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The Ni-Ru-Ti (Nickel-Ruthenium-Titanium) System

K.P. Gupta, The Indian Institute of Metals

The Ni-Ru-Ti system has been studied only to a limited extent. Only one pseudobinary section, between the two equiatomic phases NiRu and NiTi, has been established.

Binary Systems

The Ni-Ru system [1991Nas] (Fig. 1) seems to be a simple peritectic system, with the peritectic reaction L + (Ru) ↔ (Ni) occurring at 1550 °C. The (Ru) and (Ni) solid solution phase regions are quite wide at the peritectic reaction temperature, ~50 at.% Ni in Ru and ~34.5 at.% Ru in Ni, but the solubilities of Ru in Ni and of Ni in Ru decrease reasonably rapidly with decreases in temperature.

The Ni-Ti system [1991Nas] (Fig. 2) has three intermediate phases, Ni_3Ti, NiTi, and $NiTi_2$, of which the Ni_3Ti and NiTi phases melt congruently at 1380 °C and 1310 °C, respectively. The $NiTi_2$ phase forms through a peritectic reaction, L + NiTi ↔ $NiTi_2$, at 984 °C. The Ni_3Ti phase is a stoichiometric single-composition phase, and the $NiTi_2$ phase has limited solid solubility (~1 at.%). The NiTi phase possibly goes through a eutectoid decomposition, NiTi ↔ Ni_3Ti + $NiTi_2$, at ~600 °C. A martensitic transformation occurs in the NiTi phase and has martensite start (M_S) at ~60 °C. Three eutectic reactions, L ↔ (Ni) + Ni_3Ti, L ↔ Ni_3Ti + NiTi, L ↔ $NiTi_2$ + βTi, and one eutectoid reaction, βTi ↔ $NiTi_2$ + αTi, occur at 1304, 1118, 942, and 765 °C, respectively.

The Ru-Ti system [Massalski2] has only one intermediate-phase RuTi, which melts congruently at ~2130 °C. Two eutectic reactions, L ↔ (Ru) + RuTi and L ↔ βTi + RuTi, occur at ~1825 and 1575 °C, respectively. In the wide βTi-phase field (up to ~25 at.% Ru), a solidus-liquidus minimum of ~1550 °C occurs at ~15 at.% Ru. The βTi ↔ αTi transformation occurs at and below 882 °C.

Binary and Ternary Phases

There are only four binary intermediate phases in the three binaries Ni-Ru, Ni-Ti, and Ru-Ti. No ternary intermediate phase is known to form in the Ni-Ru-Ti system. The structure data for the binary phases are given in Table 1.

Ternary System

NiTi and RuTi are both isostructural phases with a CsCl-type structure having very similar lattice parameters. Hence, one should expect a complete solid solubility of the two phases in each other. An isopleth for the NiTi-RuTi system was, however, reported by [1980Bor] (as was mentioned by

