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

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In view of the technological importance of this ternary system in the development of high-temperature alloys, magnetic materials, and shape memory devices, it 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]. For a recent detailed summary, the reader is referred to the updated version of [1992Bud] by [2005Cac] and the review of [2006Ele]. [2006Ele] presented assessed experimental information on phase relationships and on thermochemical data, and Calphad-type/CVM calculations. Recently, [2007Chu] reinvestigated the Al-rich region and constructed an isothermal section at 850 °C, five vertical sections and a complete liquidus projection for this region. This update will be limited to the new results of [2007Chu].

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

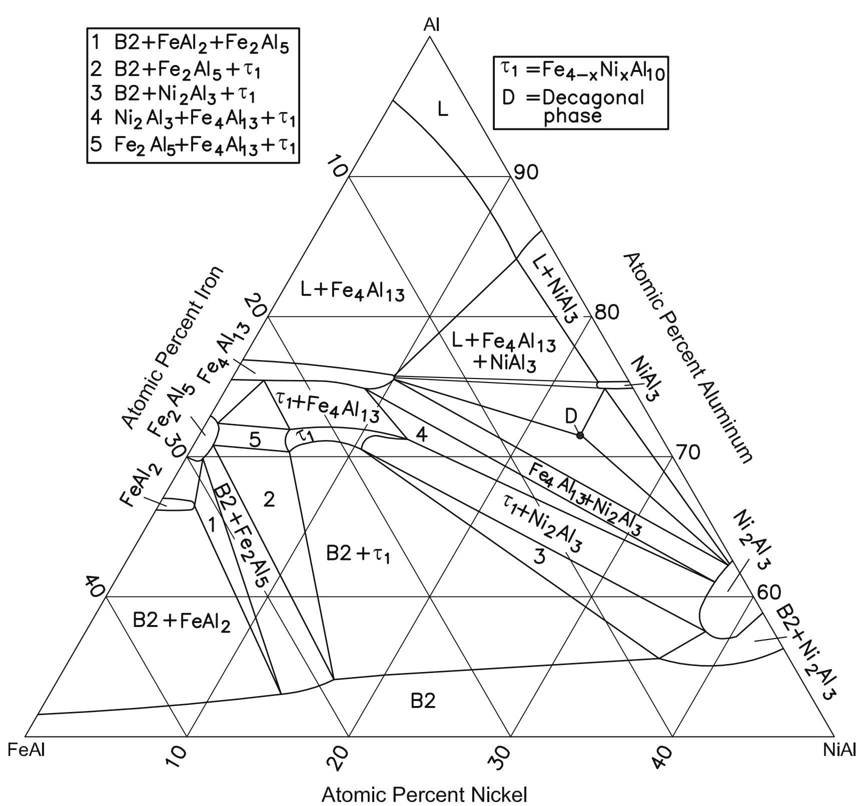

Fig. 1 Al-Fe-Ni isothermal section for Al-rich alloys at 850 °C [2007Chu]

