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

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This technologically-important system has been investigated experimentally a number of times. Many reviews and updates have also appeared in the last two decades [1988Ray, 1992Bud, 1994Rag, 1995Vil, 2005Cac, 2005Rag, 2006Ele, 2006Rag, 2008Rag]. For a recent detailed summary, the reader is referred to the updated version of [1992Bud] by [2005Cac], the review of [2006Ele] and the update by [2008Rag] on the work of [2007Chu1]. The present update will be limited to a review of three recent publications, featuring isothermal sections at 1200, 1100, 1000 and 900 °C for the Al-lean alloys by [2008Chu], two isothermal sections at 850 and 627 °C for Al-rich alloys by [2008Zha], and a vertical section along Fe_3Al-Ni_3Al join by [2007Chu2, 2008Chu].

Binary Systems

The Al-Fe phase diagram [1993Kat] shows that the face-centered cubic (fcc) solid solution based on Fe is restricted by a γ loop. The body-centered cubic (bcc) solid solution exists in the disordered *A*2 form (α), as well as the ordered *B*2 and *D*0_3 forms. Apart from the high temperature phase ε, there are three other intermediate phases in this system: $FeAl_2$ (triclinic), Fe_2Al_5 (70-73 at.% Al, orthorhombic), and $FeAl_3$ (or Fe_4Al_{13}) (74.5-76.6 at.% Al, monoclinic). The Al-Ni phase diagram [1993Oka] shows five intermediate phases: $NiAl_3$ ($D0_{11}$, Fe_3C-type orthorhombic), Ni_2Al_3 ($D5_{13}$-type hexagonal), NiAl (*B*2, 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 Fe-Ni phase diagram [1993Swa] is characterized by a very narrow solidification range with a peritectic reaction at 1514 °C between bcc δ and liquid that yields the Fe-based fcc solid solution. A continuous fcc solid solution denoted γ is stable over a wide range of temperature. At 517 °C, an ordered phase $FeNi_3$ forms congruently from γ.

Ternary Phase Equilibria

With starting metals of 99.999% Al, 99.99% Fe and 99.95% Ni, [2008Zha] arc-melted 19 ternary alloys under Ar atm. The final anneal was at 850 °C for 18 d or at

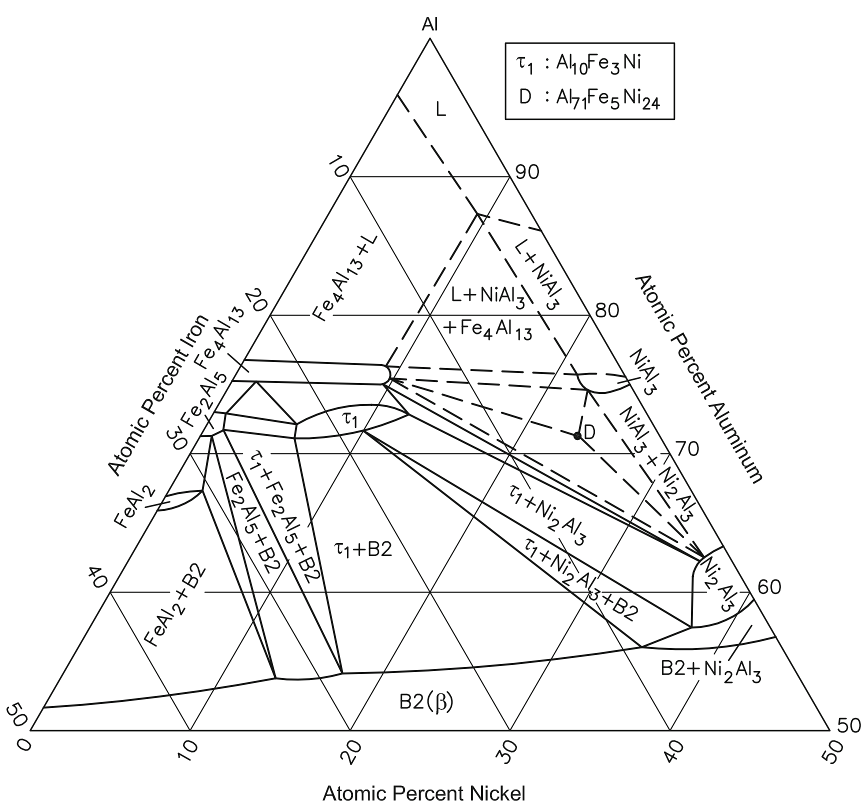

Fig. 1 Al-Fe-Ni isothermal section at 850 °C for Al-rich alloys [2008Zha]

