

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

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A number of reports on this ternary system pertain to Ni-rich alloys, in view of their importance in high-temperature applications such as gas turbines and jet engines. A few reports are available for Al-rich alloys. Two reviews of this system by [1984Mer] and [1991Rog] are known, in addition to the compilation by [1995Vil]. The review by [1984Mer] includes a partial liquidus projection from [1955Kor], isothermal sections at 1150 °C from [1958Bag], at 1025 °C from [1983Lan], and at 1000, 850, and 750 °C from [1952Tay], a reaction sequence and vertical sections along the AlNi-Cr and Ni₃Al-Ni₃Cr joins. The review by [1991Rog] gave a partial liquidus projection and isothermal sections at 1150 °C from [1985Ofo], at 1025 °C from [1982Tu] and [1983Lan], and at 850 and 750 °C from [1952Tay]. The compilation by [1995Vil] includes, in addition to the experimental data reviewed by [1984Mer] and [1991Rog], a number of computed isothermal sections from [1974Kau] and [1980Cha], as well as an isothermal section at 1200 °C from [1987Nes].

Recently, two major thermodynamic assessments of this system by [1999Hua] and [2001Dup1] were reported, with differences between them in the modeling of the phases, but with similar computed diagrams.

Binary Systems

The Al-Cr phase diagram by [2000Mah] includes a thermodynamic assessment and depicts a number of intermediate phases with significant ranges of homogeneity: CrAl₇ (V₇Al₄₅-type monoclinic), Cr₂Al₁₁ (CrAl₅-type monoclinic), CrAl₄ (monoclinic), Cr₂Al (MoSi₂-type tetragonal), and an unconfirmed low-temperature phase X at 75 at.% Cr. Between 30 and 41 at.% Cr, five phases have been reported: αCr₄Al₉, βCr₄Al₉, γCr₄Al₉, αCr₅Al₈, and βCr₅Al₈, with no well-established phase boundaries between them [2000Mah]. A report by [1999Hel] discusses a possible B2-ordering of the Cr-rich body-centered cubic (bcc) phase. The Al-Ni phase diagram [1993Oka] shows five intermediate phases: NiAl₃ (Fe₃C-type orthorhombic), Ni₂Al₃ (D5₁₃-type hexagonal), NiAl (B2, CsCl-type cubic, also denoted β), Ni₅Al₃ (Ga₃Pt₅-type orthorhombic), and Ni₃Al (L1₂, AuCu₃-type cubic; also denoted γ'). The Cr-Ni phase diagram [Massalski2] is of the simple eutectic type with the eutectic reaction at 1345 °C, with Ni dissolving up to ~50 at.% Cr and Cr dissolving up to ~32 at.% Ni.

Ternary Phases

A ternary phase at the composition Al₇₅Cr₁₅Ni₁₀ reported by [1982Tu] has not been confirmed. In as-cast Al-rich alloys, [1999Com] did not find any ternary compounds. Three Al-rich ternary phases, each with several modifica-

tions, were reported by [1996Ros]: φ (monoclinic and orthorhombic), λ (orthorhombic and triclinic), and ρ (one rhombohedral and two hexagonal). [1998Li] confirmed the existence of one hexagonal form of ρ (denoted κ by [1998Li]), with space group *P*6₃ and lattice parameters of *a* = 1.7674 nm and *c* = 1.2516 nm. None of these was included in the thermodynamic description by [1999Hua] or [2001Dup1].

Thermodynamic Assessments

[1999Hua] modeled the face-centered-cubic (fcc) and bcc phases as random substitutional solid solutions, with separate chemical and magnetic contributions to the excess Gibbs energy. Ni₃Al (γ'; L1₂-ordered fcc phase) with its extension into the ternary region was described by a two-sublattice model, (Al,Cr,Ni)_{0.75}(Al,Cr,Ni)_{0.25}. The B2 (NiAl) phase was similarly described by the two-sublattice model (Al,Cr,Ni)(Cr,Ni,Va), where Va stands for vacancy. Both these models are ternary extensions of the corresponding descriptions of the Al-Ni binary phases by adding Cr to both sublattices. Due to a lack of experimental data, all other binary phases were assumed to have no ternary solubility. No ternary compounds were considered. The ternary interaction parameters obtained by optimization were listed by [1999Hua].

