

Al-Hf-Ni (Aluminum-Hafnium-Nickel)

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The review of this ternary system by [1991Lee] presented a tentative liquidus projection and three isothermal sections at 1200, 1000, and 800 °C. The update by [2006Rag] reviewed the partial isothermal section at 1130 °C determined by [1997Nag] and the liquidus and solidus surfaces of the Ni-based face-centered cubic (fcc) solid solution from [1999Miu]. Recently, [2008Zha] carried out a thermodynamic assessment of the Ni-rich region of this system using new experimental data as additional input in the optimization and presented a liquidus projection and three isothermal sections at 1160, 1130, and 1000 °C.

Binary Systems

The Al-Hf system depicts a number of intermediate phases, see [2006Rag] for a listing. 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, denoted β), Ni₅Al₃ (Ga₃Pt₅-type orthorhombic), and Ni₃Al (*L1*₂, AuCu₃-type cubic, denoted γ'). The Hf-Ni phase diagram [2001Wan] depicts the following intermediate phases: Hf₂Ni (*C16*, CuAl₂-type tetragonal), α HfNi (*B_f*, CrB-type orthorhombic), β HfNi, Hf₉Ni₁₁ (tetragonal), Hf₇Ni₁₀ (orthorhombic), Hf₃Ni₇ (triclinic), Hf₈Ni₂₁ (triclinic), β HfNi₃ (hexagonal), α HfNi₃ (BaPb₃-type rhombohedral), Hf₂Ni₇ (monoclinic), and HfNi₅ (*C15_b*, AuBe₅-type cubic).

Computed Ternary Phase Equilibria

With starting metals of 99.99% Al, 99.9+% Hf, and 99.995% Ni, [2008Zha] arc-melted 5 Ni-rich alloys. The alloys were annealed at 1160 °C for 1 month. The phase equilibria were studied with scanning electron microscopy (in the back-scattered electron imaging mode) and by electron probe microanalysis. The compositions of the co-existing phases in the annealed samples were listed.

[2008Zha] modeled the liquid, (Al), (Hf), and (Ni) phases as substitutional solutions. Among the compounds, the focus of study was on the stoichiometric HfNi₅ and on Hf₂Ni₇, and Ni₃Al (γ'). The last two have homogeneity ranges and were described by a two sublattice model. HfNi₅ and Hf₂Ni₇ dissolve a negligible amount of Al. The optimized interaction parameters, which include ternary parameters for liquid and (Ni), were listed. For Ni-rich alloys, three isothermal sections at 1160, 1130 and 1000 °C and a liquidus projection were computed by [2008Zha]. At 1160 °C (Fig. 1), the computed isothermal section shows good agreement with the experimental tie-lines determined by them. At 1130 °C (Fig. 2), the computed equilibria are compared with the experimental tie-lines of [1997Nag] and the agreement is satisfactory. At this temperature, a four-phase equilibrium of ($\gamma + \gamma' + \text{HfNi}_5 + \text{Hf}_2\text{Ni}_7$) is seen, as suggested by [1997Nag]. At 1000 °C (Fig. 3), the computed diagram is compared with a single experimental tie-line from [1981Nas]. The primary phases of crystallization in the

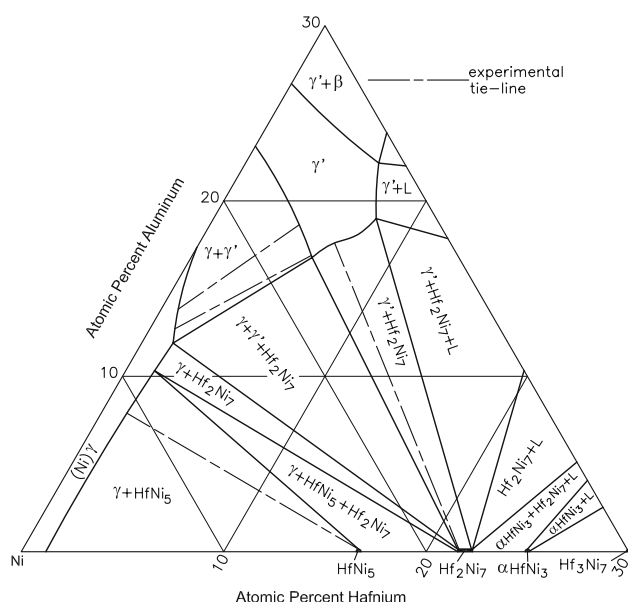


Fig. 1 Al-Hf-Ni computed isothermal section for Ni-rich alloys at 1160 °C [2008Zha]

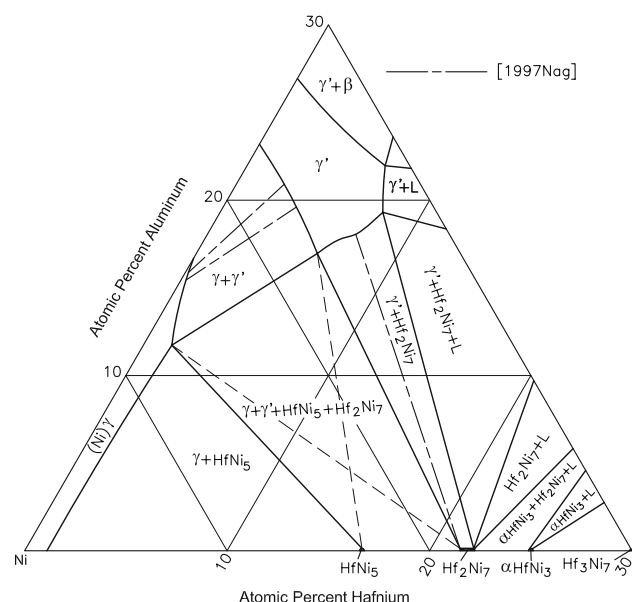


Fig. 2 Al-Hf-Ni computed isothermal section for Ni-rich alloys at 1130 °C [2008Zha]