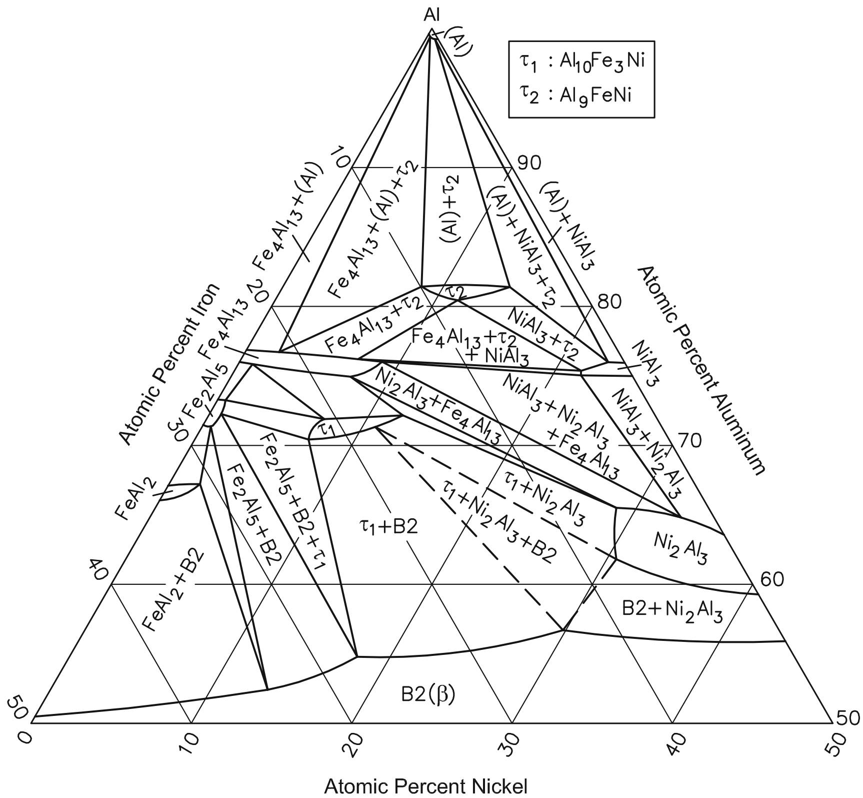

Fig. 2 Al-Fe-Ni isothermal section at 627 °C for Al-rich alloys [2008Zha]

627 °C for 50 d , followed by water quenching. The phase equilibria were studied by optical microscopy and x-ray powder diffraction. The compositions of coexisting phases were measured with energy dispersive x-ray analysis on a scanning electron microscope or by electron probe microanalysis (EPMA) and listed. The isothermal sections constructed by [2008Zha] at 850 and 627 °C are shown in Fig. 1-2.

At 850 °C (Fig. 1), the ternary phase τ_1 (denoted as τ_2 by [2008Zha]) and the quasicrystalline decagonal phase D (denoted τ_3 by [2008Zha]) are present. The homogeneity range of τ_1 is 5.7-13.1 at.% Ni and 14.4-22.2 at.% Fe. The binary phases $FeAl_2$, Fe_2Al_5, and Fe_4Al_{13} dissolve 2.1, 1.3 and 9.6 at.% Ni respectively. Al_2Ni_3 dissolves up to 4.9 at.% Fe. At 850 °C, the D phase is shown to be in four-phase equilibrium with Fe_4Al_{13}, $NiAl_3$, and Ni_2Al_3. It decomposes at this temperature through a ternary eutectoid reaction. This section at 850 °C by [2008Zha] is remarkably similar to that of [2007Chu1] reviewed by [2008Rag], the two versions appearing as independent investigations.

