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Fe-Ni-Si (Iron-Nickel-Silicon)

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The first review of this system by [1988Ray] presented a tentative liquidus projection, partial isothermal sections at 1000, 800, 600, and 450 °C for Ni-rich alloys, two computed isothermal sections at 1127 and 727 °C, and a reaction scheme. Two updates gave an additional computed isothermal section at 427 °C [1994Rag] and partial sections in the order-disorder region of Fe-rich alloys at 1200, 1100, 1000, 800, and 650 °C [2003Rag]. Recently, [2004Him] and [2005Him] reinvestigated the Ni-rich region with special reference to the fcc (γ)/$L1_2$ (γ′) equilibria.

Binary Systems

In the Fe-Ni phase diagram, a continuous face-centered cubic solid solution (denoted γ) forms between γFe and Ni and is stable over a wide range of temperature. At 517 °C, an ordered phase $FeNi_3$ ($L1_2$, $AuCu_3$-type cubic) forms congruently from γ. In the Fe-Si system, the Fe-based face-centered cubic phase γ is enclosed by a loop. The intermediate phases are: α_2 ($B2$, CsCl-type cubic), α_1 ($D0_3$, BiF_3-type cubic), Fe_2Si (stable between 1212 and 1040 °C; hexagonal), Fe_5Si_3 ($D8_8$, Mn_5Si_3-type hexagonal), FeSi ($B20$-type cubic), β$FeSi_2$ (tetragonal), and α$FeSi_2$ (orthorhombic). There are a number of intermediate phases in the Ni-Si system: Ni_3Si, $Ni_{31}Si_{12}$, Ni_2Si, Ni_3Si_2, NiSi and $NiSi_2$, with several of these having more than one crystal modification. The phases that appear in the equilibria reviewed here are Ni_3Si ($L1_2$, $AuCu_3$-type cubic) and $Ni_{31}Si_{12}$ (labeled δ; hexagonal). See [Massalski2] for the above phase diagrams.

Ternary Phase Equilibria

With starting metals of 99.9% Fe, 99.9% Ni and 99.999% Si, [2004Him] induction-melted alloys with a constant Ni content of 75 at.%. The alloys were annealed between 900 and 500 °C in the (γ + γ′) and γ′ region. The phase equilibria were studied with optical and transmission electron microscopy and x-ray powder diffraction. The compositions of co-existing phases were determined by the electron probe microanalysis. Differential scanning calorimetry, electrical resistivity, and vibrating-sample magnetometry were also used to determine the phase equilibria and the Curie temperatures. The pseudobinary section along the Ni_3Fe-Ni_3Si join constructed by [2004Him] is shown in Fig. 1. The (γ + γ′) region is broader in this system as compared to that in the Al-Fe-Si system. The Curie temperature of γ′ decreases with increasing Si content.

With starting metals of 99.9% Fe, 99.9% Ni and 99.999% Si, [2005Him] induction-melted ternary alloys

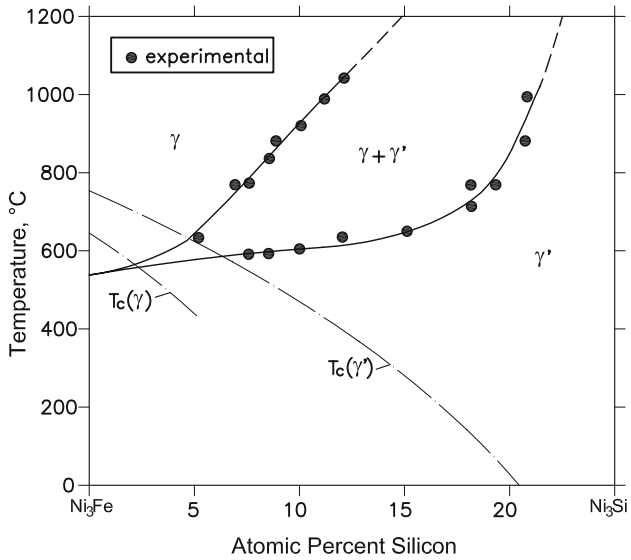

Fig. 1 Fe-Ni-Si pseudobinary section along the Ni_3Fe-Ni_3Si join [2004Him]

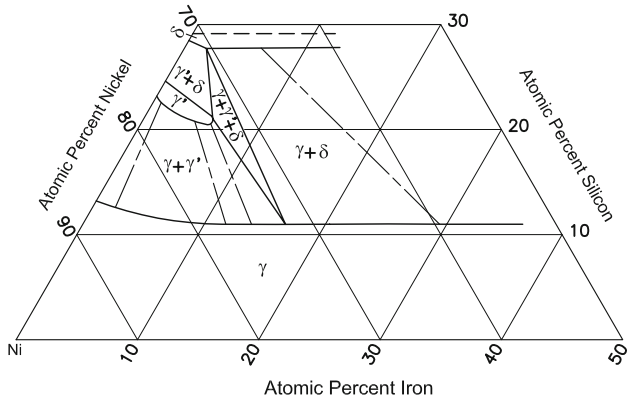

Fig. 2 Fe-Ni-Si partial isothermal section in the Ni-rich region at 900 °C [2005Him]

with Fe and Si in the range of 0-63 and 7-22 at.% respectively. The alloys were annealed between 900 and 700 °C for durations up to 122 d. The partial isothermal sections constructed by [2005Him] at 900, 800 and 700 °C are shown in Fig. 2-4. The homogeneity region of γ′ extends in a direction that lies between the Ni_3Si-Ni_3Fe join and the Ni_3Si-Fe_3Si join. The (γ′ + γ)/γ phase boundary extends approximately parallel to the Ni-Fe side.