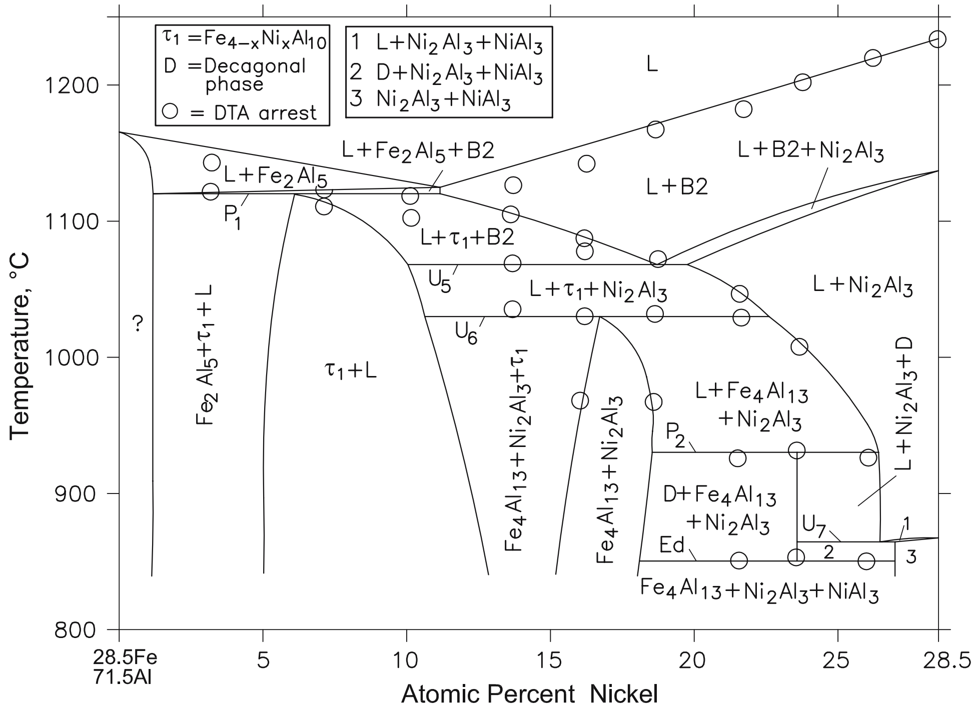

Fig. 2 Al-Fe-Ni vertical section at 71.5 at.% Al [2007Chu]

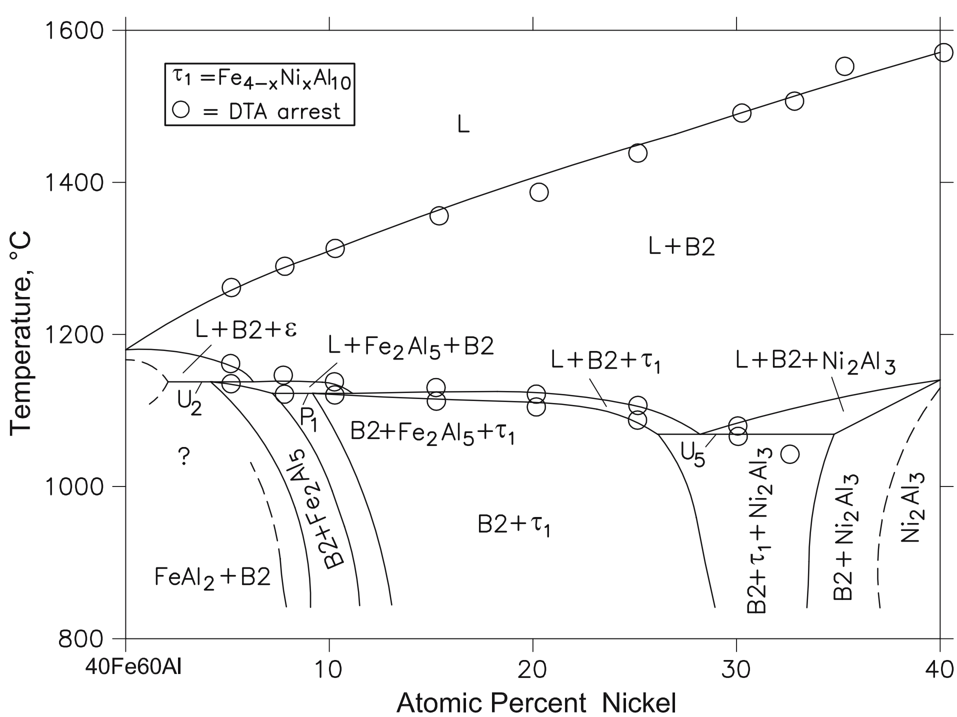

Fig. 3 Al-Fe-Ni vertical section at 60 at.% Al [2007Chu]