At 627 °C (Fig. 2), the ternary phases τ_1 (denoted τ_2 by [2008Zha]) and τ_2 (denoted τ_1 by [2008Zha]) are present. The homogeneity range of τ_1 is 7.2-12.4 at.% Ni and 15.6-22.5 at.% Fe. The range of τ_2 is 8.7-14.3 at.% Ni and 4.5-10.0 at.% Fe. The solubility of Ni in $FeAl_2$, Fe_2Al_5 and Fe_4Al_{13} is 2.0, 1.5, and 8.9 at.% respectively. Ni_2Al_3 dissolves up to 3.6 at.% Fe.

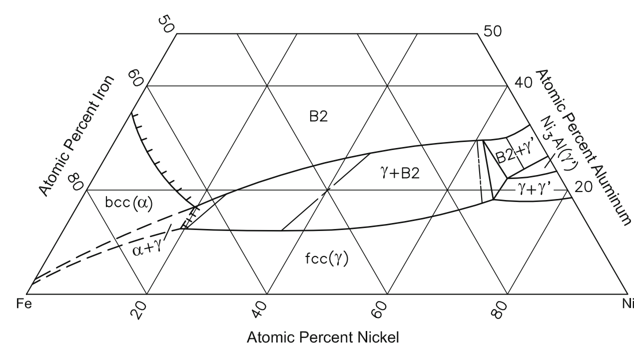

Fig. 3 Al-Fe-Ni isothermal section at 1200 °C for Al-lean alloys [2008Chu]

The phase relationships between the ordered and disordered forms of bcc Fe in the ternary region were clarified in the recent study of [2008Chu]. With starting metals of 99.999% Al, 99.99% Fe and 99.99% Ni, [2008Chu] arc-melted under Ar atm 28 ternary alloys containing up to 28 at.% Al. The samples were annealed at 1200, 1100, 1000 and 900 °C for ½, 4, 14 and 28 d respectively and quenched in water. The phase equilibria were studied with x-ray powder diffraction and electron probe microanalysis. The partial isothermal sections constructed by [2008Chu] at 1200, 1100, 1000, and 900 °C are shown in Fig. 3-6. At 1200 °C (Fig. 3) and 1100 °C

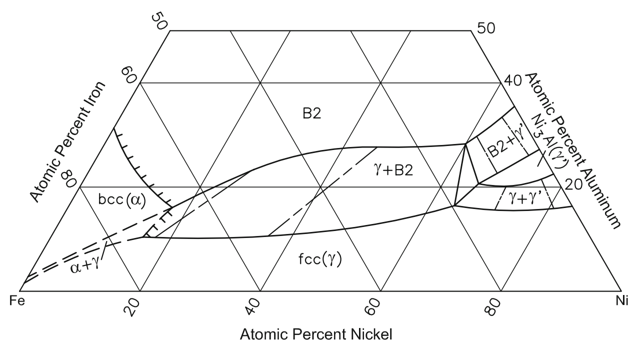

Fig. 4 Al-Fe-Ni isothermal section at 1100 °C for Al-lean alloys [2008Chu]

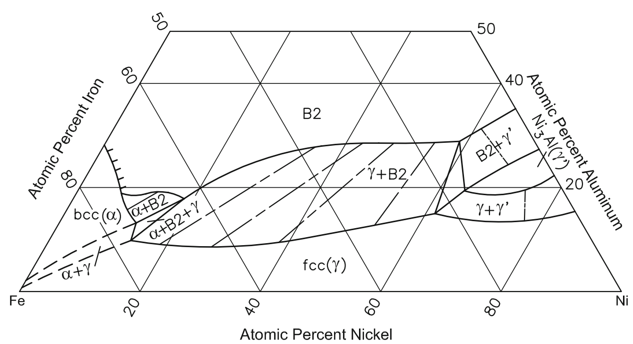

Fig. 5 Al-Fe-Ni isothermal section at 1000 °C for Al-lean alloys [2008Chu]

