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Al-Ni-Ti (Aluminum-Nickel-Titanium)

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The previous evaluation of this system by [1991Lee], which supersedes that by [1982Nas], presented a liquidus projection, a reaction scheme, a partial isothermal section at 900 °C for Al contents up to 50 at.%, and two full isothermal sections at 1150 and 800 °C. Other evaluations/compilations were done by [1993Bud] and [1995Vil]. Recently, [1999Hun] presented a full isothermal section at 900 °C, based on new experimental results. In a thermodynamic analysis of this system, [1999Zen] computed a liquidus surface and isothermal sections at 1200, 900, and 800 °C.

Binary Systems

The Al-Ni phase diagram [1993Oka] shows five intermediate phases: $NiAl_3$ (Fe_3C-type orthorhombic); Ni_2Al_3 ($D5_{13}$-type hexagonal); NiAl (CsCl-type cubic); Ni_5Al_3 (Ga_3Pt_5-type orthorhombic); and Ni_3Al ($L1_2$, $AuCu_3$-type cubic; also denoted γ'). The temperatures of the peritectic formation of Ni_3Al (1362 °C) and the eutectic solidification of (NiAl + Ni_3Al) (1360 °C) are tentative. Recently, the liquidus and solidus in the (Ni) region were redetermined by [2001Miu]. The solidus temperatures in the NiAl region were determined by [2002Bit]. The phase boundary between (Ni) and (Ni) + Ni_3Al was investigated between 600 and 1200 °C by [2003Ma]. The updated version of the Al-Ti phase diagram [2005Rag] depicts a number of intermediate phases. $TiAl_3$ has two crystal modifications: $TiAl_3$ (high temperature [HT]) ($D0_{22}$-type tetragonal) forms peritectically at 1387 °C and decomposes eutectoidally at 735 °C; and $TiAl_3$ (low temperature [LT]) (tetragonal) forms at ~950 °C and is stable at low temperatures. Ti_5Al_{11} is a superstructure based on the AuCu-type tetragonal phase. It forms peritectically at 1416 °C and decomposes eutectoidally at 995 °C to $TiAl_2$ and $TiAl_3$ (HT). $TiAl_2$ ($HfGa_2$-type tetragonal) forms congruently at 1215 °C from Ti_5Al_{11} and is stable at low temperatures. $Ti_{1-x}Al_{1+x}$ (AuCu-type tetragonal) is stable between 1445 and 1170 °C. Ti_3Al_5 is a low-temperature phase that is stable below 810 °C. TiAl, often designated γ, has the $L1_0$, AuCu-type tetragonal structure and forms peritectically at 1460 °C. (βTi) (body-centered cubic, also denoted β) and liquid undergo a peritectic reaction at 1490 °C to yield (αTi) (close-packed hexagonal, also denoted α). Ti_3Al, commonly called α_2, has the $D0_{19}$, Ni_3Sn-type hexagonal structure and forms congruently from (αTi) at 1176 °C. The Ni-Ti phase diagram [Massalski2] depicts three stable intermediate phases: Ni_3Ti ($D0_{24}$-type hexagonal; also denoted η); NiTi ($B2$-type cubic); and $NiTi_2$ (cubic).

Ternary Compounds

The crystal structure data on the four ternary compounds of this system are summarized in Table 1 from [1999Hun]. $Al_{13}Ni_2Ti_5$ (τ_1; denoted π by [1991Lee]) has the $L1_2$, $AuCu_3$-type cubic structure. Al_2NiTi (τ_2; denoted μ by [1991Lee]) with a significant homogeneity range is of the $D8_a$, Th_6Mn_{23}-type cubic structure. $Al_{30\text{-}50}Ni_{28\text{-}16}Ti_{42\text{-}34}$ (τ_3; denoted λ by [1991Lee]) is the $MgZn_2$-type hexagonal phase. The structural features of τ_3 are discussed in detail by [1999Hun]. The atom site occupancy is complex, with the occurrence of both Ti/Al and Ni/Al substitution. The phase field has a banana shape. $AlNi_2Ti$ (τ_4; denoted H by [1991Lee]) is an $L2_1$, Heusler-type cubic compound.