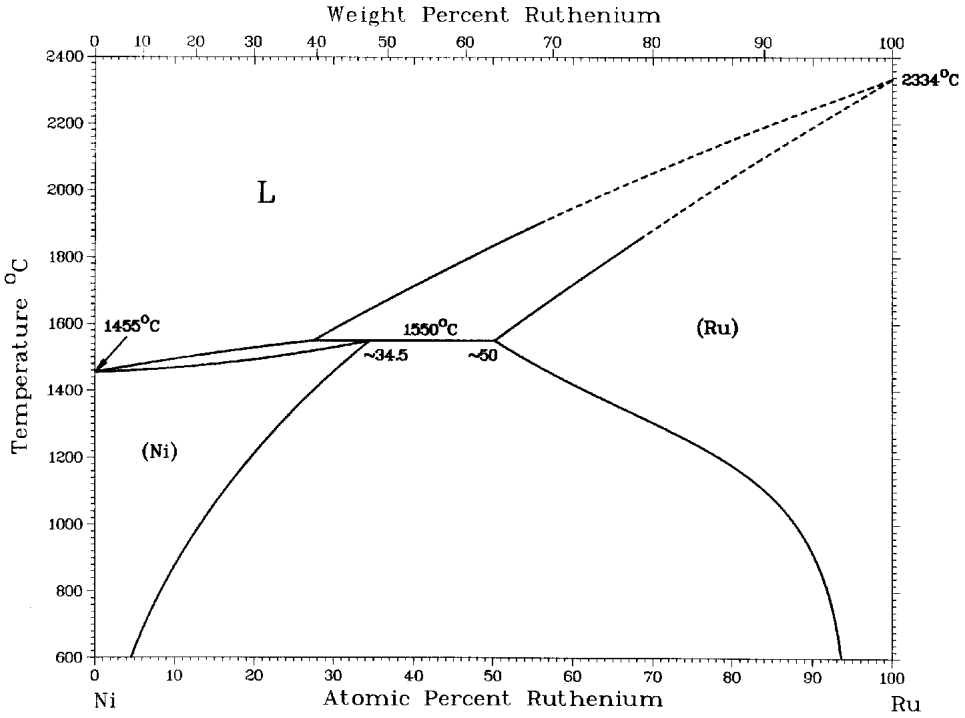

Fig. 1 Ni-Ru phase diagram [1991Nas]

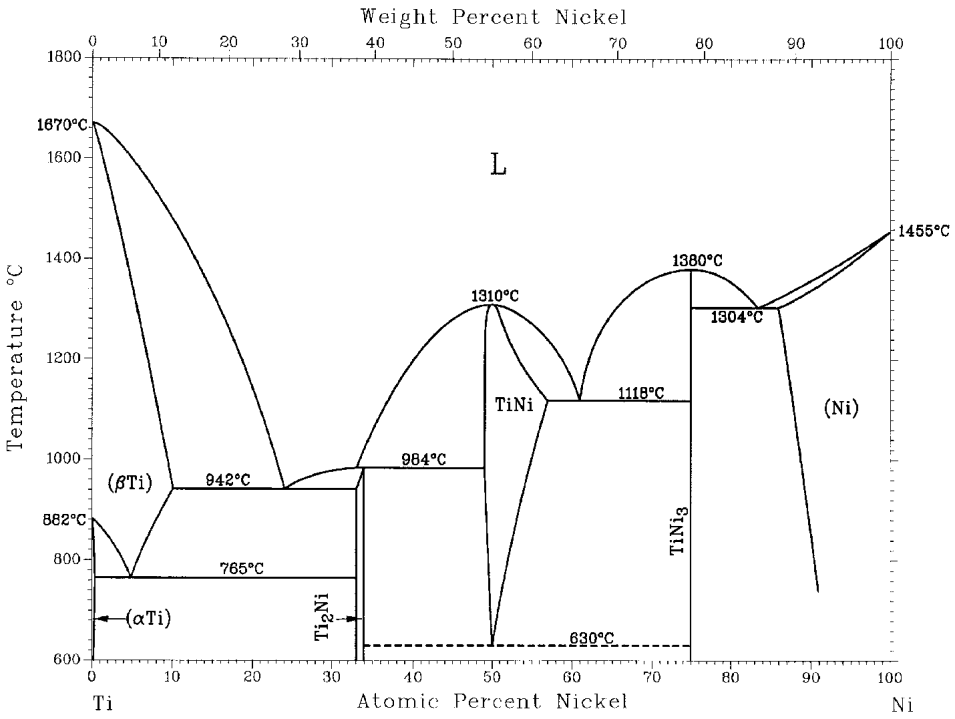

Fig. 2 Ni-Ti phase diagram [1991Nas]

