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The Ni-Re-Ti (Nickel-Rhenium-Titanium) System

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Introduction

The Ni-Re-Ti system has been investigated by only one investigator. One isothermal section has been established and is reported here.

Binary Systems

The Ni-Re system [Massalski 2] is a simple peritectic system (Fig. 1). At the Ni side of the Ni-Re system face centered cubic (fcc) solid solution γ forms through a peritectic reaction $L + \varepsilon_1 \leftrightarrow \gamma$ at 17.4 at.% Re, the peritectic reaction temperature being 1620 °C. ε_1 is the close packed hexagonal (cph) terminal solid solution of Re.

The Ni-Ti system [Massalski 2] has three intermediate phases $Ni_3Ti(\theta)$, $NiTi(\varphi)$ and $NiTi_2(\pi)$ of which the θ and φ phases melt congruently at 1380 and 1310 °C, respectively (Fig. 2). The π phase forms through a peritectic reaction $L + \varphi \leftrightarrow \pi$ at 984 °C. Three eutectic reactions $L \leftrightarrow \gamma + \theta$, $L \leftrightarrow \theta + \varphi$ and $L \leftrightarrow \alpha + \pi$, where α is the body centered cubic (bcc) terminal solid solution of βTi, occur at 1304, 1118, and 942 °C, respectively. Two eutectoid reactions $\alpha \leftrightarrow \pi + \varepsilon_2$ where ε_2 is the cph terminal solid solution of αTi, and $\varphi \leftrightarrow \theta + \pi$ occur at 765 and ~630 °C, respectively.

The Re-Ti system [Massalski 2] has only one intermediate phase $Re_{24}Ti_5(\chi)$, which forms through a peritectic reaction $L + \varepsilon_1 \leftrightarrow \chi$ at 2750 °C. A peritectic reaction $L + \chi \leftrightarrow \alpha$ occurs at 2025 °C. The α phase transforms to ε_2 phase at temperatures ≤882 °C (Fig. 3).

Binary and Ternary Phases

In the three binary systems Ni-Re, Ni-Ti and Re-Ti four intermediate phases form. No ternary phase has been reported in the Ni-Re-Ti system. The binary phases and their structure data are given in Table 1.

Ternary System

The ternary system Ni-Re-Ti system has been investigated by [1998 Sly] using diffusion couples and arc melted alloys. Sandwich diffusion couples Re/Ni/Ti were prepared by welding 50 μm thick Ni between Re and Ti at 902 °C for

