

# Al-Fe-Ni (Aluminum-Iron-Nickel)

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The first major review of this system by [1988Ray] presented partial liquidus and solidus projections, a reaction sequence, and isothermal sections at 1250, 950, 850, and 750 °C. An update by [1994Rag] added two isothermal sections at 1050 and 950 °C for Al-rich alloys from the work of [1982Kha] and a vertical section along the Ni<sub>3</sub>Al-Ni<sub>3</sub>Fe join from [1987Mas]. A second update by [2005Rag] included an isothermal section at 1100 °C from [1994Jia] in the Ni<sub>3</sub>Al ( $\gamma'$ ) region. Recent work reviewed here includes the identification of a stable decagonal phase in the Al-rich region by [1996Gru] and [2004Mi], the  $\gamma$ - $\gamma'$ -B2 equilibrium data in Ni-rich alloys by [2005Him1], and a redetermination of the Ni<sub>3</sub>Al-Ni<sub>3</sub>Fe vertical section by [2005Him2].

## Binary Systems

The Al-Fe phase diagram [1993Kat] shows that the face-centered cubic (fcc) solid solution based on Fe is restricted by a  $\gamma$  loop. The body-centered cubic (bcc) solid solution exists in the disordered A2 form ( $\alpha$ ), as well as the ordered B2 and D0<sub>3</sub> forms. Apart from the high-temperature phase  $\epsilon$ , there are three other intermediate phases in this system: FeAl<sub>2</sub> (triclinic), Fe<sub>2</sub>Al<sub>5</sub> (70-73 at.% Al, orthorhombic), and FeAl<sub>3</sub> or Fe<sub>4</sub>Al<sub>13</sub> (74.5-76.6 at.% Al, monoclinic). The Al-Ni phase diagram [1993Oka] shows five intermediate phases: NiAl<sub>3</sub> (D0<sub>11</sub>, Fe<sub>3</sub>C-type orthorhombic), Ni<sub>2</sub>Al<sub>3</sub> (D5<sub>13</sub>-type hexagonal), NiAl (B2, CsCl-type cubic, also denoted  $\beta$ ), Ni<sub>5</sub>Al<sub>3</sub> (Ga<sub>3</sub>Pt<sub>5</sub>-type orthorhombic), and Ni<sub>3</sub>Al (L1<sub>2</sub>, AuCu<sub>3</sub>-type cubic; also denoted  $\gamma'$ ). The Fe-Ni phase diagram [1993Swa] is characterized by a very narrow solidification range with a peritectic reaction at 1514 °C, between bcc  $\delta$  and liquid, that yields the Fe-based fcc solid solution. A continuous solid solution denoted  $\gamma$  between fcc

Fe and Ni is stable over a wide range of temperature. At 517 °C, an ordered phase FeNi<sub>3</sub> forms congruently from  $\gamma$ .

## Ternary Phase Equilibria

[1996Gru] prepared by induction melting an alloy of composition Al<sub>71</sub>Ni<sub>24</sub>Fe<sub>5</sub>, which was annealed at 880 °C for 340 h. The resulting structure was randomly oriented decagonal grains of 0.5 mm diameter. The decagonal D phase was stable between 930 and 847 °C with a periodicity of

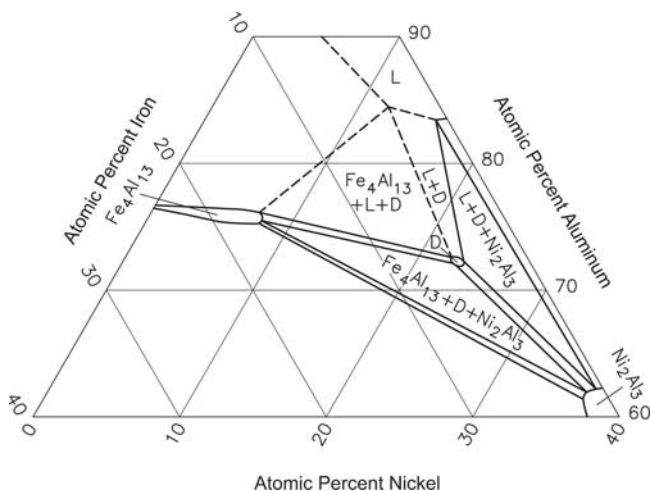


Fig. 1 Al-Fe-Ni partial isothermal section at 900 °C [2004Mi]