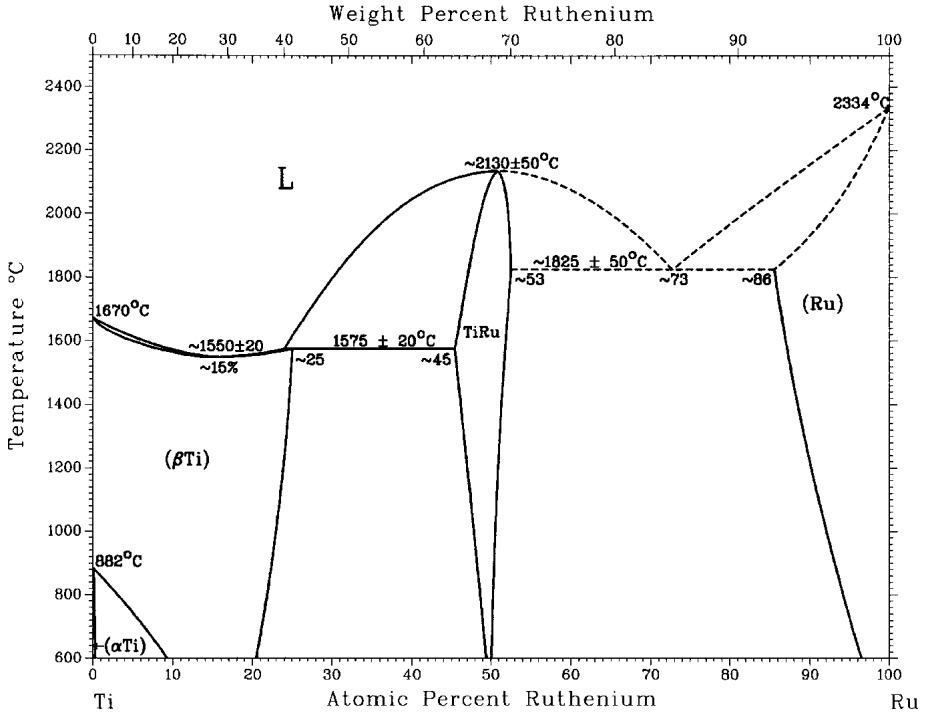

Fig. 3 Ru-Ti phase diagram [Massalski2]

[1984Ere] in their comparative study of various Ti-Ni-M systems, where M = group IV to group VIII transition metals) to be of a peritectic type (Fig. 4a), with the peritectic reaction L + RuTi ↔ NiTi occurs at 1570 °C. Since some of the known Ni-Ti-M systems with M = Fe, Co, and Pd show complete solid solubility between the NiTi and MTi phases, [1984Ere] doubted the results of [1980Bor] because the alloys were annealed at 1200 °C for too short a time (25