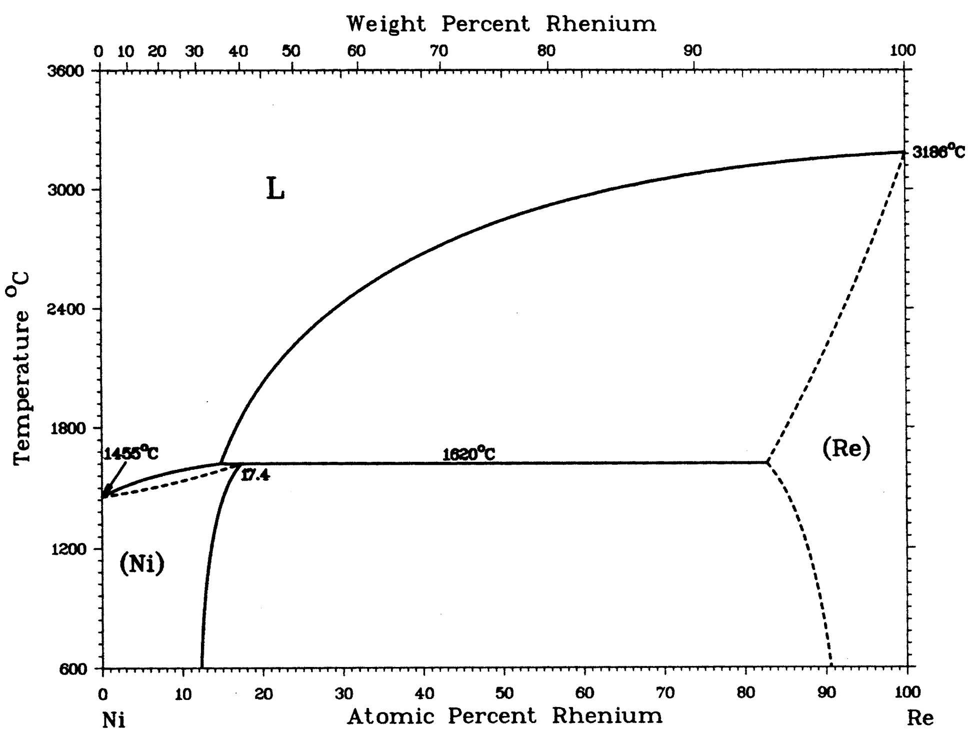

Fig. 1 The Ni-Re system [Massalski 2]

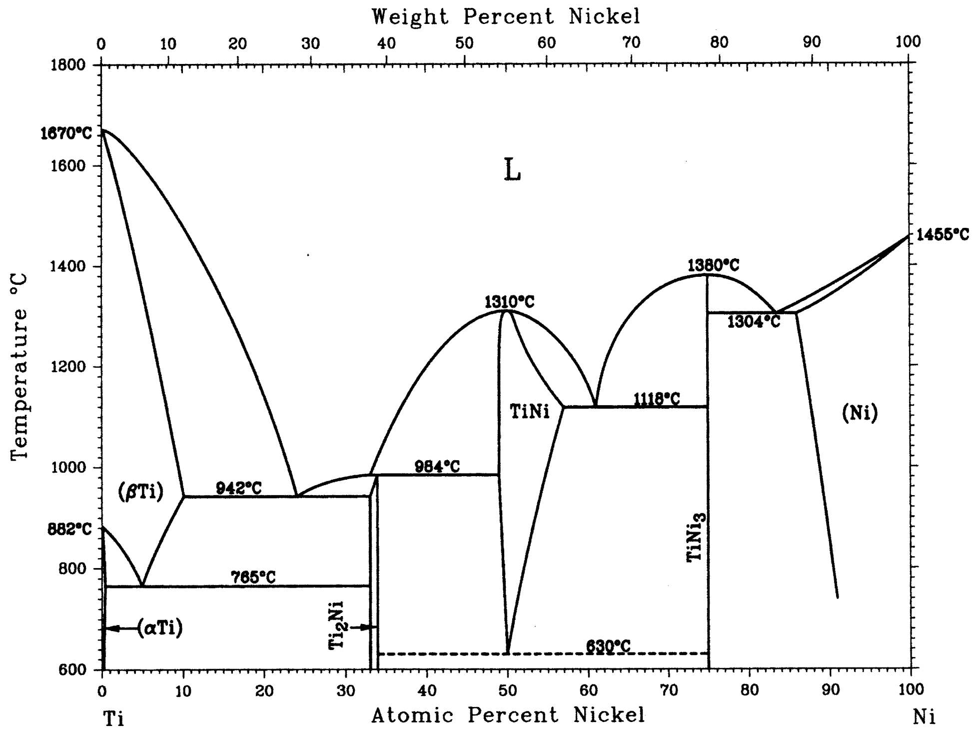

Fig. 2 The Ni-Ti system [Massalski 2]

