JPEDAV (2005) 26:70-71
DOI: 10.1361/15477030522536
1547-7037/$19.00 ©ASM International

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

V. Raghavan

The previous review of this system by [1988Ray] presented liquidus and solidus projections for Al-poor Fe-Ni alloys and for compositions near the Al corner, a reaction sequence for the solidification reactions, isothermal sections at 1250, 950, 850, and 750 °C for Al-poor compositions, and a section at 600 °C near the Al corner. An update by [1994Rag] presented isothermal sections at 1050 and 950 °C from [1982Kha] and a vertical section along the Ni_3Al-Ni_3Fe join from [1987Mas]. A number of new reports on the phase equilibria of this system have since appeared.

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 $A2$ form (α), as well as the ordered $B2$ and $D0_3$ 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] depicts five intermediate phases: Ni_3Al (23-28 at.% Al, $AuCu_3$-type cubic, denoted γ'), Ni_5Al_3 (32-36 at.% Al, Ga_3Pt_5-type orthorhombic), NiAl (31-58 at.% Al, CsCl-type cubic), Ni_2Al_3 (58-63 at.% Al, $D5_{13}$ type hexagonal); and $NiAl_3$ (75 at.% Al, Fe_3C-type orthorhombic). Recently, [2001Miu] reinvestigated the liquidus in the Ni-rich region of the Al-Ni diagram. [2002Bit] reassessed the solidus of the AlNi ($B2$) phase in this binary system. 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 solid solution denoted γ between fcc Fe and Ni is stable over a wide range of temperatures. At 517 °C, an ordered phase $FeNi_3$ forms congruently from γ.

Ternary Phases

[1988Ray] listed two ternary compounds in this system: $FeNiAl_9$ (designated τ_1, monoclinic) and Fe_3NiAl_{10} (τ_2, hexagonal). At the composition $FeNiAl_5$, [1990Ell] found a phase of hexagonal symmetry ($hP28$, a = 0.7703 nm and c = 0.7668 nm), which is isomorphous with Co_2Al_5. This phase could be the same as τ_2 in [1988Ray].

[1982Kha] found a new ternary phase of unknown structure (denoted as Q here) at the composition $Fe_{5.4}Ni_{23}Al_{71.6}$, which was reported to exist in a narrow temperature range. [1996Lem] found a decagonal quasi-crystalline phase around this composition. It is understood here that the two phases refer to the same quasi-crystalline phase [2004Gru]. According to [1996Lem], this phase forms at 930 °C through a ternary peritectic reaction ($FeAl_3 + Ni_2Al_3 + L \leftrightarrow Q$) and decomposes through a ternary eutectoid reaction at 847 °C ($Q \leftrightarrow Ni_2Al_3 + NiAl_3 + FeAl_3$). It may be noted that [1982Kha] reported the peritectic formation of Q at 925 °C and did not present an isothermal section at 900 °C, pending confirmation of the stable presence of Q.

Isothermal Sections

[1994Jia] studied the partitioning of alloying elements among the γ, γ', and $B2$ phases in Ni-Al base systems. Diffusion couples were prepared from induction-melted alloys and were annealed between 1300 and 800 °C for 10 to 1000 h. The composition of the coexisting phases was measured by electron probe microanalysis and listed. In the equilibrium of γ'/γ, Fe segregates preferentially in the γ phase. The partition coefficient K_{Fe} for γ'/γ equilibrium decreases from 0.75 at 1300 °C to ~0.33 at 800 °C. In the equilibrium of $\gamma'/B2$, Fe segregates preferentially in the $B2$ phase. Here, K_{Fe} decreases from ~0.9 at 1300 °C to ~0.75 at 900 °C. [1994Jia] constructed partial isothermal sections at 1300 and 1100 °C. The section at 1100 °C is redrawn in Fig. 1.

