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The Ni-Re-Zr (Nickel-Rhenium-Zirconium) System

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Introduction

Very little work has been done in the Ni-Re-Zr system. Only one isothermal section has been established and is reported here.

Binary Systems

The Ni-Re system [Massalski2] (Fig. 1) is a simple peritectic system. The peritectic reaction $\varepsilon + L \leftrightarrow \gamma$ occurs at 1670 °C where ε and γ are the terminal solid solutions (Re) and (Ni), respectively.

The Ni-Zr system [1991Nas] (Fig. 2) shows the presence of eight intermediate phases: $Ni_5Zr(\varepsilon)$, $Ni_7Zr_2(\pi)$, $Ni_3Zr(\kappa)$, $Ni_{21}Zr_8(\theta)$, $Ni_{10}Zr_7(\beta)$, $Ni_{11}Zr_9(\nu)$, $NiZr(\phi)$, and $NiZr_2(\xi)$, of which the π, ϕ, and ξ phases melt congruently at 1440, 1260, and 1120 °C, respectively. All the other phases form through peritectic or peritectoid reactions: $L + \pi \leftrightarrow \varepsilon$ at 1300 °C, $L + \pi \leftrightarrow \theta$ at 1180 °C, $L + \nu \leftrightarrow \beta$ at 1160 °C, $L + \phi \leftrightarrow \nu$ at 1170 °C, and $\pi + \theta \leftrightarrow \kappa$ at 920 °C. Two eutectoid reactions $\nu + \phi + \beta$ and $(\beta Zr) \leftrightarrow (\alpha Zr) + \xi$ occur at 978 and 843 °C, respectively. The π, θ, ν, ϕ, and ξ phases are of invariant compositions.

The Re-Zr system [Massalski2] (Fig. 3) has three intermediate phases. $Re_{24}Zr_5(\chi)$, $Re_2Zr(\lambda_1)$ and $ReZr_2(\zeta)$, of which the λ_1 phase melts congruently at ~2750 °C. The χ phase and the ζ form through peritectic reactions $L + \lambda_1 \leftrightarrow \chi$ at ~2500 °C and $L + \lambda_1 \leftrightarrow \zeta$ at 1640 °C. Two eutectic reactions $L \leftrightarrow (Re) + \chi$ and $L \leftrightarrow \zeta + \beta Zr$ occur at ~2400 and 1593 °C, respectively. A eutectoid reaction $\beta Zr \leftrightarrow \zeta + \alpha Zr$ occurs between 550 and 600 °C. The ζ phase is of invariant composition.

Binary and Ternary Phases

There are 11 binary intermediate phases in the three binary systems of Ni-Re, Ni-Zr, and Re-Zr. No ternary intermediate phase has been reported in the Ni-Re-Zr system. The binary phases and their structure data are given in Table 1.

Ternary System

The Ni-Re-Zr ternary system has been investigated by [1998Sly] using 9 alloys containing 10 at.% Re and Ni

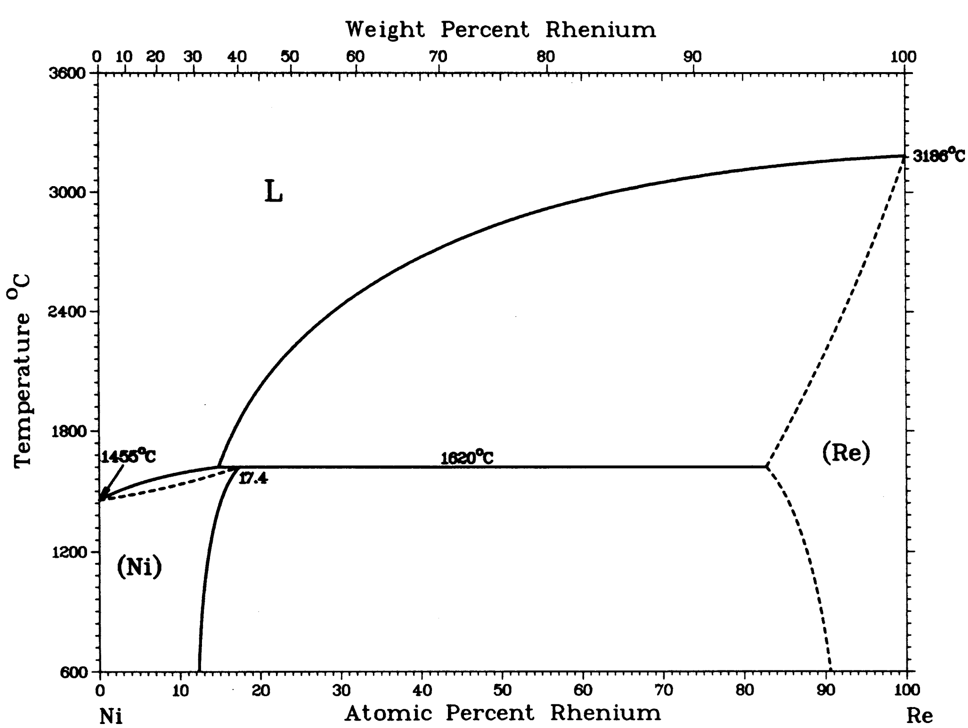

Fig. 1 Ni-Re binary phase diagram [Massalski2]

