

Al-Ni-Ru (Aluminum-Nickel-Ruthenium)

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Among the early work on this ternary system, [1986Cha] presented two isothermal sections at 1250 and 1000 °C for Al-lean alloys. The update by [2006Rag] presented five partial isothermal sections in the Al-rich region from the studies of [2003Mi], depicting several ternary phases including a quasicrystalline decagonal phase. A second update by [2008Rag] gave isothermal sections at 1100 and 1000 °C in the Ni-NiAl-RuAl-Ru region from the studies of [2006Try]. Recently, [2009Zhu] carried out selected experiments and developed a thermodynamic analysis for this system. A computed liquidus projection and two isothermal sections at 1250 and 1000 °C were presented by [2009Zhu].

Binary Systems

The Al-Ni phase diagram [1993Oka] shows five intermediate phases: NiAl₃ (*D0*₁₁, Fe₃C-type orthorhombic), Ni₂Al₃ (*D5*₁₃-type hexagonal), NiAl (*B2*, CsCl-type cubic, also denoted β), Ni₅Al₃ (*Ga*₃Pt₅-type orthorhombic), and Ni₃Al (*L1*₂, AuCu₃-type cubic; denoted γ'). The Al-Ru phase diagram [2006Rag] depicts six intermediate phases: RuAl₆ (orthorhombic, space group *Cmcm*), Ru₄Al₁₃ (monoclinic, space group *C2/m*), Ru₂Al₅ (orthorhombic, space group *Cmcm*), RuAl₂ (*C54*, TiSi₂-type orthorhombic), Ru₂Al₃ (*Os*₂Al₃-type tetragonal), and RuAl (*B2*, CsCl-type cubic). The Ni-Ru phase diagram computed by [2004Hal] is a simple peritectic system with solubility of 34.1 at.% Ru in Ni and 47.4 at.% Ni in Ru at the peritectic temperature of 1564 °C.

Ternary Phase Equilibria

Based on preliminary calculations, [2009Zhu] designed and carried out selected experiments on phase fields in

doubt. With starting metals of 99.5% Al, 99.9% Ni and 99% Ru, [2009Zhu] arc-melted under Ar atm 11 ternary alloys. The alloys were annealed at 1000 °C for 30 or 60 days. The phase equilibria were studied x-ray powder diffraction, electron probe microanalyzer, and scanning electron microscope in the backscattered electron imaging mode. The measured compositions of the coexisting phases were listed.

The Gibbs energy of the fcc family of phases (γ and γ') was derived using first-principles calculation with the cluster-site approximation (CSA) method. For the other phases, a substitutional solution model or the compound energy formalism of the CALPHAD approach was used. The ternary phases in the Al-rich region [2003Mi] were not considered by [2009Zhu]. Thus their calculations are relevant only to the Al-lean region. Two isothermal sections

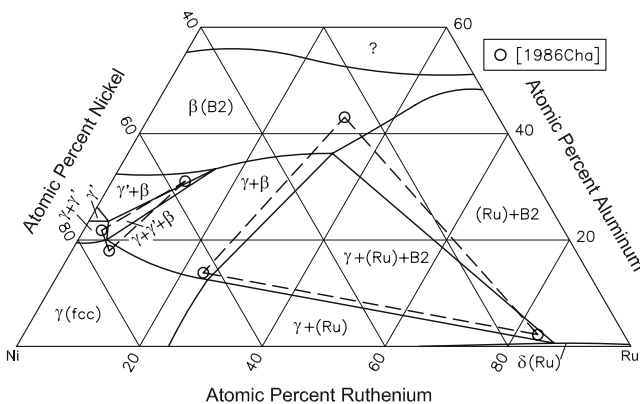


Fig. 1 Al-Ni-Ru computed isothermal section at 1250 °C in the Al-lean region [2009Zhu]

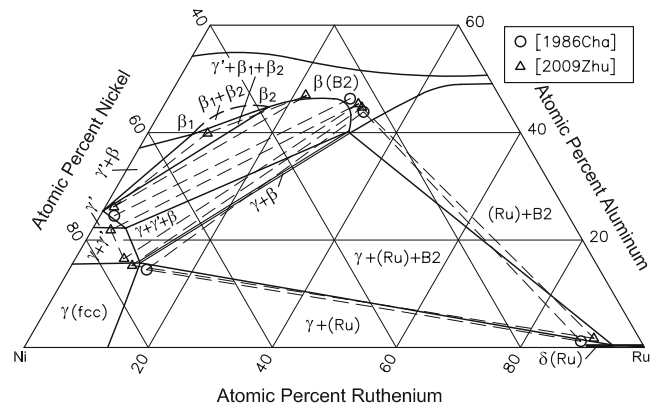


Fig. 2 Al-Ni-Ru computed isothermal section at 1000 °C in the Al-lean region [2009Zhu]