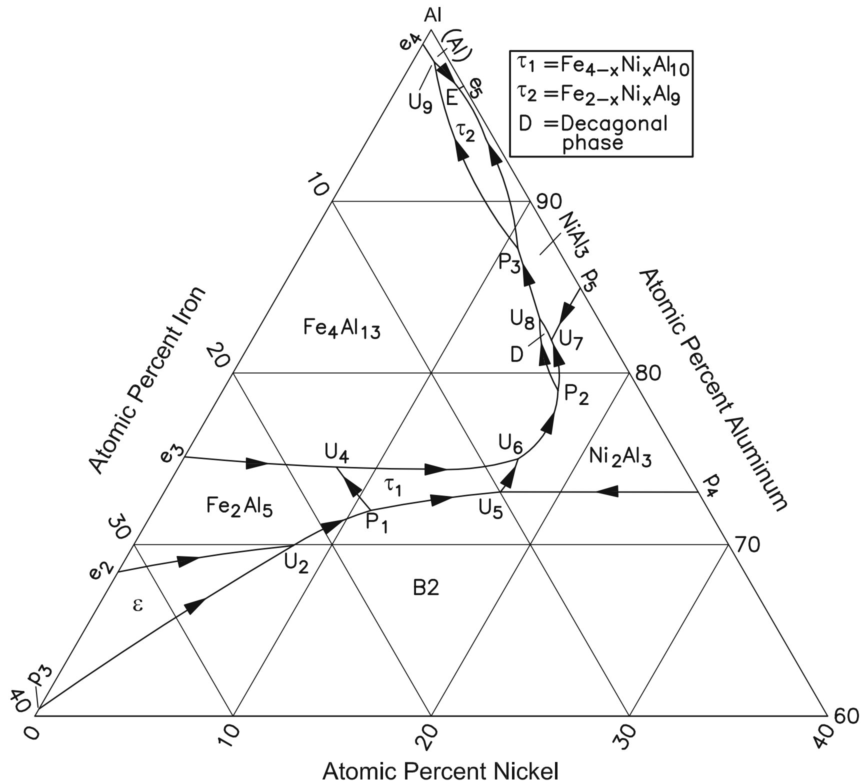

Fig. 4 Al-Fe-Ni liquidus projection for Al-rich alloys [2007Chu]

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 99.99% Ni, [2007Chu] arc-melted under Ar atm 36 ternary compositions. The alloys were annealed at 850 °C for 2-3 weeks and quenched in water. The phase equilibria were studied with x-ray powder diffraction, electron probe microanalysis, and differential thermal analysis (DTA) at heating/cooling rates of 5 °C/min.

The isothermal section constructed by [2007Chu] at 850 °C is shown in Fig. 1. At this temperature, the ternary phase $Fe_{4-x}Ni_xAl_{10}$ (τ_1, denoted as Fe_3NiAl_{10} in earlier references) is stable. It has a homogeneity range of $0.78 \leq x \leq 1.80$ and has the Co_2Al_5-type hexagonal structure with lattice parameters of $a = 0.76781$-0.77049 nm and $c = 0.77131$-0.76432 nm. The quasicrystalline decagonal phase D (denoted q by [2007Chu]) is stable at this temperature and has a fixed composition of $Fe_{4.9}Ni_{23.4}Al_{71.7}$ [2007Chu]. The solubility of Fe and Ni in Ni_2Al_3 and Fe_4Al_{11} is 4 and 11 at.%, respectively. The solubility of the third component in Fe_2Al_5, $FeAl_2$ and $NiAl_3$ is small, between 1 and 2 at.%. Using the DTA results, [2007Chu] constructed five vertical sections at 80, 75, 71.5, 67 and 60 at.% Al, respectively. Figures 2 and 3 show the vertical sections at 71.5 and 60 at.% Al. The reactions at the invariant horizontals are marked. The decagonal phase D is stable between 930 and 850 °C, as seen in the section at 71.5 at.% (Fig. 2), whereas it is not present in the section at 60 at.% Al.

[2007Chu] combined their DTA results with the literature data to construct a complete liquidus surface for the Al-rich region. This is shown in Fig. 4. The ternary phase $Fe_{2-x}Ni_xAl_9$ (τ_2, Co_2Al_9-type monoclinic) forms through the peritectic reaction P_3 at 809 °C. A reaction sequence written by [2007Chu] is given in Fig. 5. For the sake of completion, the reactions in the Al-lean region and the solid-state reactions have been added. No distinction is made between bcc and the ordered forms of bcc. For the liquidus projection in the Al-lean region, see [1988Ray]. The sequential numbering of the reactions in Figs. 4 and 5 follows the usual direction of decreasing temperature and may not tally with that adopted by [2007Chu]. The reaction sequence is consistent with the triangulations in the isothermal section at 850 °C (Fig. 1) and the liquidus projection (Fig. 4).

