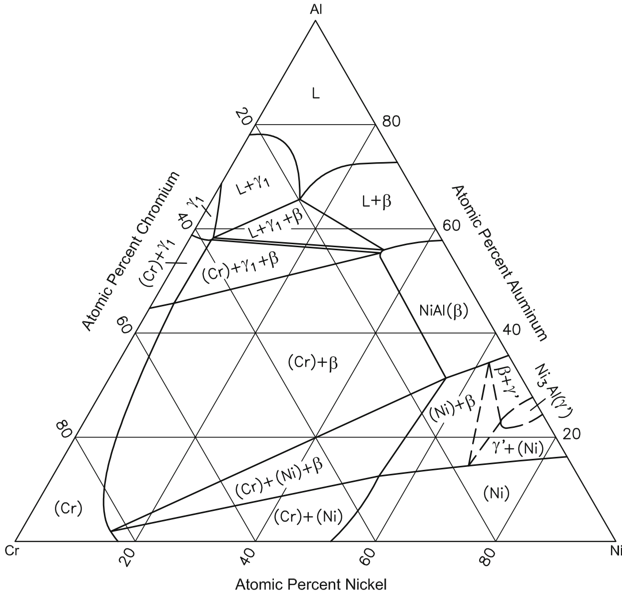

Fig. 2 Al-Cr-Ni isothermal section at 1150 °C [2008Gru1]

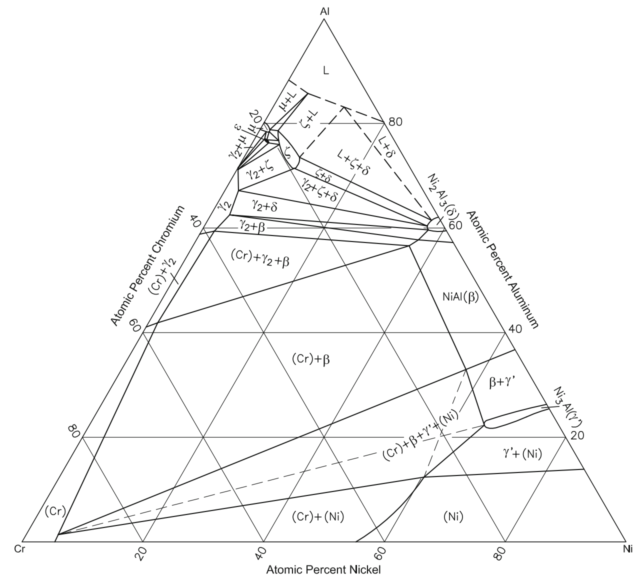

Fig. 4 Al-Cr-Ni isothermal section at 1000 °C [2008Gru1]

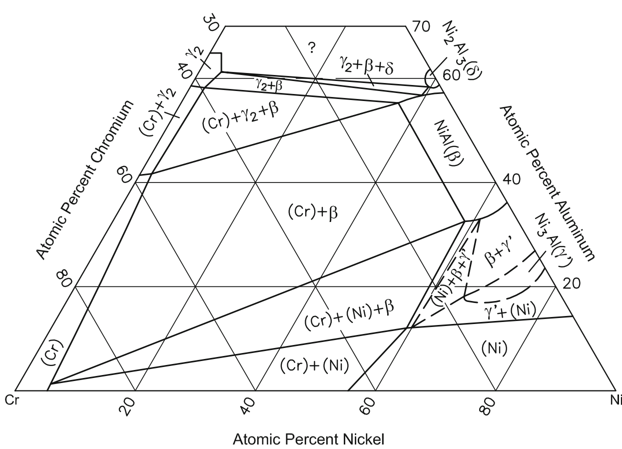

Fig. 3 Al-Cr-Ni isothermal section at 1025 °C [2008Gru1]

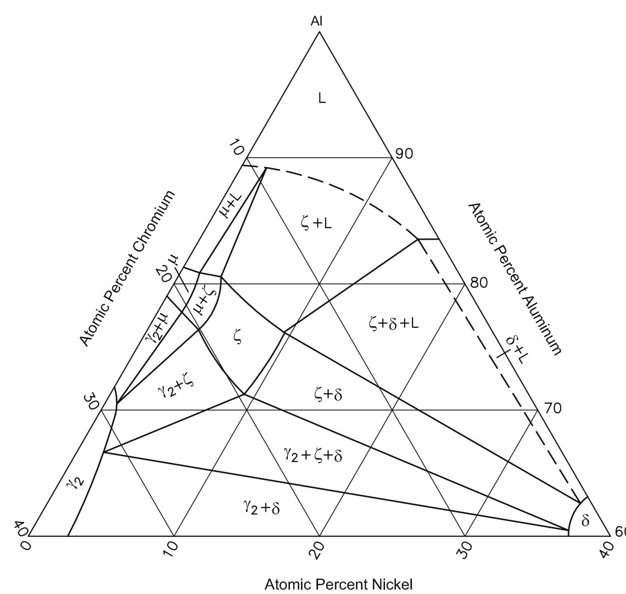

Fig. 5 Al-Cr-Ni isothermal section at 900 °C for Al-rich alloys [2008Gru1]

the ternary phase ε was not found. The homogeneity range of ζ at 900 °C becomes wider and extends between $Al_{81}Ni_3Cr_{16}$, $Al_{76.5}Ni_3Cr_{20.5}$, $Al_{76.5}Ni_9Cr_{14.5}$, and $Al_{71.5}Ni_9Cr_{19.5}$.