Using starting metals of 99.99% Al, ~99.9% Fe, and electrolytic Ni, [1996Kal] arc-melted alloys with Al ≤ 50 at.%, which were annealed at 1127 °C for 100 h. The phase

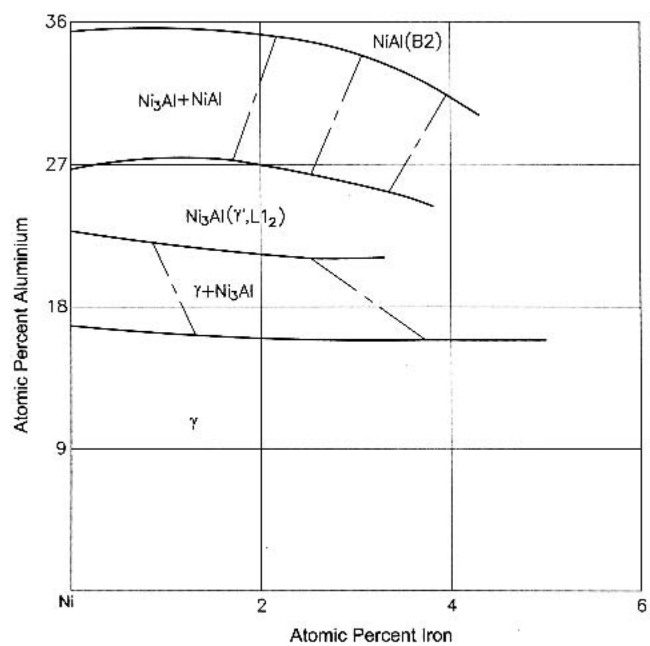

Fig. 1 Al-Fe-Ni partial isothermal section at 1100 °C [1994Jia]

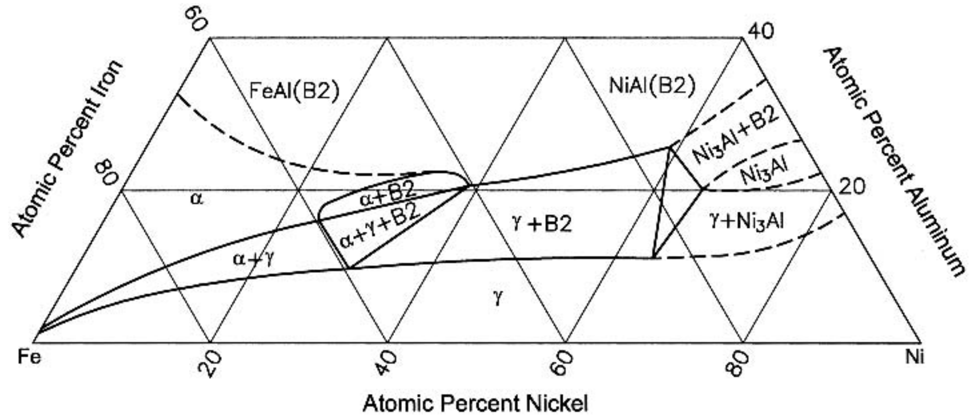

Fig. 2 Al-Fe-Ni isothermal section at 1127 °C [1996Kal]

equilibria were studied by the electron probe microanalysis and x-ray powder diffraction technique. The isothermal section constructed at 1127 °C by [1996Kal] is redrawn in Fig. 2. A small two-phase region of ($B2 + \alpha$) is located in the composition ranges of Fe and Al of 41 to 61 and 17 to 24 at.%, respectively. The second-order $\alpha \rightarrow B2$ transition without a two-phase boundary extends from the Fe-Al side into the ternary region up to ~30 at.% Ni.

Using neutron-diffraction analysis and calorimetric measurements, [1998Gom] constructed a vertical section along the Ni_3Al-Ni_3Fe join. This section is similar to the vertical section reviewed by [1994Rag]. Recently, the solidus temperatures of alloys along the NiAl-FeAl join were redetermined by [2002Bit]. The melting point of the stoichiometric NiAl was found to be 1681 °C, which is 43° higher than the data from the literature. The solidus temperature initially falls steeply at −13 °C/at.% Fe near the NiAl end. Beyond 5 at.% Fe, it changes to a nearly linear decrease of approximately −8.5 °C/at.% Fe.

[1995Shi] made a theoretical analysis of the effect of Fe on the *B*2 phase stability. [2001Tan] measured the variation of the lattice parameter of the *B*2 phase in the ternary region and plotted contour lines of constant lattice parameter as a function of composition. [2000Mar] measured the lattice parameter, density, hardness, and magnetic properties of alloys along the Fe-NiAl join.