[2001Dup1] and [2001Dup2] used a single Gibbs energy function for both γ (fcc) and γ' (L1₂) phases. Similarly, the bcc disordered A2 and the ordered B2 phases were described by a single equation. In both these cases, the Gibbs energy function is the sum of two contributions, one corresponding to the Gibbs energy of the disordered phase and the other to the ordering Gibbs energy. [1999Hua] criticized this approach stating that it introduces more interaction parameters than necessary. [2001Dup1], however, pointed out that the use of two separate descriptions for γ and γ' phases results in the disordered γ' phase being different from the stable γ phase, even though they are identical in structure. [2001Dup1] used recent experimental data in the optimization from the work of [1999Tia] and [2000Sal] and also the data of [1992Gor], which were not included by [1999Hua]. [2001Dup1] listed the optimized ternary interaction parameters.

The Liquidus Projection

Figure 1 shows the computed liquidus projection for the entire composition range from [1999Hua]. It is in reasonable agreement with that computed by [2001Dup1] for the Ni-Cr-NiAl region. The liquidus in the Al-rich portion shown in Fig. 1 by dotted lines should be considered tentative, as the existence of ternary compounds was not considered by [1999Hua]. The primary phases of crystallization are marked in Fig. 1, the prominent phases being (Ni), (Cr) and B2. Constant temperature contours at 100 °C intervals

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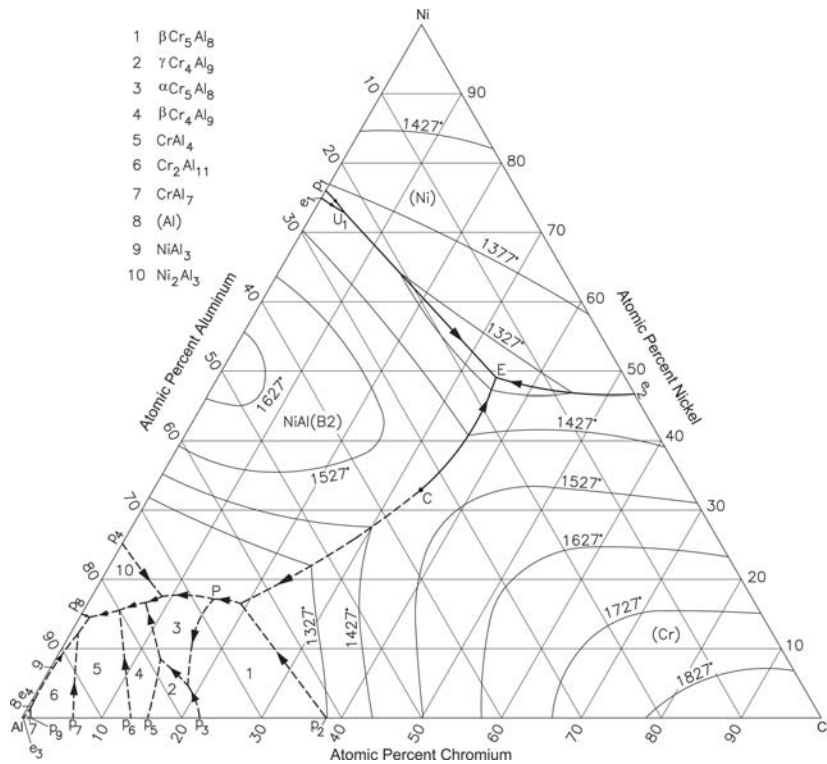


Fig. 1 Al-Cr-Ni computed liquidus projection [1999Hua]