Liquidus Projection

With starting metals of purity >99.9%, [1999Hun] arc melted about 40 alloy samples under an Ar atmosphere. The phase equilibria were studied by optical and electron metal-

Table 1 Al-Ni-Ti crystal structure and lattice parameter data

Phase	Composition, at.%	Pearson symbol	Space group	Prototype	Lattice parameters, nm
$Al_{13}Ni_2Ti_5$ (τ_1)	~64-66 Al ~7-10 Ni ~24-29 Ti	*cP*4	$Pm\bar{3}m$	$AuCu_3$	a = 0.3931-0.3939
Al_2NiTi (τ_2)	~49-57 Al ~22-26 Ni ~21-25 Ti	*cF*116	$Fm\bar{3}m$	$Mn_{23}Th_6$	a = 1.6788-1.6906
Al_3NiTi_2 (τ_3)	~30-50 Al ~16-27 Ni ~33-43 Ti	*hP*12	$P6_3/mmc$	$MgZn_2$	a = 0.4997-0.5026 c = 0.8048-0.8233
$AlNi_2Ti$ (τ_4)	~21-33 Al ~48-53 Ni ~16-28 Ti	*cF*16	$Fm\bar{3}m$	$AlCu_2Mn$	a = 0.5876-0.5950

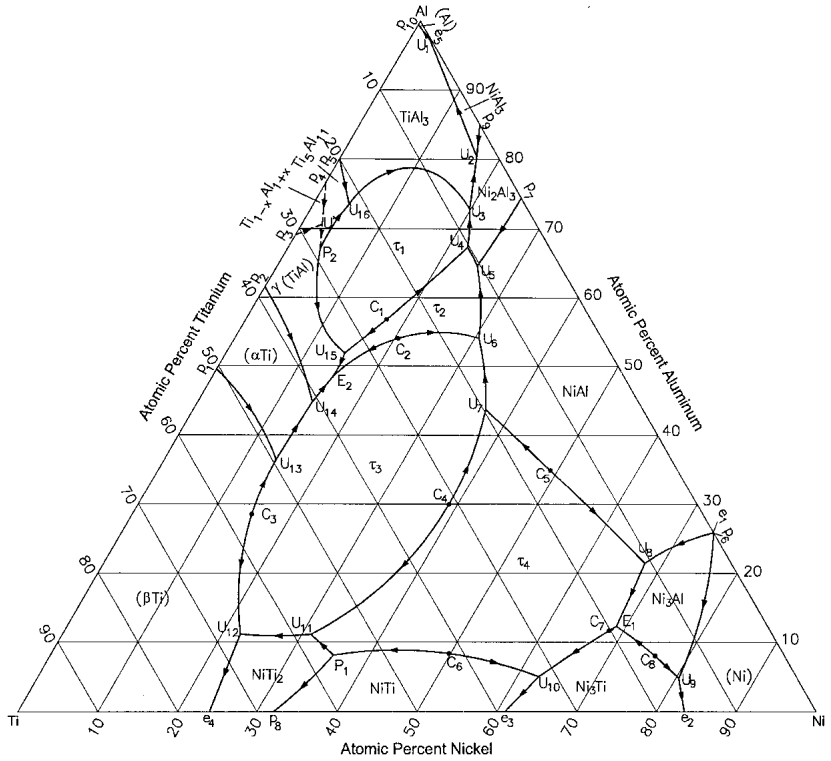

Fig. 1 Al-Ni-Ti computed liquidus projection [1999Zen]