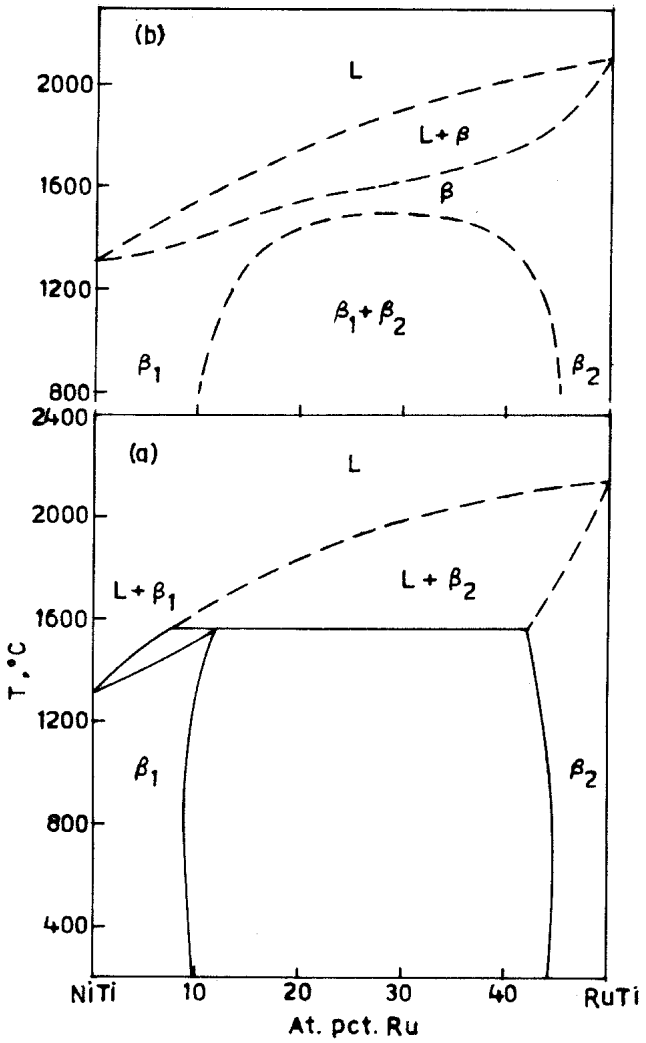

Fig. 4 **(a)** NiTi-RuTi pseudobinary section [1980Bor]. **(b)** Suggested modification of the NiTi-RuTi pseudobinary section (schematic) [1984Ere]

h) to establish the two-phase region of the peritectic system. [1984Ere] suggested that, like all other known NiTi-MTi ternary systems, an isomorphous-type pseudobinary system is to be expected with a possible phase separation at lower temperatures (Fig. 4b).

To verify the conjecture of [1984Ere], [1995Sem] restudied the NiTi-RuTi system. Pure metals, iodide Ti, Ni (99.99 mass%), and Ru powder (99.95 mass%), were used to prepare 10 alloys by arc melting under an argon atmosphere. The Ru powder for the alloys was sintered in a vacuum at 1200 °C before arc melting. A custom-made DTA apparatus that was able to go to 2300 °C was used for solidus and liquidus temperature determination. The alloys were annealed between 1200 and 1650 °C, depending on the alloy compositions. The duration of annealing at the various temperatures, however, was not mentioned. The characterization of the alloys was performed by metallography, XRD, and microhardness measurement.

The DTA results of [1995Sem], as predicted by

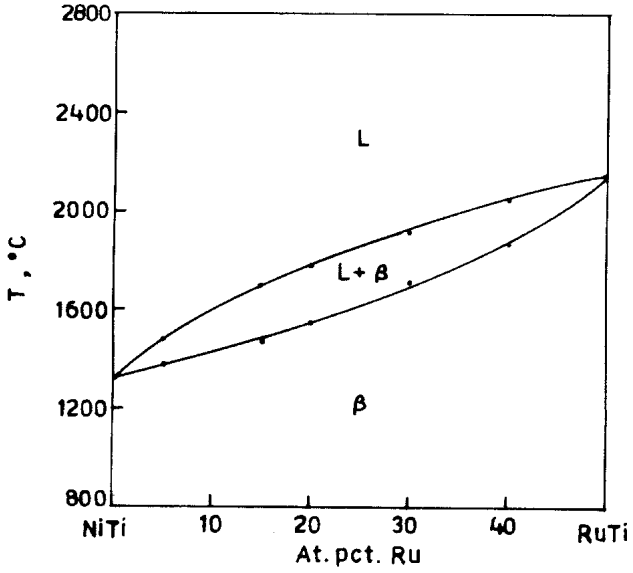

Fig. 5 NiTi-RuTi pseudobinary section [1995Sem]