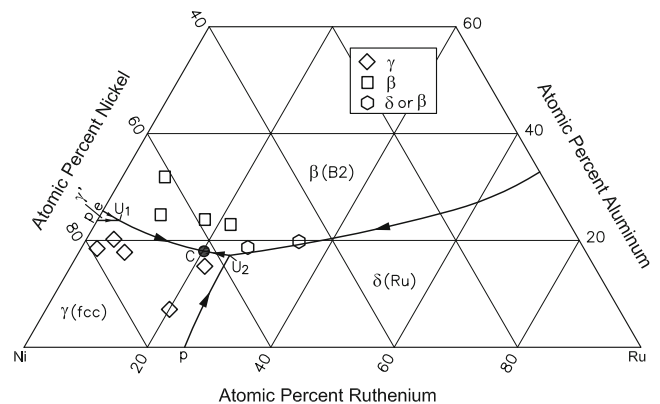


Fig. 3 Al-Ni-Ru computed liquidus projection in the Al-lean region [2009Zhu]

Section II: Phase Diagram Evaluations

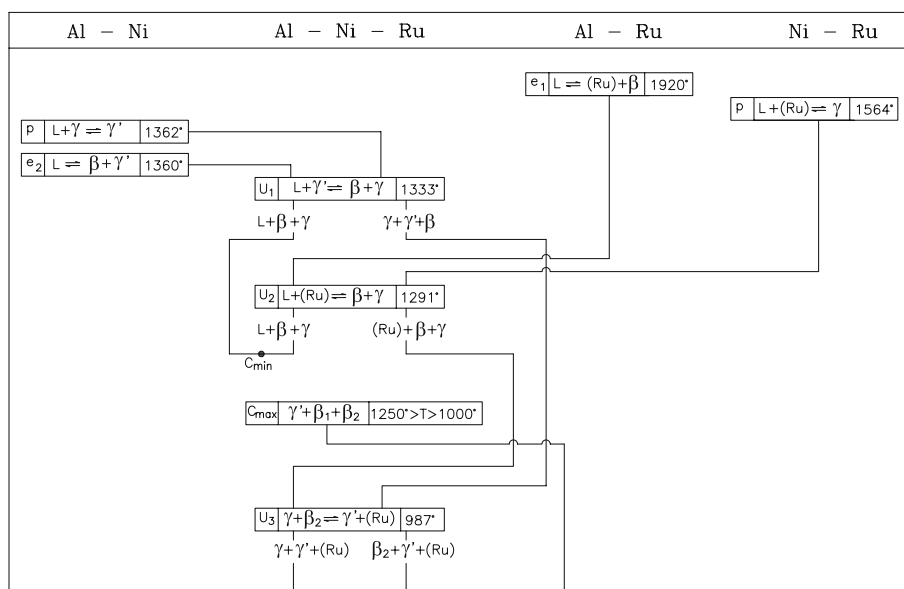


Fig. 4 Al-Ni-Ru reaction sequence for the Al-lean region [after 2009Zhu]

at 1250 and 1000 °C were computed and compared with the new experimental results as well as reported by [1986Cha], as shown in Fig. 1 and 2. The agreement with the experimental results is satisfactory.

The conflicting results in the literature about the formation of a continuous solid solution between NiAl and RuAl (both $B2$, CsCl-type) were briefly discussed by [2006Rag]. The computed results of [2009Zhu] show that there is a continuous $B2$ (β) solid solution at 1250 °C, as seen in Fig. 1. A miscibility gap arises on cooling. At 1000 °C (Fig. 2), a small gap of ($\beta_1 + \beta_2$) is present. Experimental support for the presence of a three-phase region of ($\beta_1 + \beta_2 + \gamma'$) is seen in the results of [2009Zhu] (Fig. 2). The miscibility gap lies on the Al-lean side of the stoichiometric NiAl-RuAl line. The vertical section along the NiAl-RuAl line computed by [2009Zhu] (not shown here) indicates that the miscibility gap spreads to this stoichiometric line only at very low temperatures (~ 100 °C).

A liquidus projection for the Al-lean region was calculated and compared with the experimental primary phases of crystallization, as shown in Fig. 3 [2009Zhu]. Agreement with the experimental data is good. Two invariant reactions occur in this region. U_1 : $L + \gamma' \leftrightarrow \beta + \gamma$ and U_2 : $L + (Ru) \leftrightarrow \beta + \gamma$. A temperature minimum occurs at the point C in Fig. 3. Based on the computed results of

[2009Zhu], a reaction sequence is written in Fig. 4 for the Al-lean region.

References

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