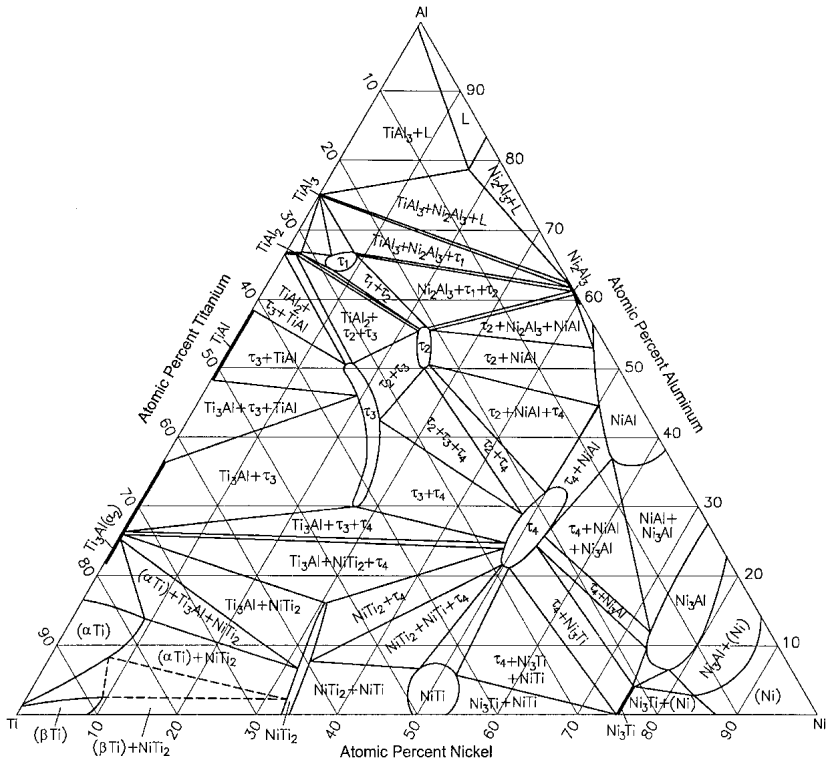

Fig. 2 Al-Ni-Ti isothermal section at 900 °C [1999Hun]

lography, x-ray powder diffraction, and electron probe microanalysis. Using the experimental results of [1999Hun], [1999Zen] carried out a thermodynamic analysis of the system and computed a liquidus surface. This surface is quite different from the one evaluated by [1991Lee]. [1999Hun] and [1999Zen] found that all of the four ternary phases (τ_1

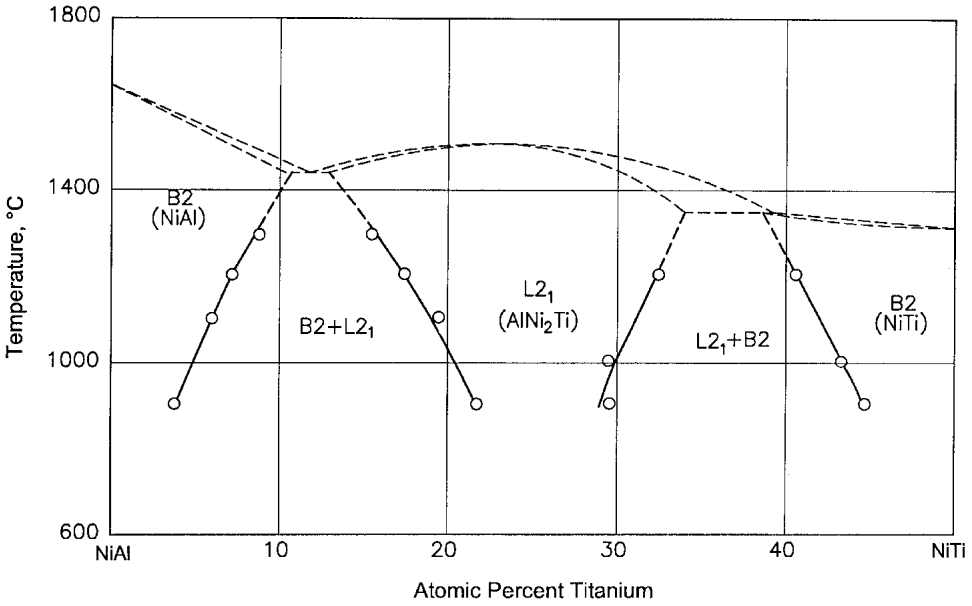

Fig. 3 Al-Ni-Ti pseudobinary section along the NiAl-NiTi join [1997Ohi]