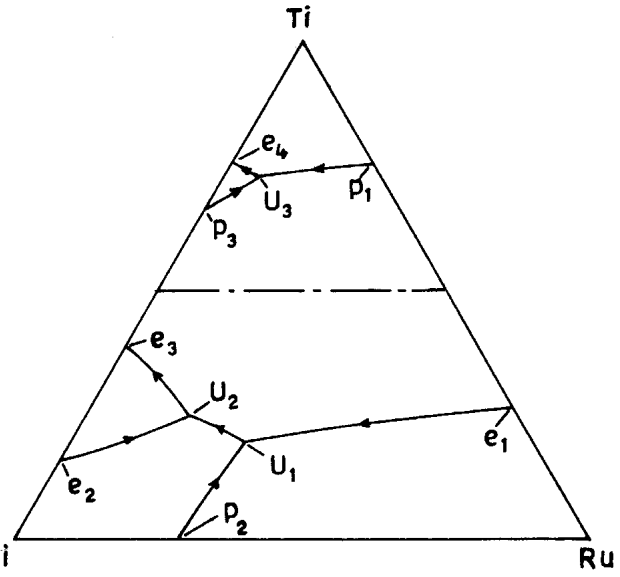

Fig. 6 Probable liquidus projection (schematic) for Ni-Ru-Ti system

[1984Ere], indicated the NiTi-RuTi system to be a simple isomorphous system (Fig. 5) with a reasonably wide gap between the liquidus and solidus lines. Due to this condition, the cast alloys on metallographic investigation showed dendritic liquation during solidification. Due to this and the short annealing time used by [1980Bor], the alloys in the earlier study [1980Bor] possibly appeared to have two-phase structures. [1995Sem] showed that, at least down to 1200 °C, the single-phase β system exists. Since the investigation of [1995Sem] was not carried out to temperatures <1200 °C, it is not known whether a phase separation exists in the NiTi-RuTi system.