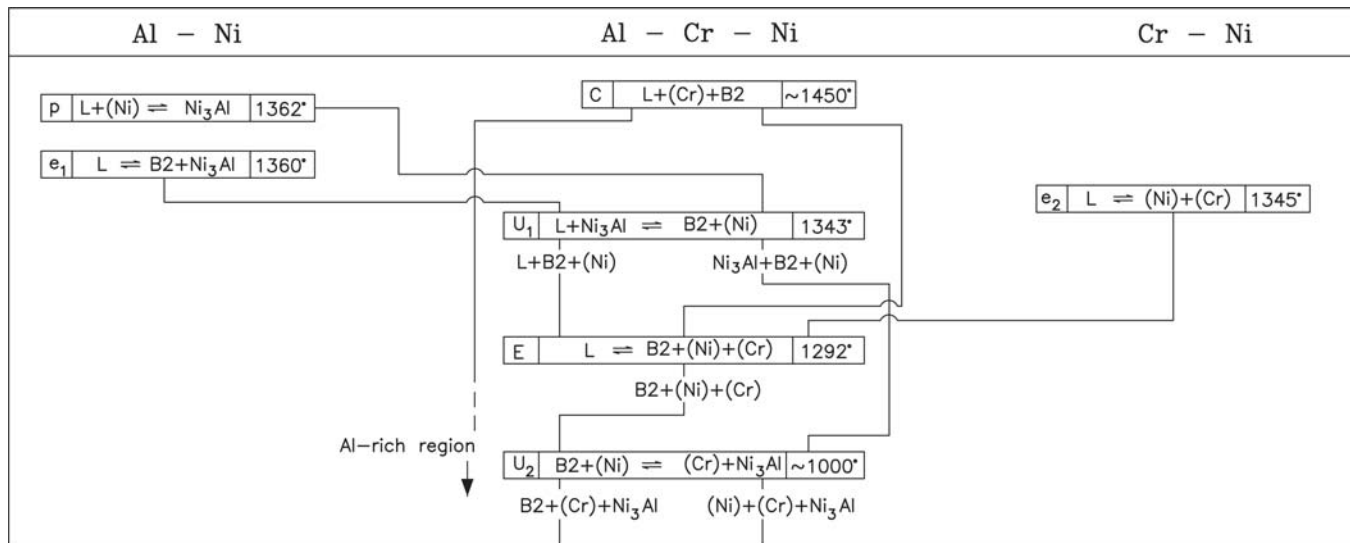


Fig. 2 Al-Cr-Ni reaction sequence for Al-poor alloys

are shown. The temperatures of the invariant reactions are: U_1 at 1343 °C [1999Hua], 1349 °C [2001Dup1], or 1340 °C [1952Tay]; E at 1292 °C [1999Hua], 1283 °C [2001Dup1], 1320 °C [1952Tay], or 1300 °C [1955Kor]. Figure 2 shows a reaction scheme for the Ni-Cr-NiAl region.

The (Ni)-liquid equilibria calculated at several temperatures by [1999Hua] are shown in Fig. 3. Satisfactory agreement was found by [1999Hua] with the experimental results of [1990Dav], [1996Wu], and [1999Sun].

Isothermal Sections

[1999Hua] computed isothermal sections at 1200, 1150, 1025, and 1000 °C and compared them with the available experimental data. The sections below 1000 °C were not computed. [1999Hua] did not use in the optimization the experimental data of [1992Gor] in this temperature range. They gave a very low weight to the data of [1952Tay] in this range, arguing that the annealing time of 3 weeks used by

[1952Tay] was too short. [2001Dup1] computed isothermal sections at 1300, 1200, 1150, 1127, 1100, 1027, 1025, 1000, 900, 850, 800, and 750 °C. At 850 and 750 °C, they used the experimental data of [1952Tay] and [1992Gor] in the optimization. [2001Jia] computed isothermal sections at 1300,

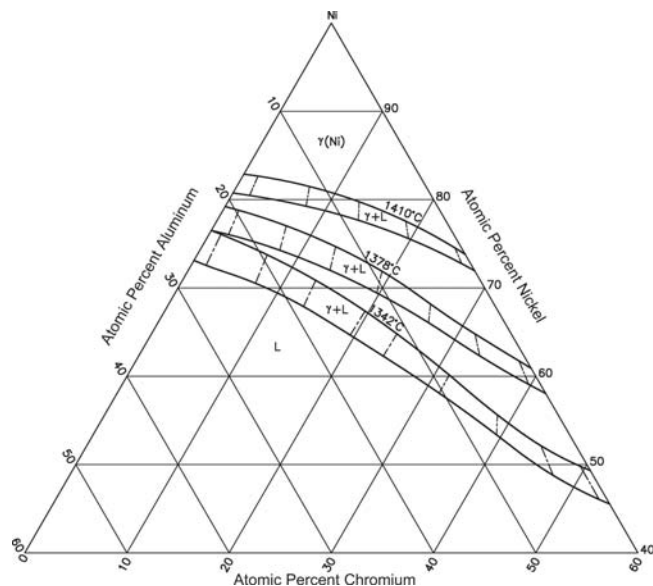


Fig. 3 Al-Cr-Ni computed ($\gamma + L$) equilibrium at the indicated temperatures [1999Hua]

1150, 1100, 1025, and 900 °C, using their own tie-line data from diffusion-couple experiments for the ($\gamma + \gamma'$) and ($\gamma' + B2$) equilibria.