through τ_4) crystallize from the liquid and occupy rather large areas of primary crystallization on the surface. In contrast, [1991Lee] found that, of the four ternary phases, only τ_4 (denoted H by [1991Lee]) crystallizes as a primary phase. The conclusions of [1999Zen] appear to depend mainly on metallographic observations, with no supporting evidence from thermal analysis experiments. The computed liquidus surface of [1999Zen] is redrawn tentatively in Fig. 1. [1999Zen] listed the computed temperatures of the invariant reactions and the computed compositions of the liquid taking part in the reactions. If a reaction sequence is written on the basis of the liquid-solid reactions and the computed isothermal sections of [1999Zen], it will be quite different from that given by [1991Lee]. This exercise is deferred, pending further confirmation of the solidification features of this system.

Isothermal Sections

[1999Hun] annealed about 40 alloy compositions at 900 °C for 240 h, followed by water quenching. Using the experimental techniques listed above, they constructed an isothermal section at 900 °C, which is redrawn in Fig. 2. All of the four ternary phases are present at 900 °C. Their composition ranges, however, differ significantly from those reviewed by [1991Lee]. In contrast to the results of [1991Lee], no tie lines were found between $NiTi_2$ and τ_3 by [1999Hun]. The isothermal section at 927 °C (1200 K) determined by [1997Xu] has a triangulation identical to that of [1991Lee], which suggests a U-type transition reaction $NiTi_2 + \tau_3 \rightarrow Ti_3Al + \tau_4$ between 927 and 900 °C. Other investigations of the partial phase equilibria at 900 °C were done been conducted by [1992Yan], [1995Hsi], and [1996Bau]. Partial isothermal relations were also reported by [1989Maz] (1200 °C), [1992Dur] (1027 °C), and [2000Kai] (1300, 1200, and 1000 °C). [1999Zen] compared

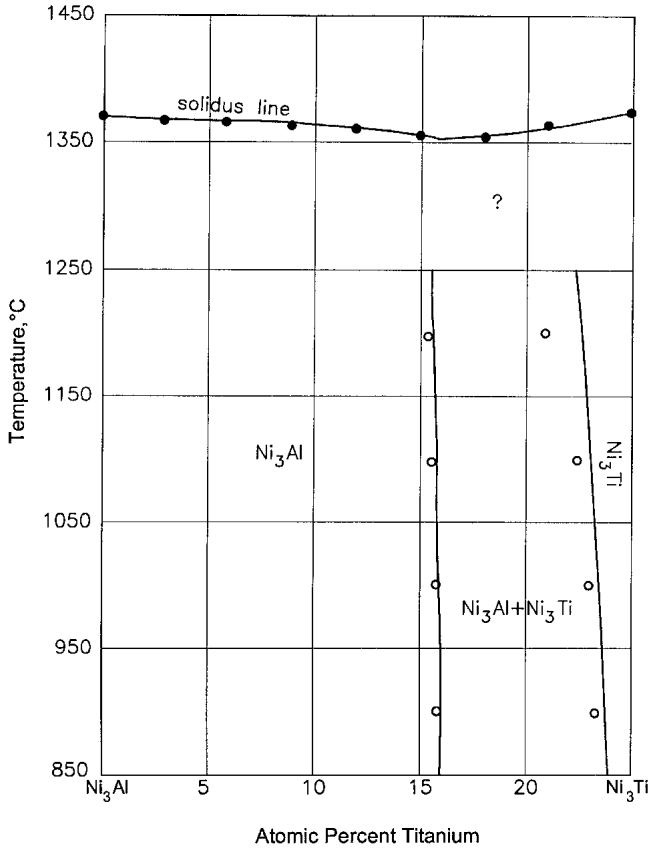

Fig. 4 Al-Ni-Ti pseudobinary section along the Ni_3Al-Ni_3Ti join [1992Yan, 1996Kap]

a calculated isothermal section at 900 °C with the experimental diagram in Fig. 2 (900 °C). Two more computed isothermal sections at 1200 and 800 °C were presented by [1999Zen].

