JPEDAV (2010) 31:186–189
DOI: 10.1007/s11669-010-9656-1
1547-7037 ©ASM International

Fe-Ni-Ti (Iron-Nickel-Titanium)

V. Raghavan

The review of this system by [1990Gup] pertained mainly to the experimental studies of [1938Vog], [1967Dud] and [1981Loo] and presented a partial liquidus projection for the Ti-lean region, a full isothermal section at 900 °C, partial isothermal sections at 1100, 1027 and 700 °C and four vertical sections at 12 mass% Ti, at Fe:Ni mass ratio 90:10 and 40:60 and along the FeTi-NiTi join respectively. An update by [2001Gup] reviewed the experimental results of [1994Ali], who determined a partial liquidus projection and several vertical sections in the Ti-rich region. Recently, the phase equilibria in Ti-rich alloys were studied by [2006Ria], who presented a partial isothermal section at 900 °C for Ti-rich alloys and a vertical section at 66 at.% Ti. From the same group of workers, [2006Cac] presented a critical evaluation of the system and presented for the entire composition range a liquidus projection, isothermal sections at 1000 °C [1999Abr] and 900 °C [1981Loo] and several vertical sections. Very recently, [2009Key] carried out a thermodynamic assessment of the system, as a sequel to the review by [2006Cac].

Binary Systems

The Fe-Ni phase diagram [1991Swa] is characterized by a very narrow solidification range with a peritectic reaction at 1514 °C, between bcc δ (or α) 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 $FeNi_3$ ($L1_2$, $AuCu_3$-type cubic) forms congruently from γ. At 345 °C, γ decomposes to (α + $FeNi_3$). The Fe-Ti phase diagram [1998Dum] depicts two intermediate phases: Fe_2Ti ($C14$, $MgZn_2$-type hexagonal) and FeTi ($B2$, CsCl-type cubic). The computed Fe-Ti phase diagram of [2009Key] shows a smaller homogeneity range of Fe_2Ti (especially at lower temperatures) than that indicated in earlier reports. The Ni-Ti phase diagram [2009Key] has three intermediate phases: Ni_3Ti ($D0_{24}$, Ni_3Ti-type hexagonal), NiTi ($B2$, CsCl-type cubic) and $NiTi_2$ ($E9_3$-type cubic).

Computed Ternary Phase Equilibria

The liquid and the disordered part of the solid solutions (bcc, fcc and cph) were described as substitutional solutions by [2009Key]. To be applicable in a future modeling of the Al-Fe-Ni-Ti quaternary system, a four sublattice model was used for the ordered fcc phases. An ordering energy term was added to the Gibbs energy term describing the disordering state. The intermetallic phases such as $NiTi_2$, NiTi, Ni_3Ti, FeTi and Fe_2Ti were modeled with two or more sublattices with provision for the ternary solubility, which is appreciable in these phases. The optimized parameters for all the phases were listed.

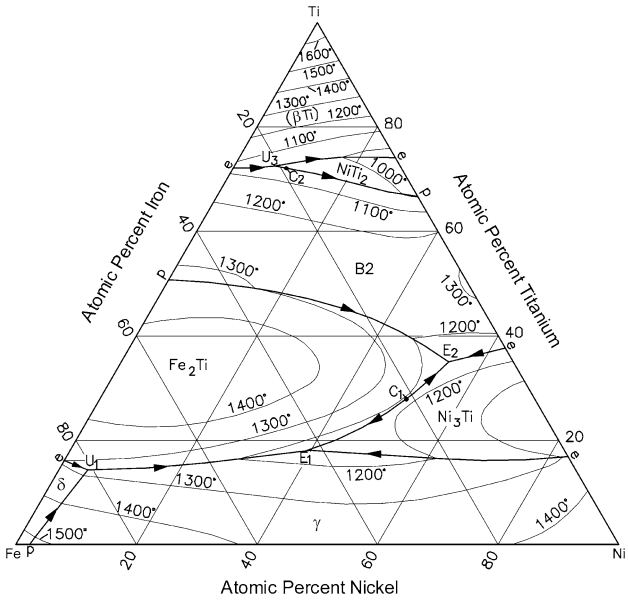

Fig. 1 Fe-Ni-Ti computed liquidus projection [2009Key]