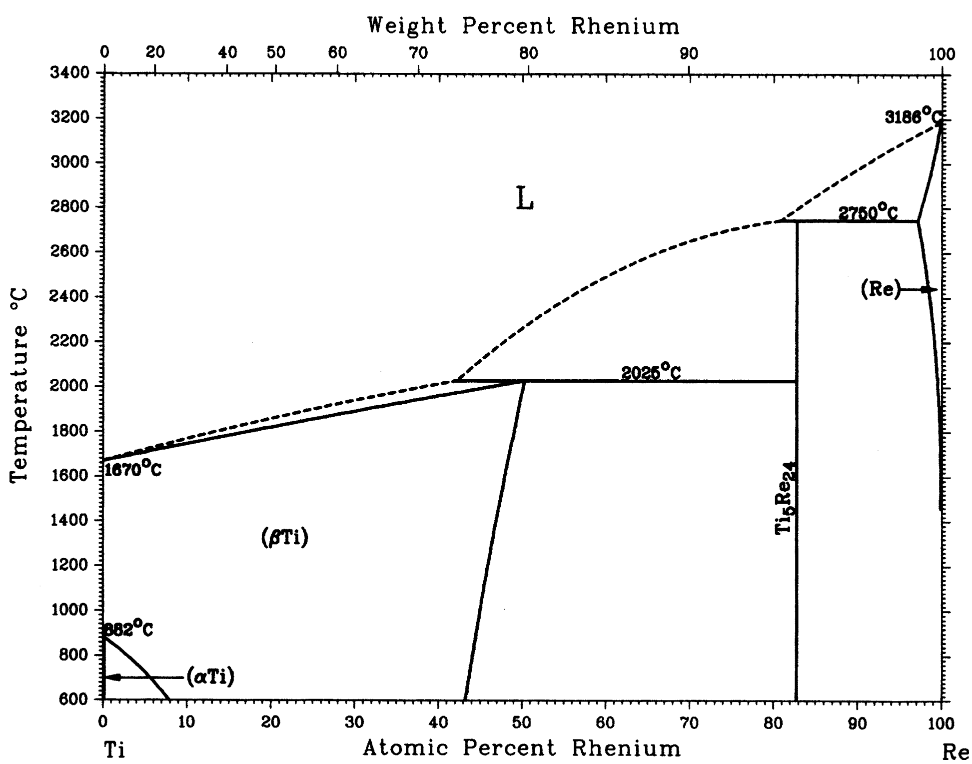

Fig. 3 The Re-Ti system [Massalski 2]

10 min. under 15 MPa pressure. The diffusion couples were diffusion annealed at 902 °C for 4 to 49 h. Six ternary alloys were arc melted under argon. The alloys were sealed in evacuated silica capsules annealed for 300 h at 902 °C. The diffusion zones of the diffusion couples and the annealed alloys were characterized using scanning electron

Table 1 Binary phases of the Ni-Re, Ni-Ti and Re-Ti system and their structure data

					Lattice parameters, nm		
Phase designation	**Composition**	**Pearson's symbol**	**Space group**	**Type**	***a***	***b***	***c***
γ	(Ni)	*cF*4	$Fm\bar{3}m$	Cu	…	…	…
α	(βTi)	*cI*2	$Im\bar{3}m$	W	…	…	…
ε_1	(Re)	*hP*2	$P6_3/mmc$	Mg	…	…	…
ε_2	(αTi)	*hP*2	$P6_3/mmc$	Mg	…	…	…
θ	Ni_3Ti	*hP*16	$P6_3/mmc$	Ni_3Ti	0.5101	…	0.8307
φ	NiTi	*cP*2	$Pm\bar{3}m$	CsCl	0.3015	…	…
π	$NiTi_2$	*cF*96	$Fd\bar{3}m$	$NiTi_2$	1.1324	…	…
χ	$Re_{24}Ti_5$	*cI*58	$I\bar{4}3m$	αMn	0.9595	…	…

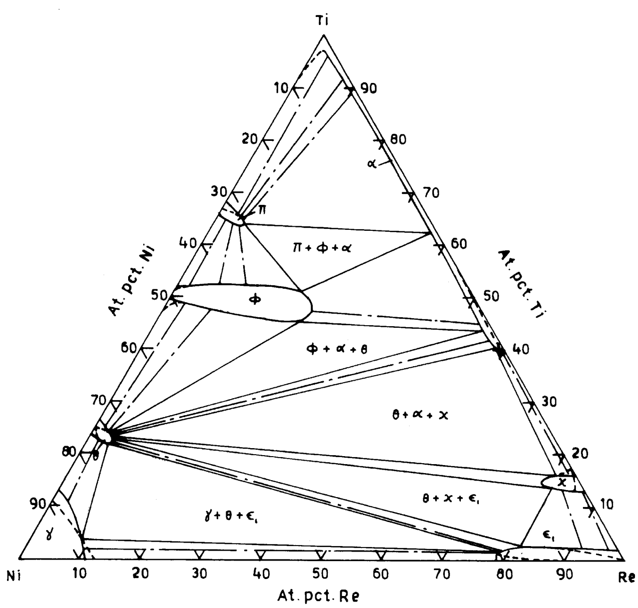

Fig. 4 An isothermal section of the Ni-RE-Ti system at 902 °C [1998 Sly]