The NiTi-RuTi isomorphous pseudobinary system di-

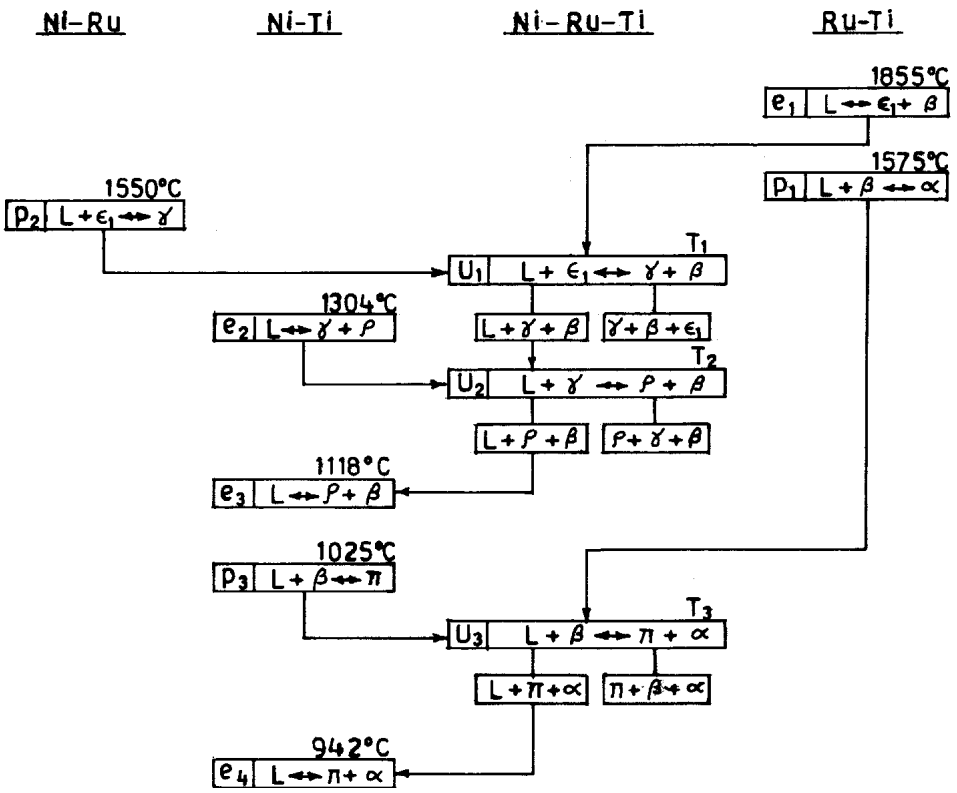

Fig. 7 Reaction scheme for the proposed liquidus projection

Table 1 Structure Data of Binary Phases in the Ni-Ru-Ti System

Phase Designation	Composition	Pearson Symbol	Space Group	Type	Lattice Parameters, nm	
					a	*c*
γ	(Ni)	*cF*4	$Fm\bar{3}m$	Cu	…	…
α	(βTi)	*cI*2	$Im\bar{3}m$	W	…	…
ε	(αTi)	*hP*2	$P6_3/mmc$	Mg	…	…
ϵ_1	(Ru)	*hP*2	$P6_3/mmc$	Mg	…	…
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	…
π	$NiTi_2$	*cF*96	$Fd\bar{3}m$	cFe_3W_3	1.1324	…
β	RuTi	*cP*2	$Pm\bar{3}m$	CsCl	0.3067	…

vides the Ni-Ru-Ti system into two parts. On the lower Ti side of the pseudobinary, there are three eutectic reactions (one in the RuTi system and the other two in the Ni-Ti system) and one peritectic reaction in the Ni-Ru system. The probable liquidus projection (Fig. 3) for the Ni-Ru-RuTi-NiTi region of the Ni-Ru-Ti system is expected to show liquid composition passing through two four-phase reaction points, U_1 and U_2, and solidification should finally occur at the eutectic point e_3 at 1118 °C in the Ni-Ti system. On the high-Ti side of the NiTi-RuTi pseudobinary, one peritectic reaction occurs in the Ru-Ti system, and a peritectic and a eutectic reaction occur in the Ni-Ti system. The probable liquidus projection for the high-Ti side of the Ni-Ru-Ti system should give a four-phase reaction, U_3, and the last liquid should solidify at the eutectic point e_4 in the Ni-Ti system at 942 °C (Fig. 7). Figure 8 gives the probable reaction scheme, corresponding to the proposed liquidus projection seen in Fig. 7. The liquidus projection and the reaction scheme proposed here lack experimental verification.

[1995Sem] measured the lattice parameters of the NiTi-RuTi alloys using a least squares extrapolation method. A plot of lattice parameters of the β-phase as a function of Ru content shows (Fig. 8) reasonable scatter in the data. A linear variation of the lattice parameter between the NiTi and RuTi β-phase is observed.

[1995Sem] also observed that the alloys with up to 2 at.% Ru showed martensitic transformation of the β-phase.

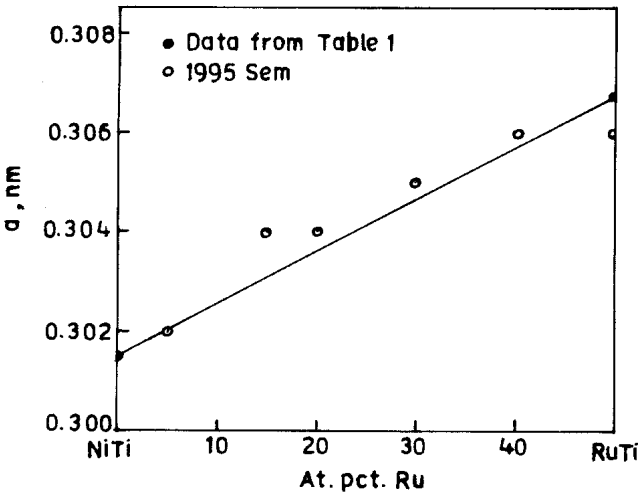

Fig. 8 Lattice parameter of the β-phase as a function of Ru content [1995Sem]

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# indicates presence of a phase diagram.

Ni-Ru-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 1993. Dr. Gupta is the Alloy Phase Diagram Program Co-Category Editor for ternary nickel alloys.