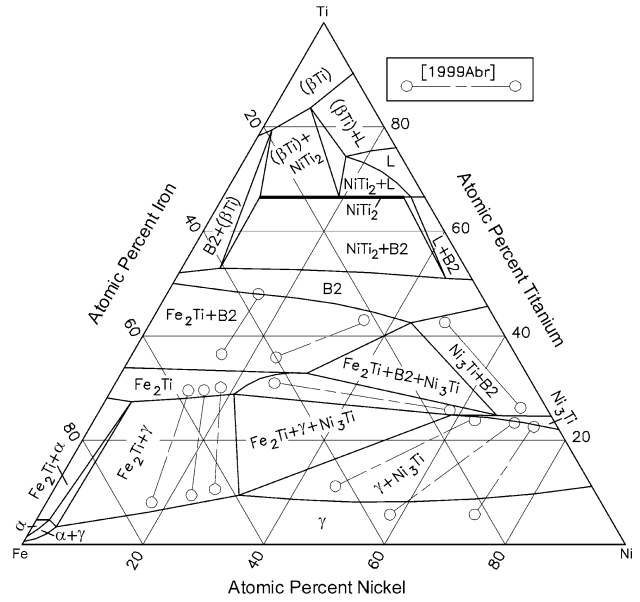

Fig. 2 Fe-Ni-Ti computed isothermal section at 1000 °C [2009Key]

[2009Key] computed a liquidus projection, five isothermal sections at 1300, 1000, 900, 600 and 100 °C, and four vertical sections at 66 at.% Ti, 12 mass% Ti, Fe/Ni atom ratio = 1 and Fe/Ni mass ratio = 4/6, respectively. The calculated sections were compared with the available experimental data from the literature. No experimental data are known for comparison with the isothermal sections computed at 600 and 100 °C. Two metastable isothermal sections at 700 °C depicting the equilibria between the ordered and disordered forms of bcc and fcc respectively were also computed by [2009Key].

The computed liquidus projection is shown in Fig. 1. The monovariant liquidus lines in Fig. 1 generally agree with those evaluated by [2006Cac]. At the Ti-lean region, the

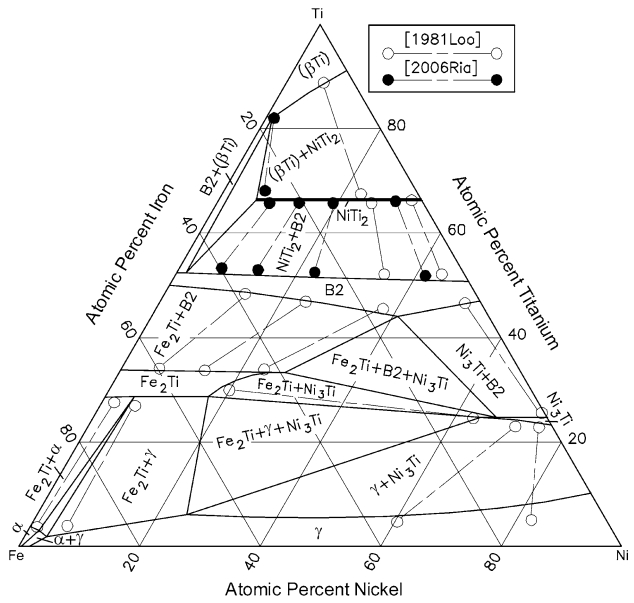

Fig. 3 Fe-Ni-Ti computed isothermal section at 900 °C [2009Key]