References

1982Kha: M. Khaidar, C.H. Allibert, and J. Driole, Phase Equilibria of the Fe-Ni-Al System for Al Content Above 50 at.% and Crystal Structures of Some Ternary Phases, *Z. Metallkde.,* Vol 73 (No. 7), 1982, p 433-438

1987Mas: N. Masahashi, H. Kawazoe, T. Takasugi, and O. Izumi, Phase Relations in the Section Ni_3Al-Ni_3Fe of the Al-Fe-Ni System, *Z. Metallkde.,* Vol 78 (No. 11), 1987, p 788-794

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

1990Ell: M. Ellner and T. Rohrer, On the Structure of the Ternary Phase $FeNiAl_5$, *Z. Metallkde.,* Vol 81(No. 11), 1990, p 847-849 (in German)

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

1993Oka: H. Okamoto, Al-Ni (Aluminum-Nickel), *J. Phase Equilibria,* Vol 14 (No. 2), 1993, 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, 1993, p 256-278

1994Jia: C.C. Jia, K. Ishida, and T. Nishizawa, Partition of Alloying Elements Between γ ($A1$), γ' ($L1_2$), and β ($B2$) Phases in Ni-Al Base Systems, *Metall. Mater. Trans. A,* Vol 25A, 1994, p 473-485

1994Rag: V. Raghavan, Al-Fe-Ni (Aluminum-Iron-Nickel), *J. Phase Equilibria,* Vol 15 (No. 4), 1994, p 411-413

1995Shi: T. Shinoda, Y. Mishima, and T. Suzuki, Phase Stabilities in Some *B*2 Type Ordered Ni-Al-X Alloys, Pt. 1, *Mater. Res. Soc. Symp. Proc.,* 1995, Vol 364, 1995, p 573-578

1996Kal: K.B. Kalmykov, N.E. Rusina, and S.F. Dunaev, Phase Equilibria in the System Al-Fe-Ni at 1400 K, *Vestn. Mosk. Univ. Ser. 2: Khim,* Vol 37 (No. 5), 1996, p 469-473 (in Russian); TR: *Moscow Univ. Chem. Bull.,* Vol 51 (No. 5), 1996, p 37-41

1996Lem: U. Lemmerz, Investigations of the Ternary Alloy Systems Al-Ni-Fe and Al-Cu-Ru with Specific Regard to Quasicrystalline Phases, *Ber. Forschungscentr. Juelich,* Vol 3243, 1996, p 1-124 (in German)

1998Gom: V.I. Gomankov, S.M. Tretyakova, E.V. Monastyrskaya, and L.E. Fykin, Structural Diagrams of Quasi-Binary Alloys Ni_3Fe-Ni_3Al, Ni_3Mn-Ni_3Al, and Ni_3Mn-Ni_3Ga, *Metally,* (No. 6), 1998, p 104-108 (in Russian); TR: *Russ. Metall.,* (No. 6), 1998, p 125-131

2000Mar: G. Marcon and S. Lay, Equilibrium Phases in the Miscibility Gap of the Fe-NiAl System in Connection with the Physical Properties of the Alloys, *Ann. Chim. Sci. Mat.,* Vol 25 (No. 1), 2000, p 21-40 (in French)

2001Miu: S. Miura, H. Unno, T. Yamazaki, S. Takizawa, and T. Mohri, Reinvestigation of Ni-Solid Solution/Liquid Equilibria in Ni-Al Binary and Ni-Al-Zr Ternary Systems, *J. Phase Equilibria,* Vol 22 (No. 4), 2001, p 457-462

2001Tan: Y. Tan, T. Shinoda, Y. Mishima, and T. Suzuki, Stoichiometry Splitting of β Phase in Ni-Al-Mn, Ni-Al-Co and Ni-Al-Fe Systems, *Mater. Trans.,* Vol 42 (No. 3), 2001, p 464-470

2002Bit: H. Bitterlich, W. Loser, and L. Schultz, Reassessment of the Ni-Al and Ni-Fe-Al Solidus Temperatures, *J. Phase Equilibria,* Vol 23 (No. 4), 2002, p 301-304

2004Gru: B. Grushko and T.Ya. Velikanova, Stable and Metastable Quasicrystals in Al-Based Alloy Systems with Transition Metals, *J. Alloy. Compd.,* Vol 367, 2004, p 58-63