JPEDAV (2008) 29:194–197
DOI: 10.1007/s11669-007-9016-y
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The Nb-Ni-Ti (Niobium-Nickel-Titanium) System—Update

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Nb-Ni-Ti system was reviewed by [1991Gup] on the basis of experimental data available till 1988. Recently, a complete isothermal section of the Nb-Ni-Ti system at 900 °C was established and is reported here.

Binary Systems

The binary systems Nb-Ni, Nb-Ti, and Ni-Ti were reviewed earlier, and the accepted phase diagrams are those given by [Massalski2] (Fig. 1-3). For the purpose of discussing the new results of the Nb-Ni-Ti system, it is relevant to mention the binary phases that exist in the three binary systems at 900 °C. The Nb-Ni system has three intermediate phases: the Nb_7Ni_6 (μ), $NbNi_3$ (π), and $NbNi_8$ (δ); the δ phase exists at $T < 535$ °C. Three intermediate phases exist in the Ni-Ti system: Ni_3Ti (ρ), NiTi (β), and $NiTi_2$ (ζ); all three phases exist at 900 °C. The Nb-Ti system is an isomorphous system with Nb and Ti forming a body-centered cubic (bcc) solid solution α at all compositions. The bcc βTi → cph αTi transformation occurs at the Ti side at $T < 765$ °C.

Binary and Ternary Phases

In the review of the Nb-Ni-Ti system [1991Gup] used the available experimental data of [1958Kor], [1966Vuc], and [1966Pry]. While [1958Kor] and [1966Vuc] studied the $NbNi_3$-Ni_3Ti section of the Nb-Ni-Ti system, [1966Pry] studied the Ni-rich region (up to 50 at.% Nb and 50 at.% Ti) of the ternary system and established two partial isothermal sections at 1000 and 900 °C. [1958Kor], using thermal analysis, metallography, electrical resistivity, and hardness measurements on a series of $Ni_3(Nb,Ti)$ alloys, suggested the existence of an isomorphous system with a minimum of 1285 °C at ~19 at.% Ti. An isomorphous pseudo-binary in $NbNi_3$-Ni_3Ti system is, however, not possible because the two terminal phases are not isostructural. A probable peritectic-type pseudo-binary that needs experimental verification was suggested by [1991Gup] for the $NbNi_3$-Ni_3Ti system. The ternary intermediate phase reported by [1966Vuc] and [1966Pry] are given in Table 1.

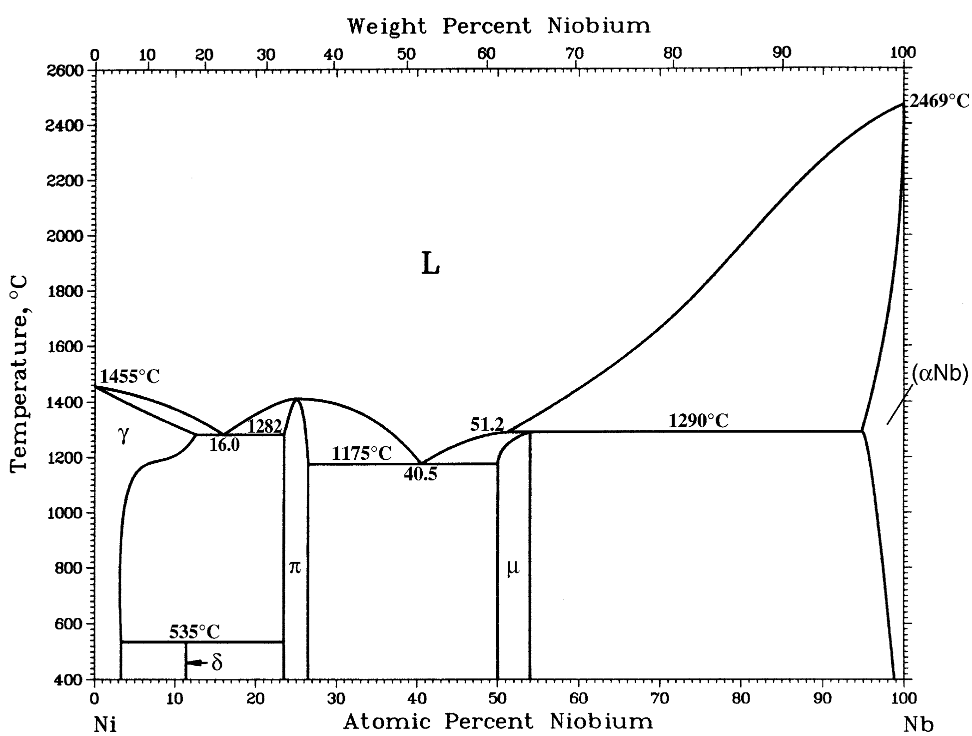

Fig. 1 Binary Nb-Ni system [Massalski2]