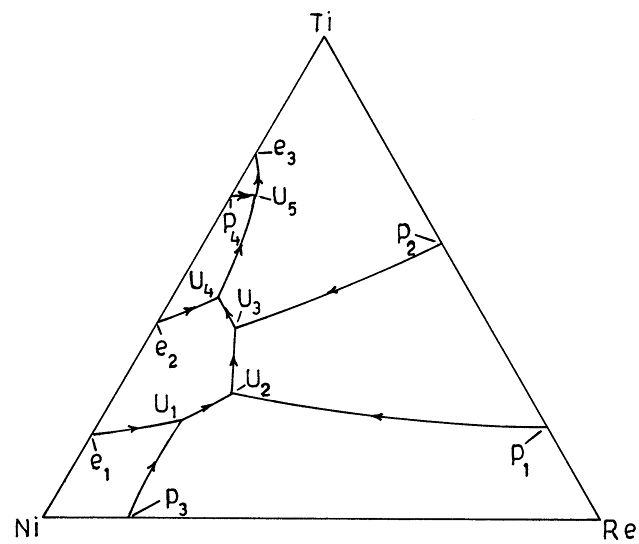

Fig. 5 A probable liquidus projection (schematic) for the Ni-Re-Ti system

microscopy (SEM), electron probe microanalysis (EPMA), and x-ray diffraction (XRD).

The diffusion zones of the diffusion couples revealed that initially Ti reacted with Ni to form the π, φ, and θ phases but after 25 h annealing of the diffusion couples the χ phase also formed. The sequence of phases found after 25 h anneal of diffusion couples was α/π/φ/θ/χ/ε. Of the six arc melted alloys four contained 10 at.% Re with 20, 25, 30, and 60 at.% Ti whereas the other two alloys contained 40 at.% Re with 40 and 45 at.% Ti. Phase analysis of the alloys showed that two of these alloys, with 20 and 45 at.% Ti, were 2-phase with θ + ε and θ + α phases, respectively. The rest of the alloys were found to contain 3 phases, the 25, 30, 40, and 60 at.% Ti alloys were with θ + ε_1 + χ, θ + α + χ, θ + φ + α and π + α + φ phases, respectively. On the basis of phase analysis of the alloys an isothermal section of the Ni-Re-Ti system at 902 °C has been drawn and is given in Fig. 4. Figure 4 also shows several tie lines determined through the diffusion couples and the annealed arc melted alloys. In Fig. 4 the 3 phase boundaries of the region γ + ε_1 + θ was not determined through EPMA analysis of a 3-phase alloy but the three phase boundaries are shown to indicate that the 3-phase region should exist in the isothermal section. An annealed alloy in the 3-phase region γ + ε_1 + θ should be used to establish the 3-phase boundaries of the γ + ε_1 + θ region.

The isothermal section given in Fig. 4 shows that no ternary intermediate phase exists in the Ni-Re-Ti system. Among the binary intermediate phases only the φ phase extends into the ternary up to about 22 at.% Re. All the other binary intermediate phases extend into the ternary only to a limited extent, π up to ~2 at.% Re, θ up to ~3 at.% Re and χ up to ~5 at.% Ni. The terminal solid solutions ε_1 and α extend into the ternary only up to ~2 at.% Ti or Ni. The Ni solid solution γ has been shown in Fig. 4 to extend reasonably into the ternary, up to ~11 at.% Ti and Re. The phase boundaries of the phases, shown in Fig. 4 by solid lines, however, do not agree well with the phase boundaries of the accepted binary diagrams at 902 °C. Both the θ and χ phases are single composition phases and not with some solid solution region as shown in