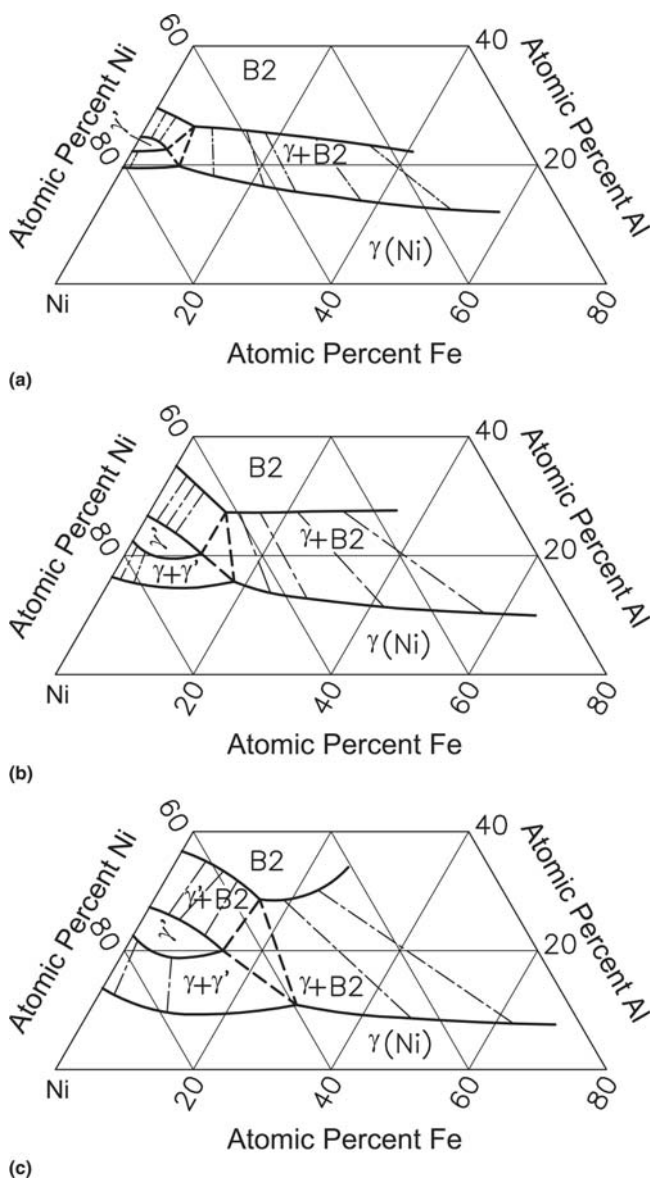
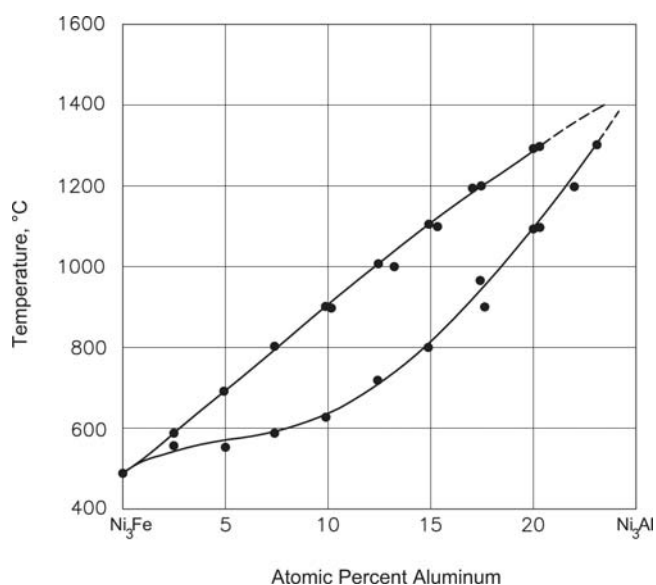


Fig. 2 Al-Fe-Ni partial isothermal sections at (a) 1300, (b) 1100, and (c) 900 °C [2005Him1]

## Section II: Phase Diagram Evaluations



**Fig. 3** Al-Fe-Ni vertical section along  $\text{Ni}_3\text{Fe}$ - $\text{Ni}_3\text{Al}$  join [2005Him2]

1.6 nm. [1996Gru] determined an isothermal section at 800 °C for this region, but the decagonal phase is not stable at this temperature. [2004Mi] presented an isothermal section at 900 °C by interpolation of the data of [1982Kha] and [1996Gru]. This is shown in Fig. 1. At 900 °C, the  $D$  phase forms tie-lines with  $\text{Fe}_4\text{Al}_{13}$  (or  $\text{FeAl}_3$ ),  $\text{Ni}_2\text{Al}_3$ , and liquid.

With starting metals of purity of 99.7% Al, 99.9% Fe, and 99.9% Ni, [2005Him1] induction melted under Ar atm about 14 ternary alloys. The samples were annealed at 1300, 1100, and 900 °C for durations up to 122 d and quenched in iced water. The phase equilibria were studied by optical and transmission electron microscopy, energy dispersive x-ray spectroscopy, and electron probe microanalysis. [2005Him1] constructed partial isothermal sections at 1300, 1100, and 900 °C (Fig. 2), by combining their results with those of [1994Jia]. These are consistent with the results reviewed by [1988Ray] in this temperature range. [2005Him1] also estimated the metastable extension of  $\gamma'$  field at 750 °C through electrical resistivity measurements.

Using the same starting metals and experimental techniques as above, [2005Him2] carried out in addition differential scanning calorimetric analysis at a heating rate of 3 °C/min to determine the  $\gamma/(\gamma + \gamma')$  and  $\gamma'/(\gamma + \gamma')$  phase boundaries. The vertical section constructed by [2005Him2] along the  $\text{Ni}_3\text{Fe}$ - $\text{Ni}_3\text{Al}$  join is shown in Fig. 3. The width of the  $(\gamma + \gamma')$  field here is significantly smaller than that found by [1987Mas] (reviewed in [1994Rag]).

By combining ab initio electron theory and statistical mechanics, [2004Lec] investigated the energetics of this ternary system in the ground state and at finite temperatures. The ab initio phase diagram based on the bcc and fcc lattices with the tetrahedron approximation confirmed a miscibility gap in the  $B2$  phase at 977 °C.

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