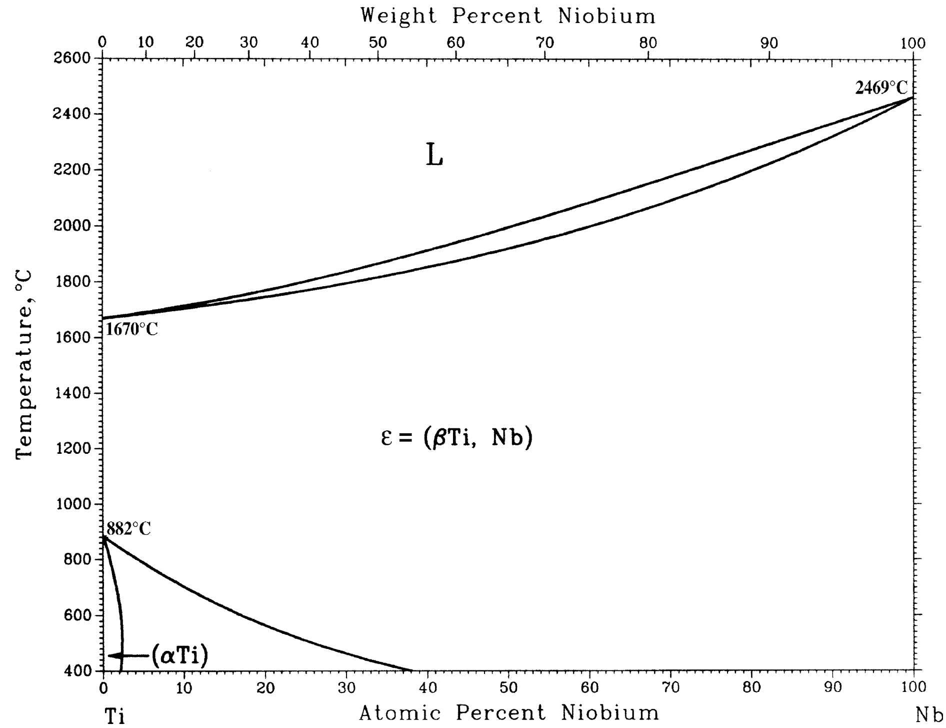

Fig. 2 Binary Nb-Ti system [Massalski2]