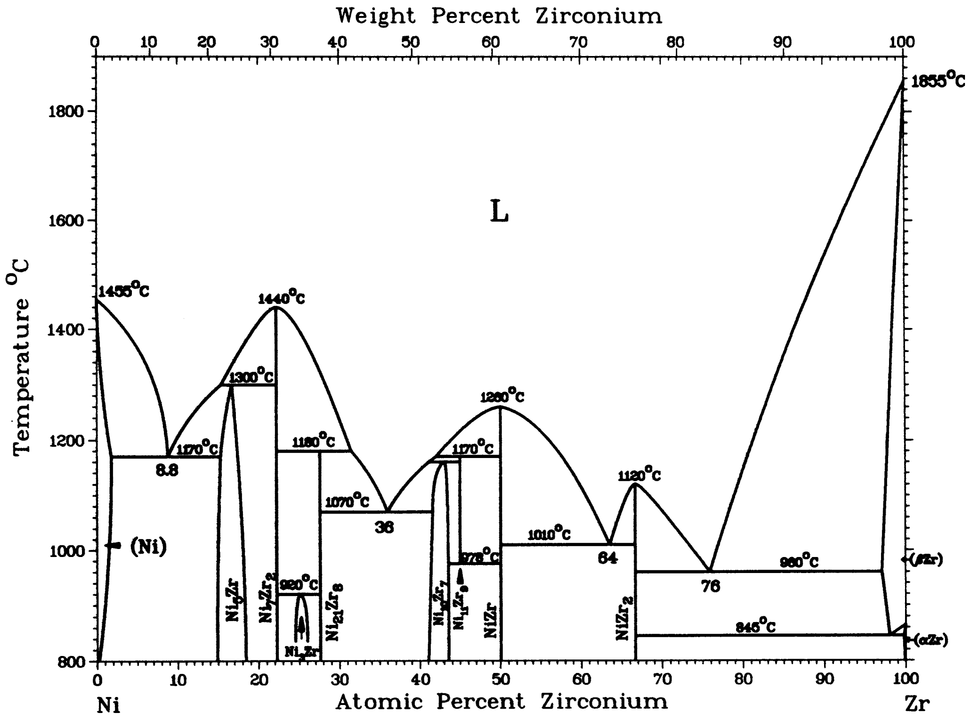

Fig. 2 Ni-Zr binary phase diagram [Massalski2]