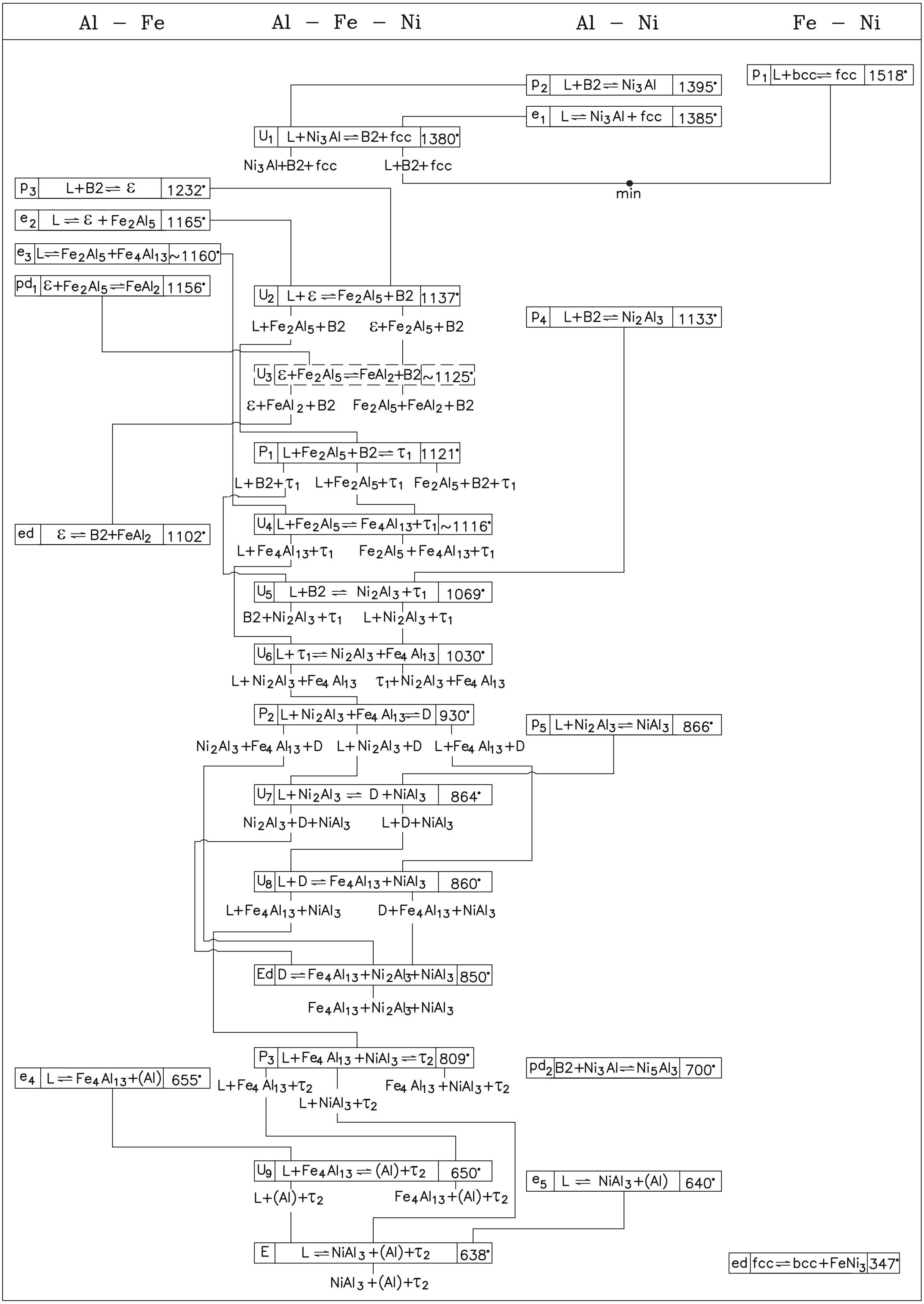

Fig. 5 Al-Fe-Ni reaction sequence during solidification [after 2007Chu]

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