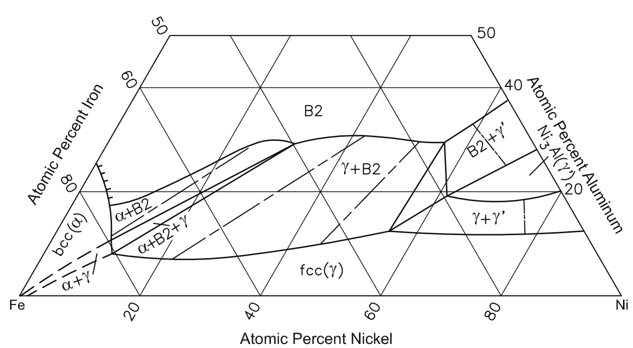

Fig. 6 Al-Fe-Ni isothermal section at 900 °C for Al-lean alloys [2008Chu]

(Fig. 4), the bcc ↔ *B*2 transition is fully second order. At 1000 and 900 °C (Fig. 5 and 6), the transition is partially second-order and partially first-order. The (bcc + *B*2) two-phase region gives rise to a three-phase (fcc + bcc + *B*2) equilibrium.

[2006Rag] reviewed the vertical section along the Ni_3Fe-Ni_3Al join from the studies of [2005Him], omitting the region near the Ni_3Al end, where the binary Ni_3Al forms through a peritectic reaction. The details of this region were studied recently by [2007Chu2]. Their results are shown in Fig. 7. An invariant U-type transition reaction: L + γ′ ↔ γ + *B*2 occurs at 1366 °C, with the composition (in at.%) of

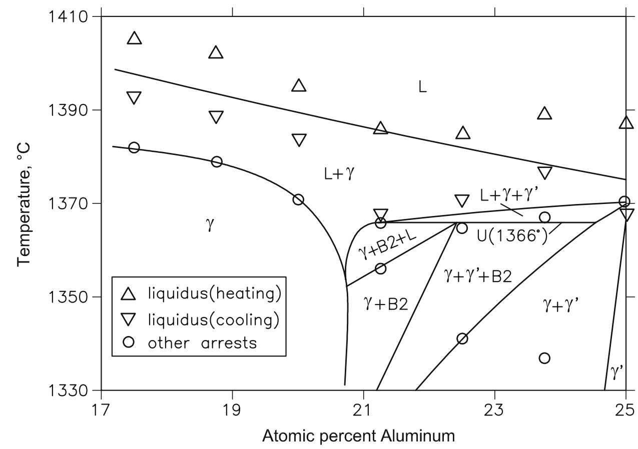

Fig. 7 Al-Fe-Ni invariant horizontal near the Ni_3Al-end of the vertical section along the Ni_3Fe-Ni_3Al join [2007Chu2]

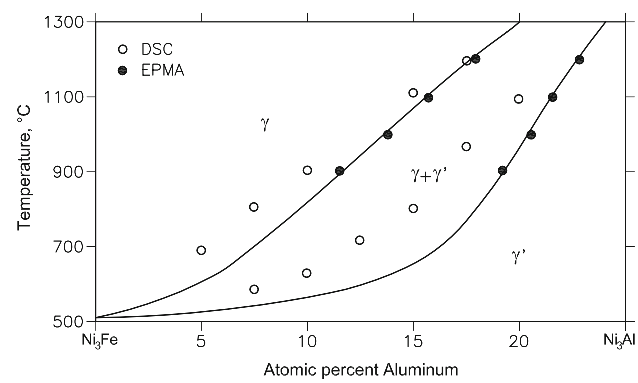

Fig. 8 Al-Fe-Ni pseudobinary region of the vertical section along the Ni_3Fe-Ni_3Al join [2008Chu]

the participating phases being L (5Fe73Ni22Al), γ′ (0.5Fe75Ni24.5Al), γ (4Fe76Ni20Al), and *B*2 (0.5Fe71.5-Ni28Al). Towards the Ni_3Fe-side, the vertical section is pseudobinary in nature. [2008Chu] found that the location of the phase boundaries in this region is influenced by the experimental technique used, as shown in Fig. 8. The experimental points from differential scanning calorimetry (DSC) used by [2005Him] are consistently higher than those found with EPMA used by [2008Chu]. The EPMA analysis of equilibrated samples is to be considered more accurate, as compared to those obtained from the dynamic method of DSC.