Figure 4 shows the isothermal section for Ni-rich alloys at 1200 °C from [2001Dup1], giving the experimental tie-lines of [1994Jia] and [1994Yeu] for the (Ni) + B2 equilibrium. The data points from the thesis work of [1984Car] and [1998Qia] (not available to this reviewer) are presumably end-points of tie-lines. Figure 5 shows the computed section for the entire composition range at 1150 °C from [1999Hua], with comparison from the experimental tie-lines of [1985Ofo]. In Fig. 6, 7, and 8 at 1025, 1000, and 900 °C, respectively, the computed phase boundaries of [1991Hua] and [2001Dup1] are superposed. The results of the two assessments are very similar. The homogeneity region of γ' in these figures shows a ‘bulge’ at the right top end in the boundary computed by [1999Hua]. The superposed experimental points of [1952Tay] in this region in Fig. 7 favor the computed boundary of [2001Dup1] over that of [1999Hua]. In Fig. 8, the tie-lines from the recent work of [2002Bro] also appear to favor the boundary computed by [2001Dup1]. As discussed earlier, [2001Dup1] used a single Gibbs energy function to describe both the disordered and ordered states in the modeling of the fcc and bcc phases. In Fig. 9, the computed section of [2001Dup1] at 850 °C for the Ni-Cr-NiAl region is compared with the experimental data of [1952Tay] and [1992Gor]. The computed section at 750 °C [2001Dup1] (not shown) is similar to that at 850 °C.

Very recently, [2005Cao] used the cluster/site approximation (CSA) developed by [1999Oat] to compute the

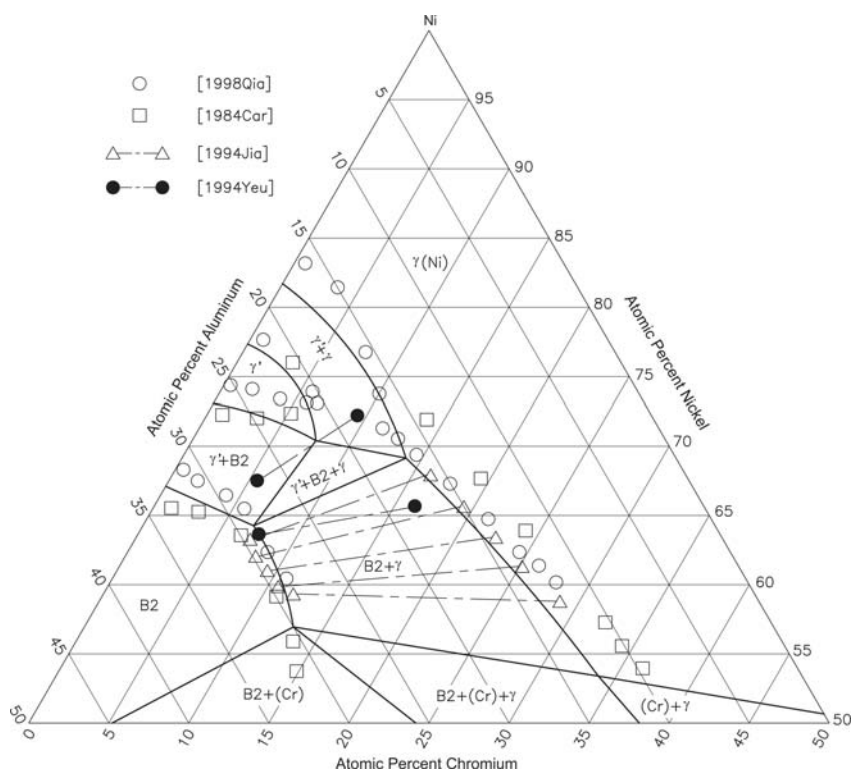


Fig. 4 Al-Cr-Ni computed isothermal section at 1200 °C [2001Dup1]

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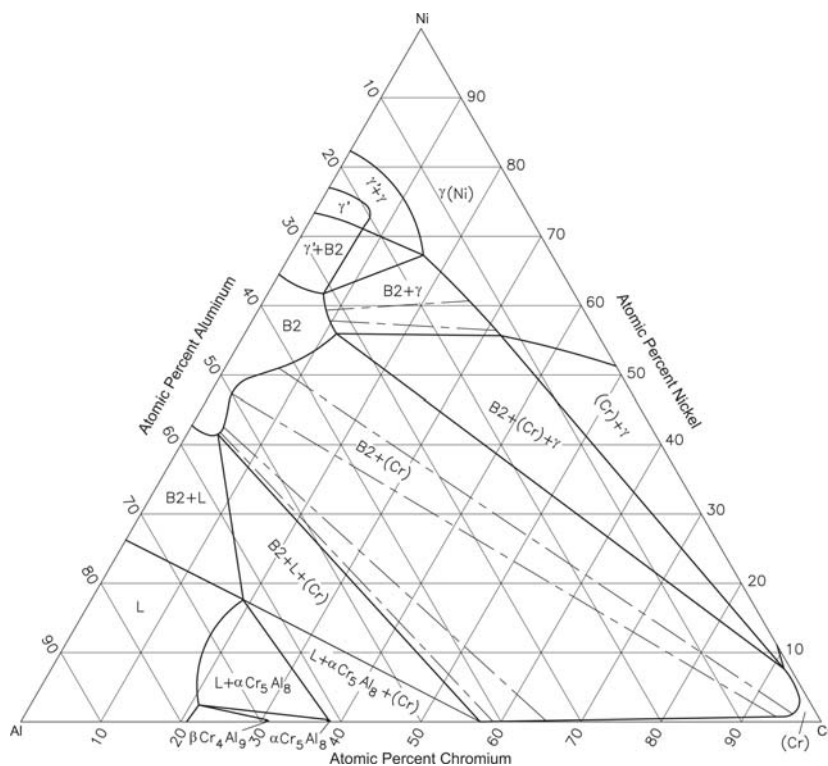