With starting metals of 99.99% purity, [2008Wei] arc-melted more than 30 Al-rich ternary alloys under Ar atm. The alloys were annealed between 950 and 600 °C for 2 weeks and quenched in water. The phase equilibria were studied with x-ray powder diffraction, metallography, energy dispersive x-ray analysis on a scanning electron microscope, and DTA at a heating and cooling rate of 5 °C/min. The homogeneity range of ζ (designated τ_1 by [2008Wei]) at 700 °C was found to match with that found by [2008Gru1] at 900 °C. The second ternary phase labeled τ_2 had an x-ray pattern characteristic of decagonal phases. The third ternary phase τ_3 had a complex pattern. The structures of τ_2 and τ_3 were not resolved. The isothermal section at 700 °C constructed by [2008Wei] is shown in Fig. 6. The binary phase field designated $\gamma_2 Cr_5Al_8$-$\gamma_3 Cr_4Al_9$ by [2008Wei] is shown as γ_2. The binary phase Ni_2Al_3 (δ) was found to dissolve up to 12 at.% Cr, which is much higher than 2.5 at.% found by [2008Gru1]. $CrAl_3$ (ν) shown tentatively stable up to 750 °C by [2008Gru2] was not found by [2008Wei] at 700 °C.

The liquidus projection constructed by [2008Wei] is shown in Fig. 7, with some tentative modifications. [2008Wei] adopted three phases in the γ-region of the

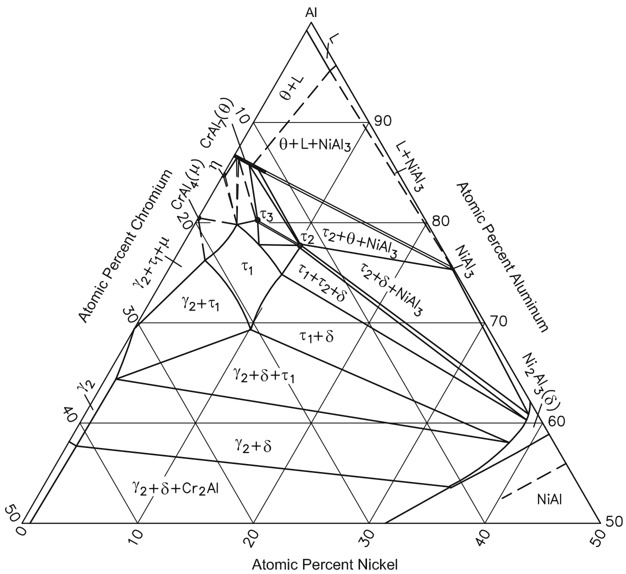

Fig. 6 Al-Cr-Ni isothermal section at 700 °C in the Al-rich region [2008Wei]

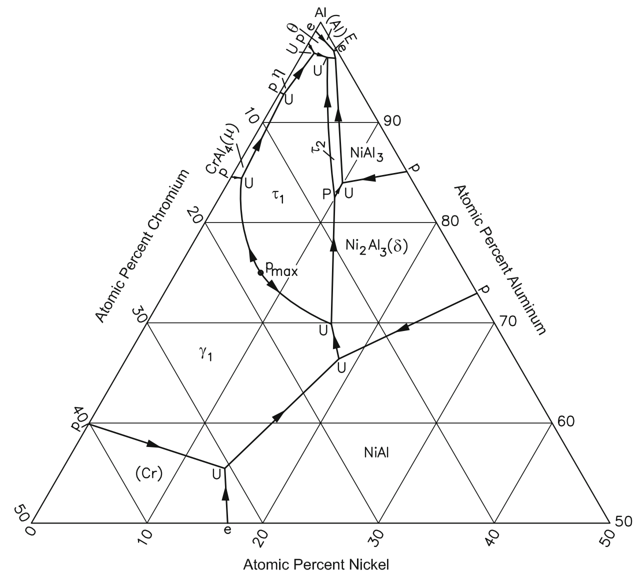

Fig. 7 Al-Cr-Ni liquidus projection in the Al-rich region [2008Wei]

Al-Cr system designated as γ_1(Cr,Al) or $\gamma_1Cr_5Al_8$, $\gamma_2Cr_5Al_8$ and $\gamma_3Cr_4Al_9$. In the Al-Cr phase diagram accepted here, only γ_1 (cubic) and γ_2 (rhombohedral) are recognized. Accordingly, the liquid-solid reactions involving $\gamma_3Cr_4Al_9$ are omitted in Fig. 7. Only one binary peritectic reaction L + (Cr) $\leftrightarrow \gamma_1$ is shown. [2008Wei] admitted that the issues regarding $\gamma_2Cr_5Al_8$-$\gamma_3Cr_4Al_9$ are not entirely resolved. Clearly, there is need for a general consensus on the phases present in the γ field of the Al-Cr system. A reaction scheme developed by [2008Wei] (not shown here) will need modification, if the tentative view accepted here regarding the Al-Cr system prevails.

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