References

1988Ray: G.V. Raynor and V.G. Rivlin, Al-Fe-Ni, *Phase Equilibria in Iron Ternary Alloys*, Institute of Metals, London, 1988, p 107-121

1992Bud: P. Budberg and A. Prince, Aluminum-Iron-Nickel, *Ternary Alloys*, G. Petzow and G. Effenberg, Eds., Vol. 5, VCH Verlag, Weinheim, Germany, 1992, p 309-323

1993Kat: U.R. Kattner and B.P. Burton, Al-Fe (Aluminum-Iron), *Phase Diagrams of Binary Iron Alloys*, H. Okamoto, Ed., ASM International, Materials Park, OH, 1993, p 12-28

1993Oka: H. Okamoto, Al-Ni (Aluminum-Nickel), *J. Phase Equilib.*, 1993, **14**(2), p 257-259

1993Swa: L.J. Swartzendruber, V.P. Itkin, and C.B. Alcock, Fe-Ni (Iron-Nickel), *Phase Diagrams of Binary Iron Alloys*, H. Okamoto, Ed., ASM International, Materials Park, OH, 1993, p 256-278

1994Rag: V. Raghavan, Al-Fe-Ni (Aluminum-Iron-Nickel), *J. Phase Equilib.*, 1994, **15**(4), p 411-413

1995Vil: P. Villars, A. Prince, and H. Okamoto, Al-Fe-Ni, *Handbook of Ternary Alloy Phase Diagrams*, Vol. 3, ASM International, Materials Park, OH, 1995, p 3525-3581

2005Cac: G. Cacciamani, R. Ferro, B. Grushko, P. Perrot, and R. Schmid-Fetzer, Light Metal Ternary Systems: Phase Diagrams, Crystallographic and Thermodynamic Data, *Light Metal Systems*, Vol. 11A2, Part 2, Springer, Berlin, 2005, p 329-358

2005Him: Y. Himuro, Y. Tanaka, N. Kamiya, I. Ohnuma, R. Kainuma, and K. Ishida, Stability of Ordered $L1_2$ Phase in Ni_3Fe-Ni_3X (X: Si and Al) Pseudobinary Alloys, *Intermetallics*, 2005, **13**, p 635-643

2005Rag: V. Raghavan, Al-Fe-Ni (Aluminum-Iron-Nickel), *J. Phase Equilib. Diffus.*, 2005, **26**(1), p 70-71

2006Ele: L. Eleno, K. Frisk, and A. Schneider, Assessment of the Fe-Ni-Al System, *Intermetallics*, 2006, **14**, p 1276-1290

2006Rag: V. Raghavan, Al-Fe-Ni (Aluminum-Iron-Nickel), *J. Phase Equilib. Diffus.*, 2006, **27**(5), p 489-490

2007Chu1: I. Chumak, K.W. Richter, and H. Ipser, The Fe-Ni-Al Phase Diagram in the Al-Rich (>50 at.% Al) Corner, *Intermetallics*, 2007, **15**, p 1416-1424

2007Chu2: I. Chumak, K.W. Richter, S.G. Fries, and H. Ipser, Experimental Phase Diagram Investigations in the Ni-Rich Part of Al-Fe-Ni and Comparison with Calculated Phase Equilibria, *J. Phase Equilib. Diffus.*, 2007, **28**(5), p 417-421

2008Chu: I. Chumak, K.W. Richter, and H. Ipser, Isothermal Sections in the (Fe,Ni)-Rich Part of the Fe-Ni-Al Phase Diagram, *J. Phase Equilib. Diffus.*, 2008, **29**(4), p 300-304

2008Rag: V. Raghavan, Al-Fe-Ni (Aluminum-Iron-Nickel), *J. Phase Equilib. Diffus.*, 2008, **29**(2), p 180-184

2008Zha: L. Zhang, Y. Du, H. Xu, C. Tang, H. Chen, and W. Zhang, Phase Equilibria of the Al-Fe-Ni System at 850 °C and 627 °C, *J. Alloys Compd.*, 2008, **454**, p 129-135