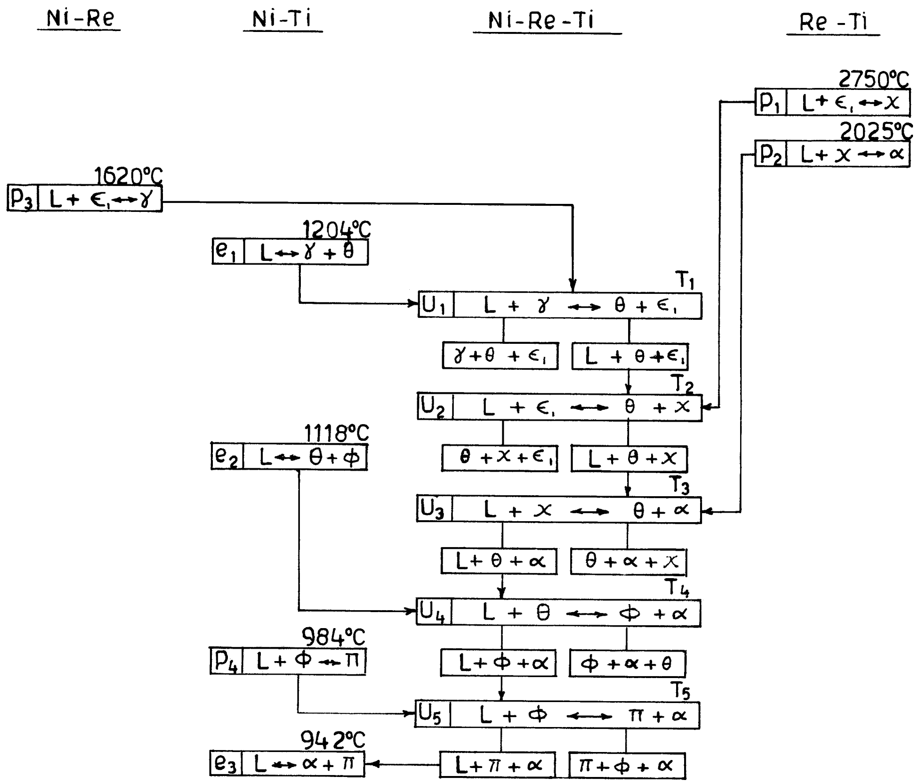

Fig. 6 Reaction scheme for the probable liquidus projection of Fig. 5

Fig. 4. Moreover, the phase boundaries of the γ, φ, π, α, and ε phases do not agree with the binary data. The probable phase boundaries of all these phases are shown in Fig. 4 by dashed lines.

Figure 4 shows that no ternary intermediate phase forms in the Ni-Re-Ti system and five three-phase regions exist in the isothermal section. Of these, four 3-phase regions are due to equilibrium of the θ phase with the terminal solid solution γ, ε_1 and α and the intermediate phases φ and χ. The isothermal section of Fig. 4 can be used to suggest a probable liquidus projection for the Ni-Re-Ti system. The Ni-Re system has only one peritectic reaction ρ_3 at 1620 °C. The Ni-Ti system has three eutectic and one peritectic reactions: e_1 at 1204 °C, e_2 at 1118 °C, e_3 at 942 °C and ρ_4 at 984 °C. The Re-Ti system has two peritectic reactions: ρ_1 at 2750 °C and ρ_2 at 2025 °C. The probable liquidus projection which will be consistent with the isothermal section of Fig. 4 is given in Fig. 5. Figure 5 shows the liquid compositions from e_1 and ρ_3 interact at U_1 to give the three phase region $\gamma + \theta + \varepsilon_1$. The liquid composition from U_1 reacts with the liquid composition from ρ_1 at U_2 to give the $\theta + \chi + \varepsilon_1$ 3-phase region. The liquid composition from U_2 interacts at U_3 with the liquid composition from ρ_2 to give the $\theta + \alpha + \chi$ 3-phase region. The liquid from U_3 interacts with the liquid composition from e_2 at U_4 to give the 3 phase region $\theta + \varphi + \alpha$. The liquid composition from U_4 interacts with the liquid composition from ρ_4 at U_5 to give the $\varphi + \pi + \alpha$ 3 phase region. The last liquid from U_5then solidifies at the Ni-Ti binary at e_3.The reaction scheme for the liquidus projection is given in Fig. 6. The probable liquidus projection has to be established experimentally.

References

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# indicates presence of phase diagram.

Ni-Re-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 1996. Dr. Gupta is the Alloy Phase Diagram Co-Category Program Editor for ternary nickel alloys.