Fig. 5 Al-Cr-Ni computed isothermal section at 1150 °C [1999Hua]

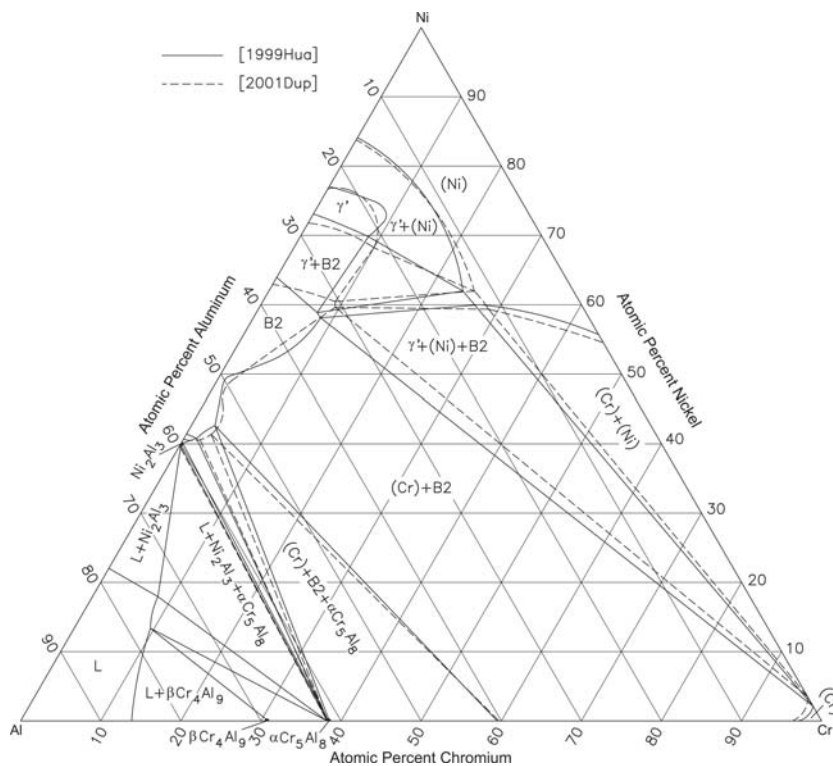


Fig. 6 Al-Cr-Ni computed isothermal section at 1025 °C [2001Dup1, 1999Hua]

phase equilibria of this ternary system. In CSA, the existence of short-range order (SRO) is taken into account, as is the case in the cluster variation method (CVM) and is thus

superior to the point or Bragg-Williams approximation, where SRO is not considered. The CSA model is much less demanding computationally, as the independent variables