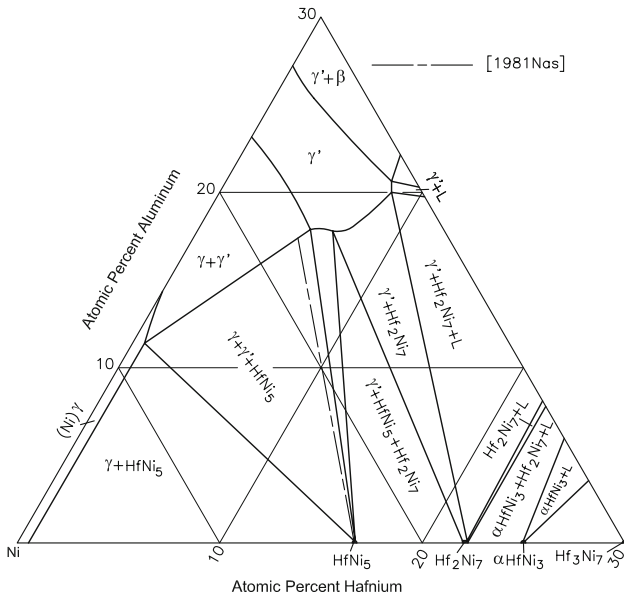


Fig. 3 Al-Hf-Ni computed isothermal section for Ni-rich alloys at 1000 °C [2008Zha]

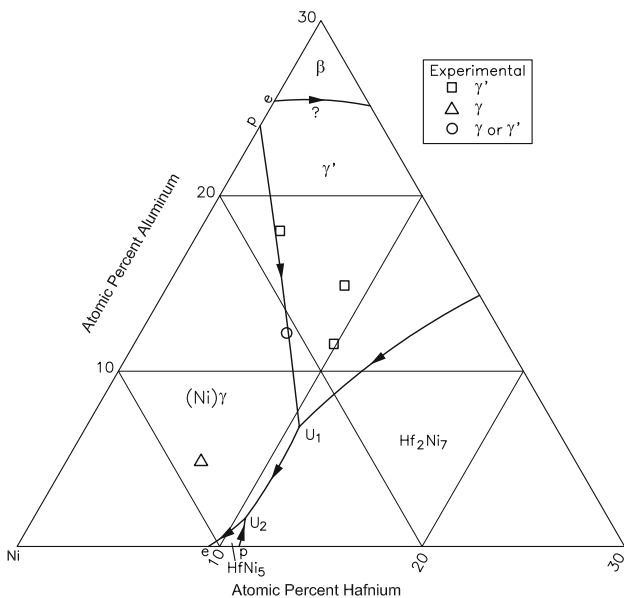


Fig. 4 Al-Hf-Ni computed liquidus projection for Ni-rich alloys [2008Zha]

partial liquidus projection computed by [2008Zha] (Fig. 4) tally with the single-phase microstructures observed by [2008Zha]. A partial reaction sequence is shown in Fig. 5 for the Ni-rich alloys of this system. Figure 6 compares the computed liquidus and solidus of the (Ni) solid solution with those determined by [1999Miu]. The agreement is good in the case of the liquidus. It is not satisfactory in the case of the solidus. There is a wide scatter in the experimental solidus data.

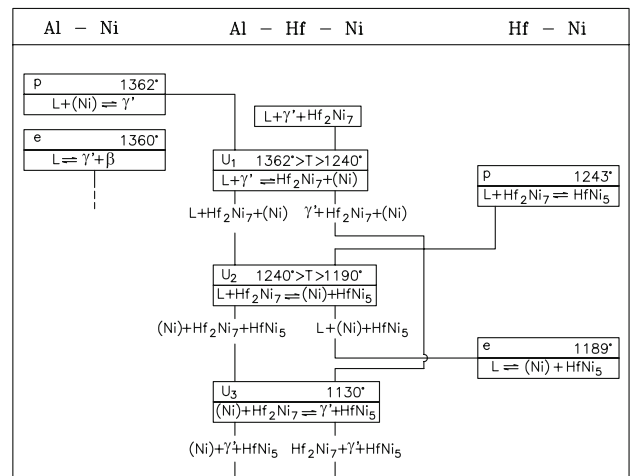


Fig. 5 Al-Hf-Ni partial reaction sequence for Ni-rich alloys down to 1000 °C

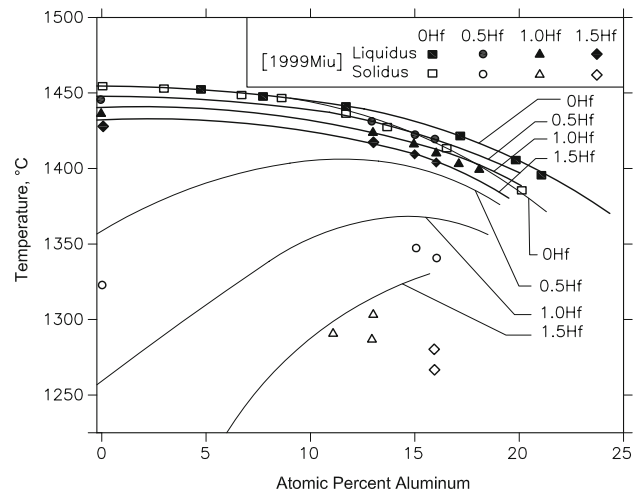


Fig. 6 Al-Hf-Ni computed liquidus and solidus of (Ni) solid solution [2008Zha]

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Section II: Phase Diagram Evaluations

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