Figure 5 and 6 show the γ/(γ + γ′) solvus line determined by electrical resistivity measurements for indicated

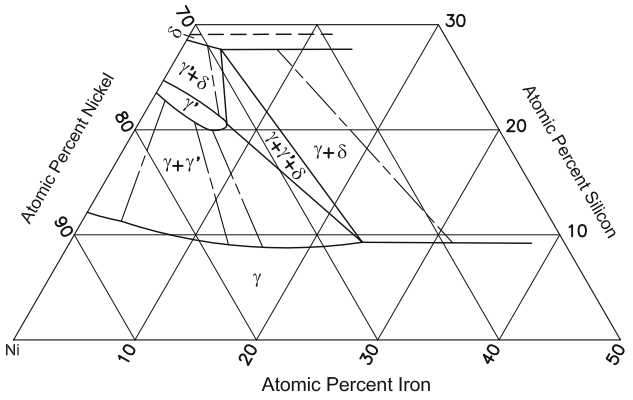

Fig. 3 Fe-Ni-Si partial isothermal section in the Ni-rich region at 800 °C [2005Him]

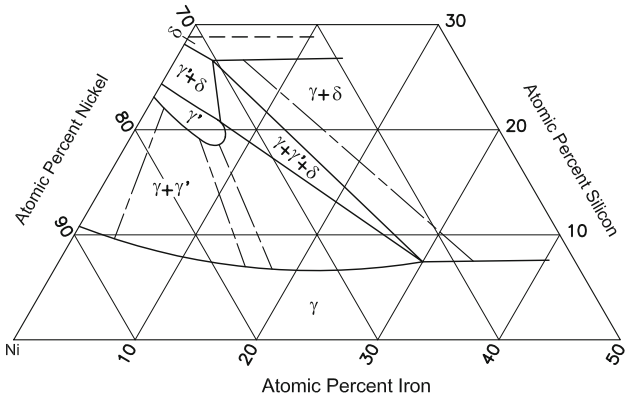

Fig. 4 Fe-Ni-Si partial isothermal section in the Ni-rich region at 700 °C [2005Him]

values of Ni or Si. The solvus shows a monotonic change with Si (Fig. 5), but passes through a maximum at about 75 at.% Ni, when plotted as a function of Fe (Fig. 6). The data of Fig. 5 and 6 can be used to derive the solvus for any temperature and ternary composition of the system within the applicable range.

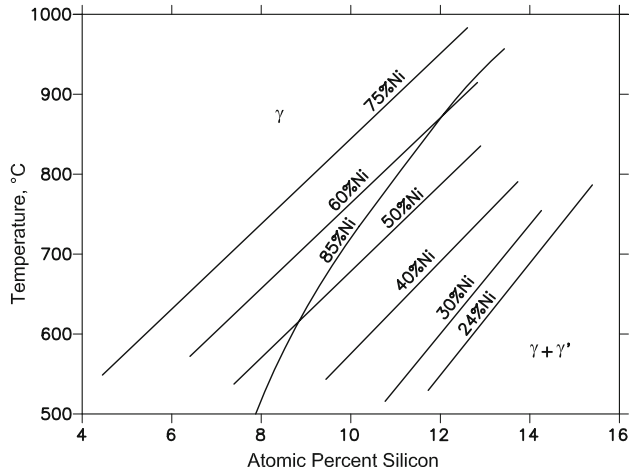

Fig. 5 Fe-Ni-Si $\gamma/(\gamma + \gamma')$ solvus at indicated Ni contents [2005Him]

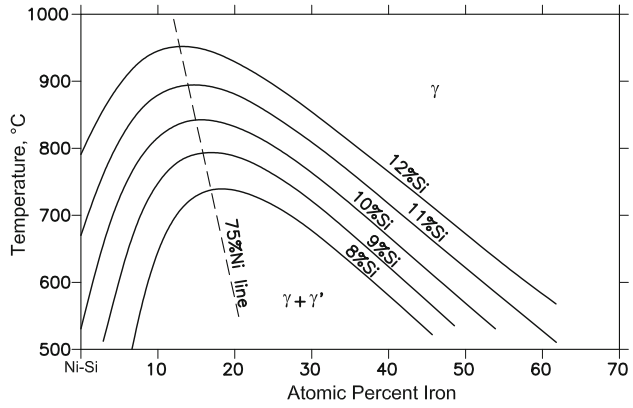

Fig. 6 Fe-Ni-Si $\gamma/(\gamma + \gamma')$ solvus at indicated Si contents [2005Him]

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