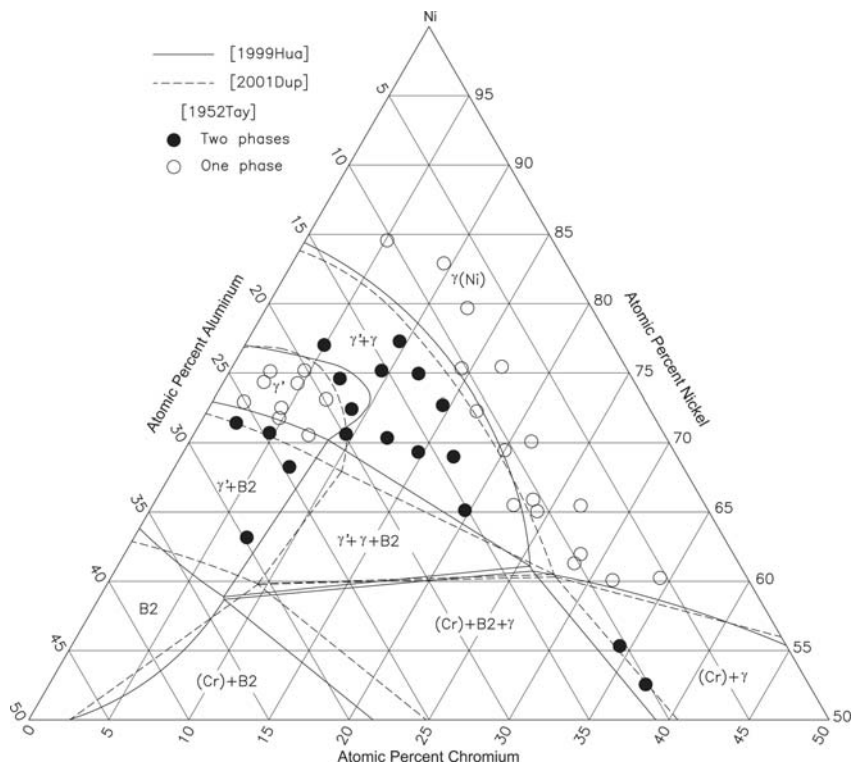


Fig. 7 Al-Cr-Ni computed isothermal section at 1000 °C [2001Dup1, 1999Hua]

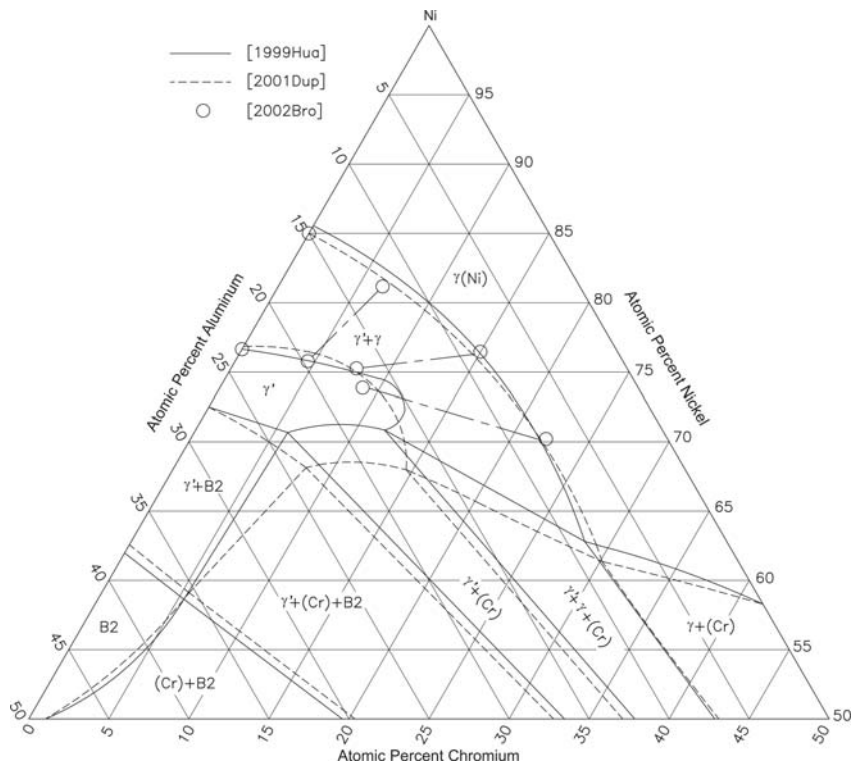


Fig. 8 Al-Cr-Ni computed isothermal section at 900 °C [2001Dup1, 1999Hua]

are far fewer in CSA as compared with CVM. [2005Cao] computed isothermal sections for Ni-rich alloys of this ternary system at 1200, 1150, and 1000 °C and compared them

with the experimental data of [1952Tay], [1983Och], [1994Yeu], and [1998Qia]. As an example, the CSA-computed isothermal section at 1000 °C is drawn with the