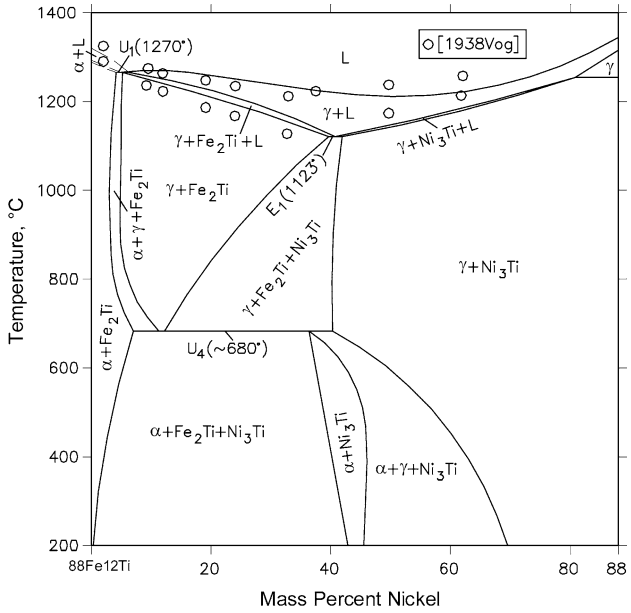

Fig. 5 Fe-Ni-Ti computed vertical section at 12 mass% Ti [2009Key]

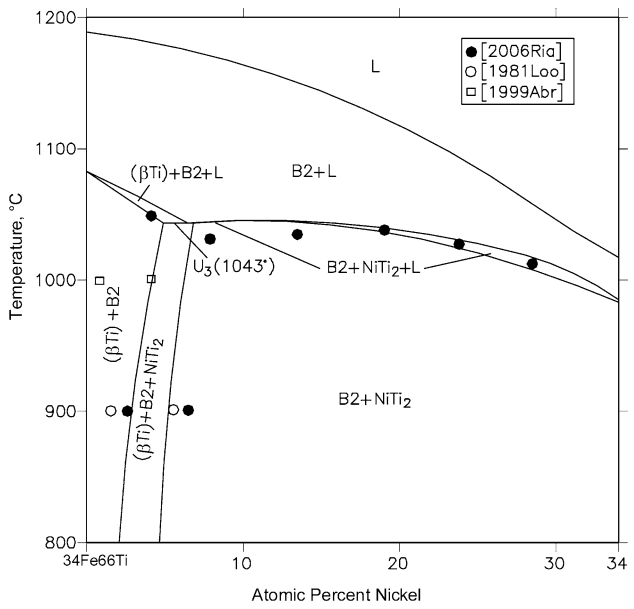

Fig. 4 Fe-Ni-Ti computed vertical section at 66 at.% Ti [2009Key]

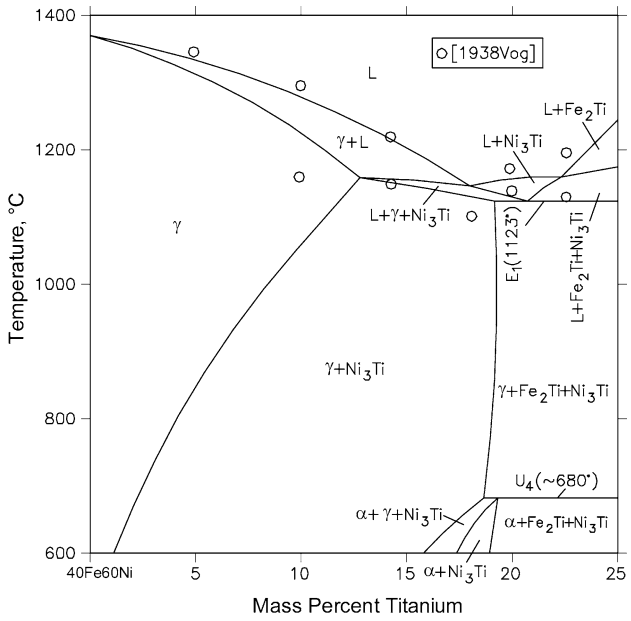

Fig. 6 Fe-Ni-Ti computed vertical section at Fe/Ni mass ratio of 4/6 [2009Key]