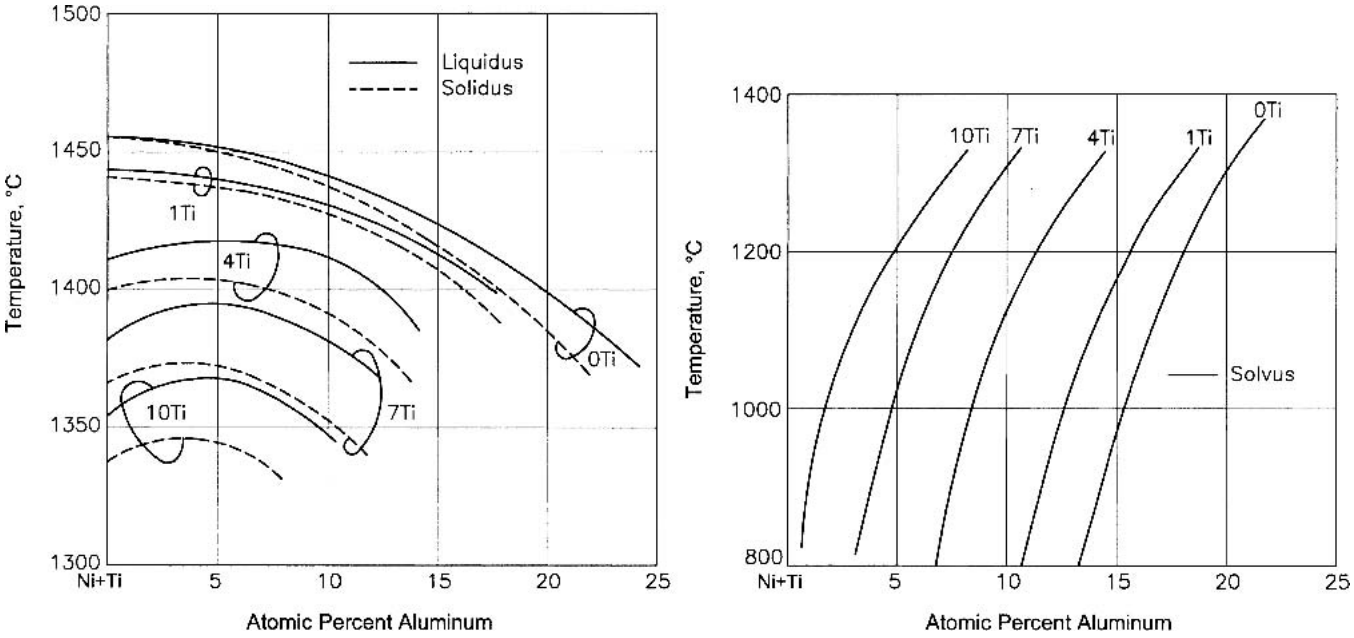

Fig. 5 Al-Ni-Ti liquidus, solidus, and solvus temperatures of γ (Ni) [1999Miu]

Vertical Sections

A partial pseudobinary section along the NiAl-NiTi join was determined by [1997Ohi] and [2002Ish]. The results of [1997Ohi], obtained by electron probe microanalysis, are shown in Fig. 3. The phase boundaries are in satisfactory agreement with several calculated results. The experimental boundaries are extended schematically in Fig. 3 to complete the section. The vertical section along the Ni_3Al-Ni_3Ti join was determined by [1967Min] and is reviewed in [1995Vil]. [1992Yan] computed a partial vertical section along this line (Fig. 4) and compared it with some unpublished experimental results. The experimental solidus temperatures along this join determined by [1996Kap] are also shown in Fig. 4.

Employing differential thermal analysis, [1999Miu] determined the liquidus and solidus temperatures in the region of the primary crystallization of (Ni) as a function of Al and V, as well as the solvus temperatures of (Ni). These are shown in Fig. 5.

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