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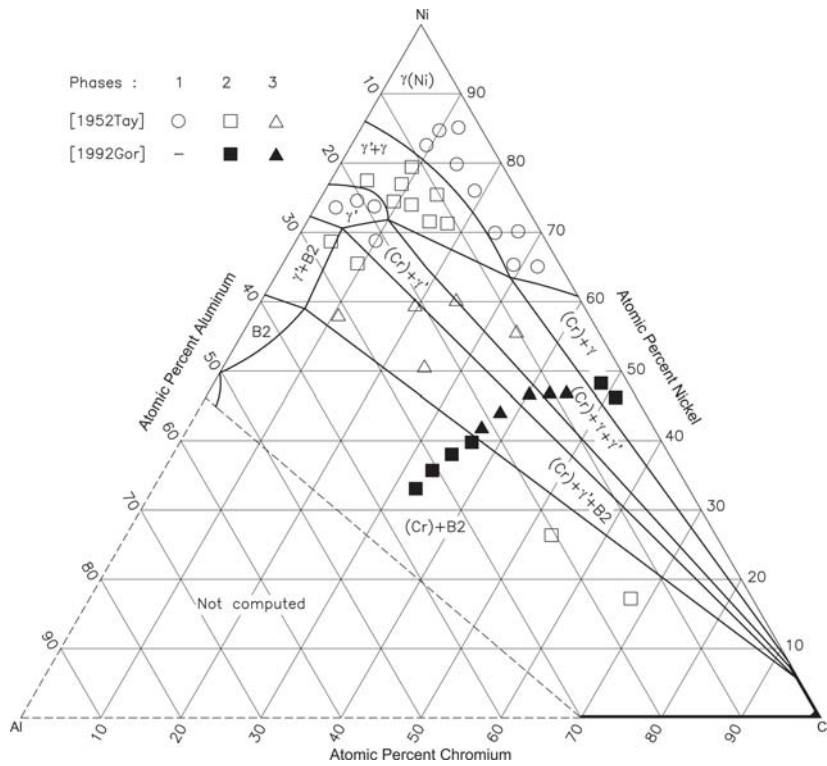


Fig. 9 Al-Cr-Ni computed isothermal section at 850 °C [2001Dup1]

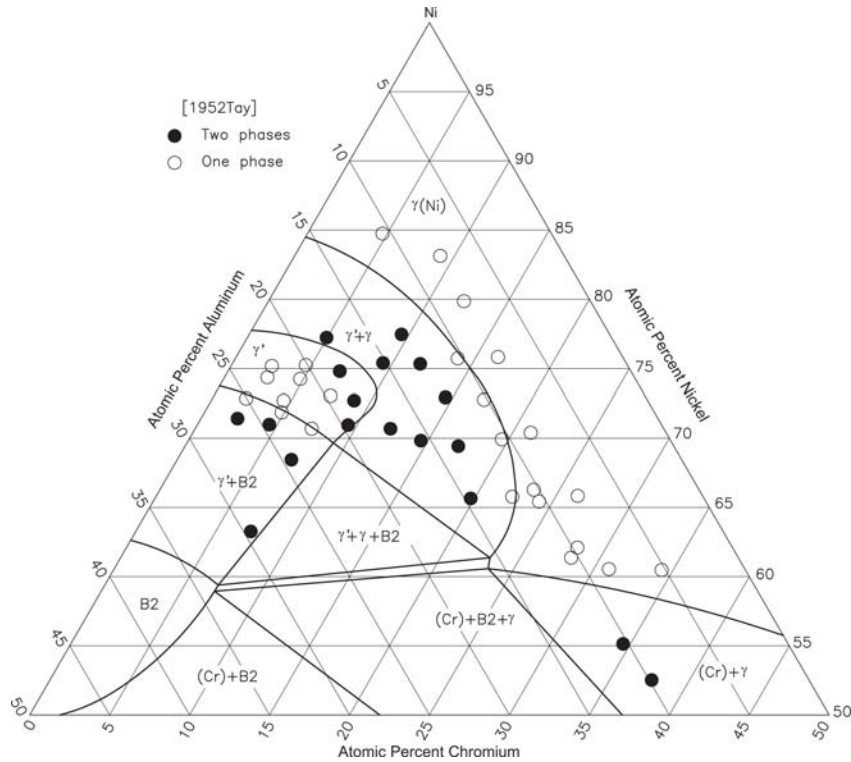


Fig. 10 Al-Cr-Ni CSA-computed isothermal section at 1000 °C [2005Cao]

experimental data of [1952Tay] in Fig. 10, which should be compared with Fig. 7. The good agreement indicates the success of the CSA model in describing the equilibria.

[2005Cao] also computed several metastable isothermal sections to illustrate the usefulness of the CSA approach.