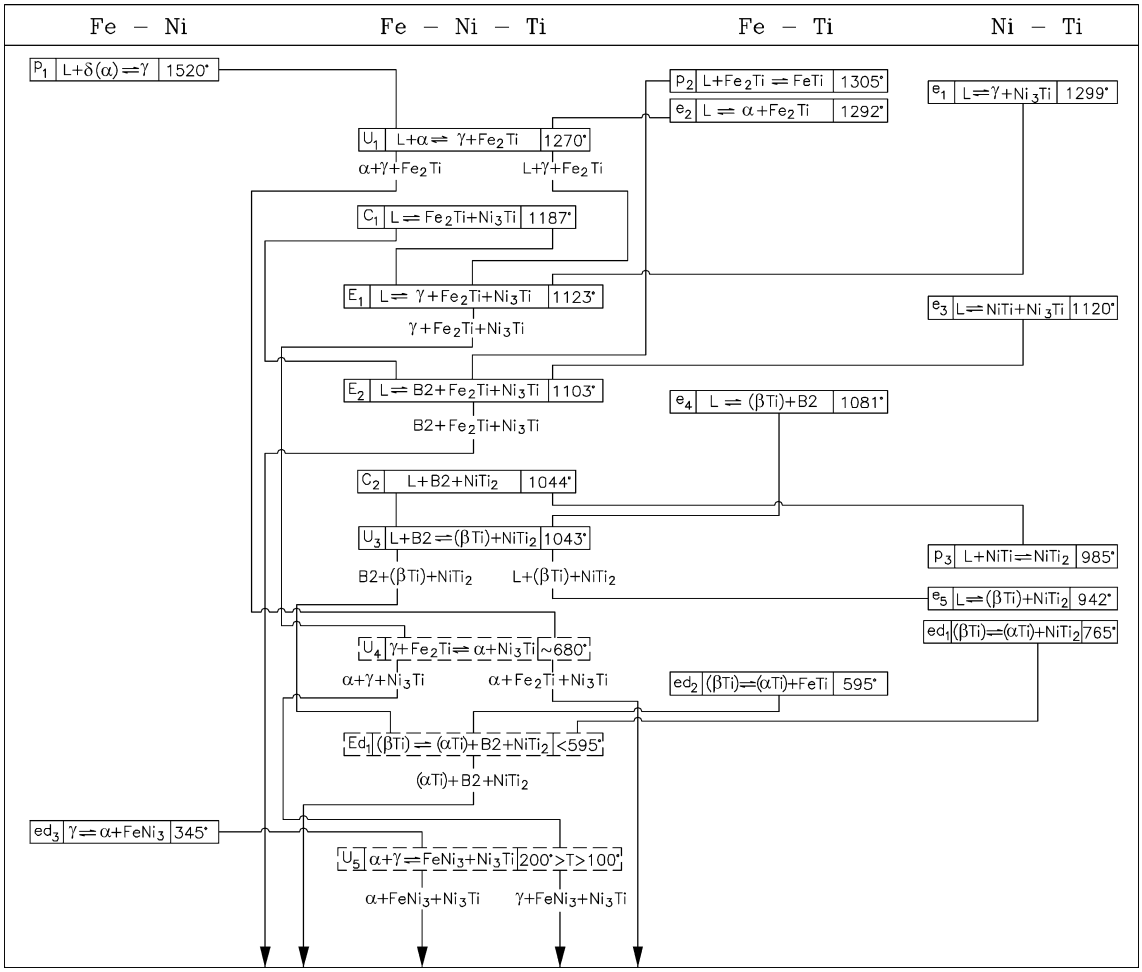

Fig. 7 Fe-Ni-Ti reaction sequence [after 2009Key]

final solidification occurs through two ternary eutectic reactions E_1 and E_2. $NiTi_2$ nucleates in the ternary region at the critical point C_2 [2009Key]. C_2 is very close to the transition reaction U_3 (just 1 °C higher).