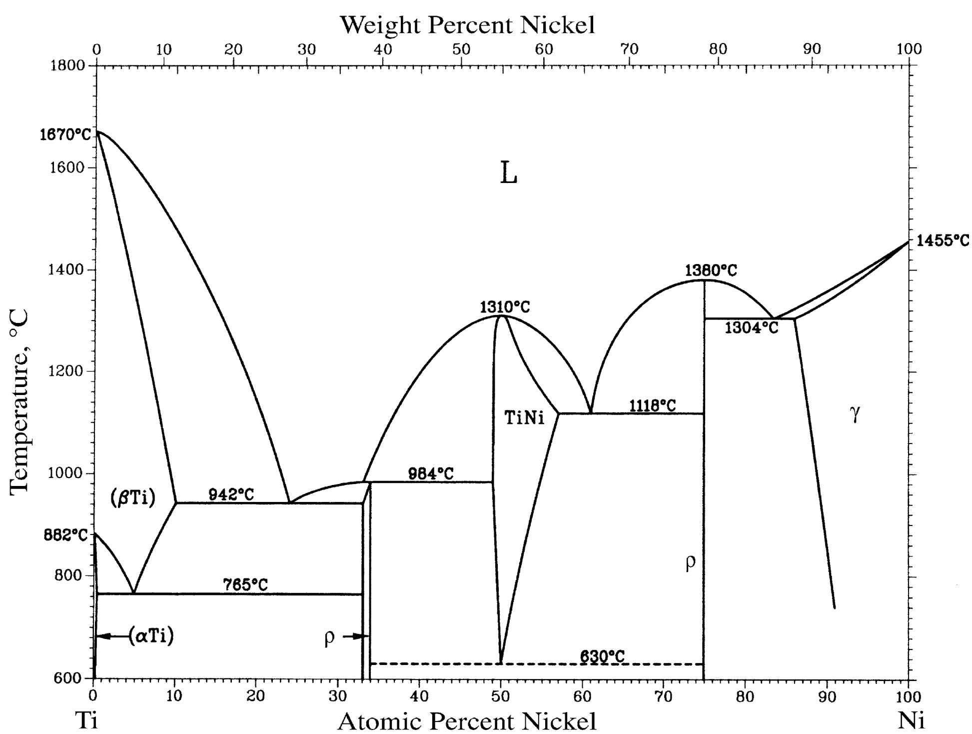

Fig. 3 Binary Ni-Ti system [Massalski2]

Ternary System

The Nb-Ni-Ti system has been studied recently by [2000Gua] at 900 °C using a diffusion couple technique. For this study five binary alloys—$Ti_{80}Ni_{20}$ (TN_2), $Ti_{70}Ni_{30}$ (TN_3), TiNi, $Nb_{25}Ni_{75}$ (Ni_3Nb), and (Ni_6Nb_7)—were arc melted using 99.99 mass-% pure component elements. Slices of these alloys and of pure Ni and Ti were prepared

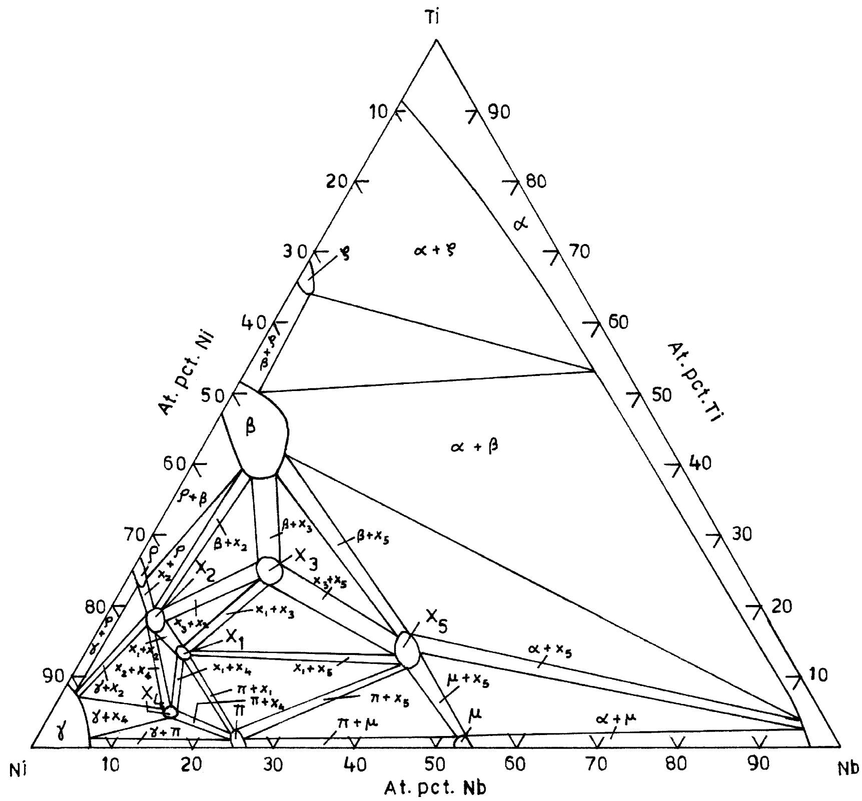

Fig. 4 The 900 °C isothermal section of the Nb-Ni-Ti system [2000Gua]