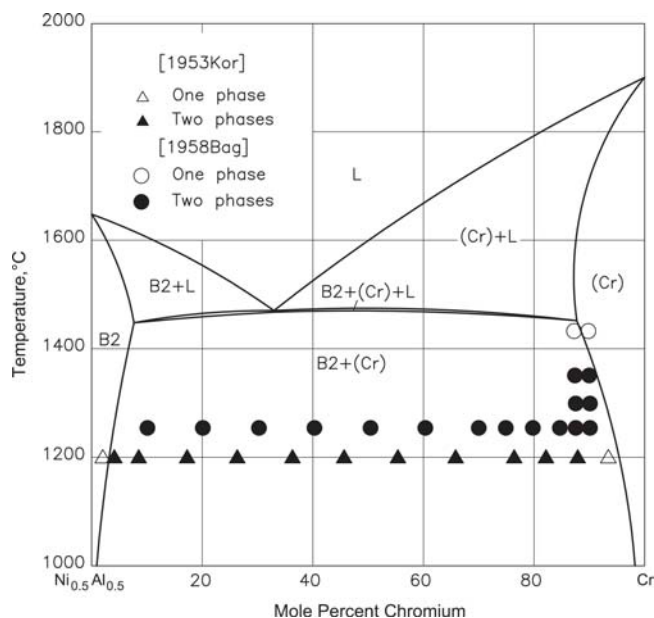


Fig. 11 Al-Cr-Ni computed vertical section along the NiAl-Cr join [1999Hua]

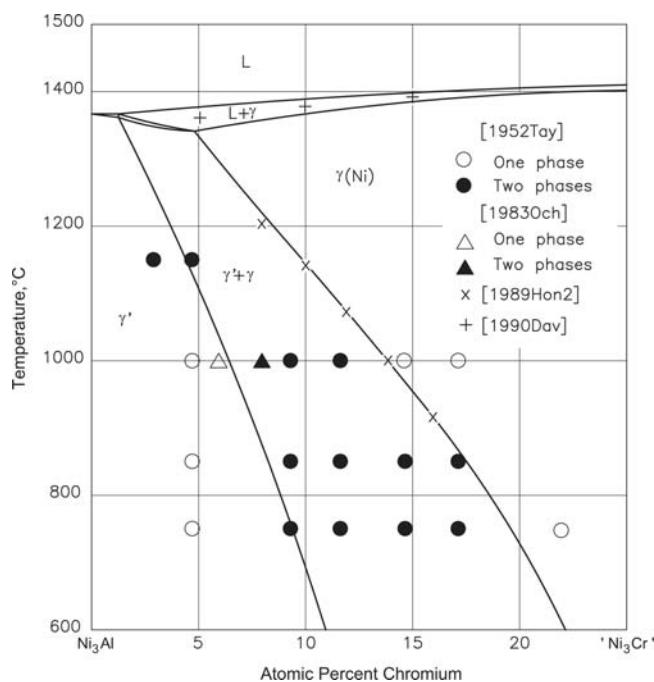


Fig. 12 Al-Cr-Ni computed vertical section along the Ni₃Al-Ni₃Cr join [2001Dup1]

Vertical Sections

In Fig. 11, the computed vertical section of [1999Hua] along the NiAl-Cr join is compared with the experimental data of [1953Kor] and [1958Bag]. In the early experimental literature [1953Kor, 1958Bag], this section was presented as a pseudobinary. This is not the case in Fig. 11. Figure 12

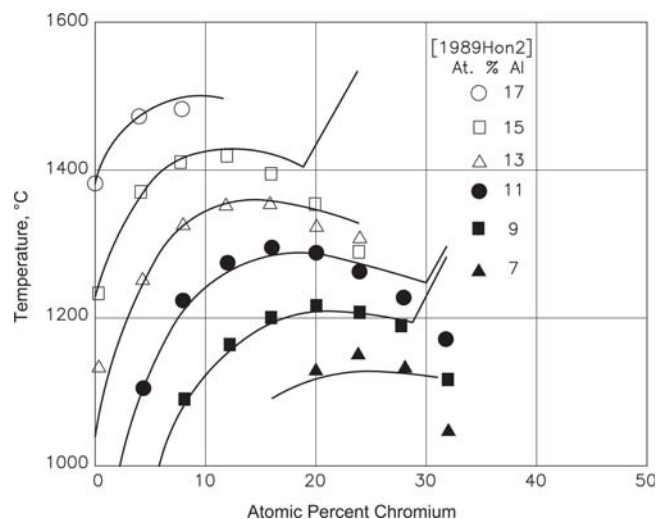


Fig. 13 Al-Cr-Ni computed γ solvus [2001Dup1]

shows the vertical section along the Ni₃Al-“Ni₃Cr” join [2001Dup1], which is not pseudobinary.

Both [1999Hua] and [2001Dup1] compared the computed γ solvus with the experimental results of [1989Hon1] and [1989Hon2], respectively, and found good agreement. Figure 13 shows the computed γ solvus from [2001Dup1] as a function of Al and Cr, along with the experimental points of [1989Hon2].

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