The isothermal section computed by [2009Key] at 1300 °C was compared with the experimental results of [1982Dra] in the Ti-lean region. This section is not consistent with the liquidus projection and the reaction scheme given by [2009Key]. The reasons for this anomaly are not clear. The computed isothermal sections at 1000 and 900 °C are shown in Fig. 2 and 3. The agreement with the experimental data is generally good. The isomorphous pair FeTi-NiTi forms a continuous solid solution *B*2 at all temperatures from 1300 to 100 °C.

Three computed vertical sections at 66 at.% Ti, 12 mass% Ti and Fe/Ni mass ratio = 4/6 respectively are shown in Fig. 4-6. The reactions at the invariant horizontals are indicated. The agreement with the experimental data is satisfactory. A reaction sequence written by [2009Key] is shown in Fig. 7. Using the computed isothermal sections at 600 and 100 °C and the vertical sections of [2009Key] as a guide, the reaction sequence has been extended down to room temperature.

References

1938Vog: R. Vogel and H.S. Wallbaum, The System Fe-Ni_3Ti-Fe_2Ti, *Arch. Eisenhuttenwes*., 1938, **12**, p 299-304, in German

1967Dud: L.P. Dudkina and I.I. Kornilov, Equilibrium Diagram of the TiNi-TiFe System, *Russ. Metall*., 1967, (4), p 98-101

1981Loo: F.J.J. van Loo, J.W.G.A. Vroljik, and G.F. Bastin, Phase Relations and Diffusion Paths in the Ti-Ni-Fe System at 900 °C, *J. Less Common Met*., 1981, **77**, p 121-130

1982Dra: S.C. Drake, "Phase Equilibria in the Fe-Ni-Ti System," B.S. Thesis, Massachusetts Institute of Technology, Cambridge, MA, 1982, p 1-34 (quoted by [1990Gup])

1990Gup: K.P. Gupta, The Fe-Ni-Ti (Iron-Nickel-Titanium) System, *Phase Diagrams of Ternary Nickel Alloys. Part 1*, Indian Institute of Metals, Calcutta, 1990, p 321-343

1991Swa: L.J.Swartzendruber, V.P. Itkin, and C.B. Alcock, The Fe-Ni (Iron-Nickel) System, *J. Phase Equilib*., 1991, **12**(3), p 288-312

1994Ali: S.P. Alisova, P.B. Budberg, T.I. Barmina, and N.V. Lutskaya, Ti-TiFe-TiNi System, *Metally*, 1994, (1), p 158-163, in Russian

1998Dum: L.F.S. Dumitrescu, M. Hillert, and N. Saunders, Comparison of Fe-Ti Assessments, *J. Phase Equilib*., 1998, **19**(5), p 441-448

1999Abr: N.L. Abramycheva, I.V. V'yunitskii, K.B. Kalmykov, and S.F. Dunaev, Isothermal Cross-section of the Phase Diagram of the Fe-Ni-Ti System at 1273 K, *Vestn. Mosk. Univ., Ser 2: Khim*., 1999, **40**(2), p 139-143, in Russian

2001Gup: K.P. Gupta, The Fe-Ni-Ti (Iron-Nickel-Titanium) System Update, *J. Phase Equilib*., 2001, **22**(2), p 171-175

2006Cac: G. Cacciamani, J. de Keyzer, R. Ferro, U.E. Klotz, J. Lacaze, and P. Wollants, Critical Evaluation of the Fe-Ni, Fe-Ti and Fe-Ni-Ti Alloy Systems, *Intermetallics*, 2006, **14**, p 1312-1325

2006Ria: P. Riani, G. Cacciamani, Y. Thebaut, and J. Lacaze, Phase Equilibria and Phase Transformations in the Ti-Rich Corner of the Fe-Ni-Ti System, *Intermetallics*, 2009, **14**, p 1226-1230

2009Key: J. de Keyzer, G. Cacciamani, N. Dupin, and P. Wollants, Thermodynamic Modeling and Optimization of the Fe-Ni-Ti System, *CALPHAD*, 2009, **33**, p 109-123