Table 1 Phases present in the Nb-Ni-Ti system and their structure data

Phase designation	Composition	Pearson's symbol	Space group	Type	Lattice parameter, nm		
					a	*b*	*c*
α	(β Ti,Ni), (β Ti,Nb)	*cI*2	$Im\bar{3}m$	W	...	...	...
γ	(Ni)	*cF*4	$Fm\bar{3}m$	Cu	...	...	...
ε	(α Ti,Ni), (α Ti,Nb)	*hP*2	$P6_3/mmc$	Mg	...	...	...
δ	$NbNi_8$	*tI*18	...	$NbNi_8$	1.08	...	0.36(a)
π	$NbNi_3$	*oP*8	*Pmmm*	Cu_3Ti	0.5116	0.4259	0.4565
μ	Nb_7Ni_6	*hR*13	$R\bar{3}m$	W_6Fe_7	0.4893	...	2.664(b)
ρ	Ni_3Ti	*hP*16	$P6_3/mmc$	Ni_3Ti	0.5101	...	0.8307
β	NiTi	*cP*2	$Pm\bar{3}m$	CsCl	0.3015	...	...
ζ	$NiTi_2$	cF96	$Fd\bar{3}m$	CFe_3W_3	1.1324	...	...
X_1(c)	$Nb_{13}Ni_{75}Ti_{12}$	*h*	...	...	0.257	...	0.422
X_2	$Nb_5Ni_{75}Ti_{20}$	...	...	...	...	...	...
X_3	$Nb_{15}Ni_{56}Ti_{29}$	*o*	...	...	0.879	1.187	0.881
X_4	$Nb_{15}Ni_{80}Ti_5$	...	...	...	...	...	...
X_5	$Nb_{40.3}Ni_{45.1}Ti_{14.6}$	...	...	...	...	...	...
Z_1(d)	$Nb_{0.75}Ni_{75}Ti_{24.25}$	*h*	...	...	0.5106	...	2.081
Z_2	$Nb_{2.75}Ni_{75}Ti_{22.25}$	*hR*	...	$BaPb_3$	0.5118	...	1.8809
Z_3	$Ni_{8.25}Ni_{75}Ti_{16.75}$	*h*	...	Ni_3Sn	0.5130	...	0.4211(e)

(a) Lattice parameter of face-centered tetragonal (fct) cell with 36 atoms/cell. (b) Lattice parameter of hexagonal cell with 39 atoms/cell. (c) X_n with n = 1-4 from [1966Pry] and X_5 from [2000Gua]. (d) Z_n phases are from [1966Vuc]; Z_1 and Z_2 existed only in the as-cast state of the alloys. (e) Probably the same phase as X_1 with doubled *a* parameter by spark erosion, mechanically polished, and resistance welded in vacuum to form the following diffusion couples: (TiNi-Nb_6Ni_7)/Ni, (TiNi-Ni_3Nb)/Ni, (TiNi-TN_3)/Ni, (Ti-TN_2)/TiNi, (TiNi-TN_3)/Ni, and (Ti-TN_3)/TiNi. The diffusion couples, sealed in evacuated silica capsules, were annealed for 400 h at 900 °C and water quenched. The diffusion zones of the various couples were examined metallographically, and an electron probe microanalyzer (EPMA) was used to determine the concentration penetration curves for each element to identify the phases present in the diffusion zones and to determine the tie lines of phases in equilibrium. The 900 °C isothermal section by [2000Gua] is given in Fig. 4.

Figure 4 shows the presence of all the binary phases existing at 900 °C, that is, the ρ, β, ζ, π, and μ phases. Extension of all the binary phases, except the β phase, is <5 at.% Nb or Ti. The β phase extends up to ~10 at.% Nb. A small face-centered cubic (fcc) γ -phase region exists at the Ni corner. The bcc α phase region extends from the Nb corner to the Ti corner; the solubility of Ni in the α phase is smaller at the Nb side than at the Ti side. In this investigation the presence of a new ternary phase X_5 was found between the Nb_7Ni_6 and NiTi phase at ~$Nb_{40}Ni_{45}Ti_{15}$ composition. The other intermediate phases found in this investigation are X_1, X_2, and X_3, which were reported earlier by [1966Pry]. The X_4 phase region was not found due to the choice of diffusion couples, and it is shown in Fig. 4 on the basis of the results of [1966Pry]. The new ternary intermediate phase X_5 is in equilibrium with the α, μ, β, X_3, X_1, and π . The bcc α phase is found in equilibrium with the ζ, β, X_5, and μ phases. The X_3 phase is in equilibrium with the β, X_2, X_1, and X_5 phases. The X_2 phase is in equilibrium with the fcc γ, ρ, X_4, X_1, and X_3 phases. The X_1 phase is in equilibrium with the X_2, X_4, π, X_5, and X_3 phases, The X_4 phase is in equilibrium with the γ, X_2, X_1, and π phases. Whether the X_5 phase also exists at 1000 °C is unknown. The crystal structures of the phases were not determined by [2000Gua].

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# indicates presence of phase diagram.

Nb-Ni-Ti evaluation contributed by **K.P. Gupta**, The Indian Institute of Metals, Metal House, Plot 13/4, Block AQ, Sector V, Calcutta, India. Literature searched through 2000. Dr. Gupta is the Alloy Phase Diagram Co-Category Program Editor for ternary nickel alloys.