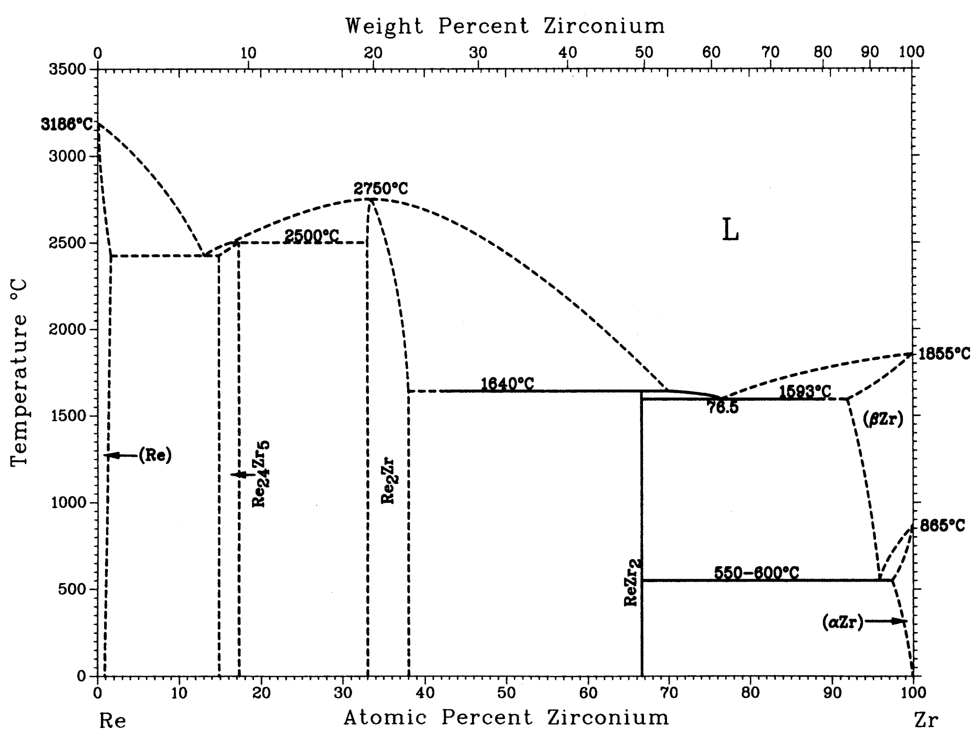

Fig. 3 Re-Zr binary phase diagram [Massalski2]

content varying from 10 to 80 at.% Ni. The alloys were arc melted under argon atmosphere, homogenized at 902 °C in a vacuum furnace and finally annealed at 902 °C for 300 h in a sealed quartz capsule filled with argon. The phase analysis of the annealed alloys was done using scanning electron microscopy (SEM), electron probe

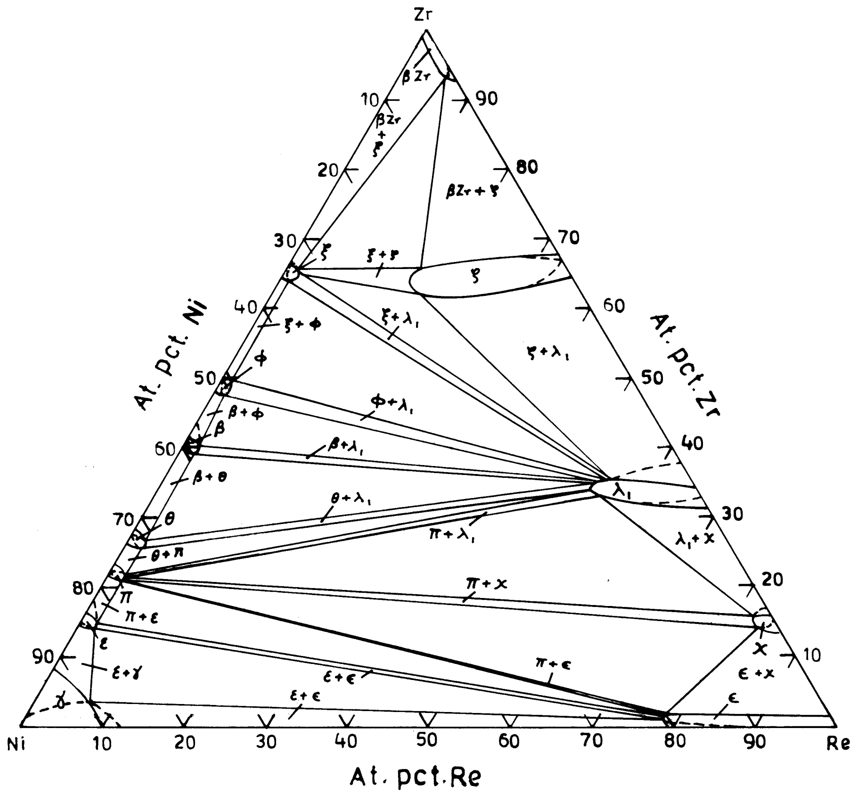

Fig. 4 An isothermal section of the Ni-Re-Zr system at 902 °C [1998Sly]

Table 1 Phases of the binary systems Ni-Re, Ni-Zr, and Re-Zr and their structure data

Phase designation	Composition	Pearson's symbol	Space group	Type	Lattice parameter, nm		
					a	*b*	*c*
γ	(Ni)	*cF*4	$Fm\bar{3}m$	Cu	…	…	…
ε	(Re)	*hP*2	$P6_3/mmc$	Mg	…	…	…
βZr	(βZr)	*c*I2	$Im\bar{3}m$	W	…	…	…
αZr	(αZr)	*c*158	$I\bar{4}3m$	Mg	…	…	…
χ	$Re_{24}Zr_5$	*c*158	$I\bar{4}3m$	αMn	…	…	…
$λ_1$	Re_2Zr	*hP*12	$P6_3/mmc$	$MgZn_2$	0.5270	…	0.8636
ζ	$ReZr_2$	…	…	…	…	…	…
ε	Ni_5Zr	*cF*24	$F\bar{4}3m$	$AuBe_5$	0.671	…	…
π	Ni_7Zr_2	*Mc*36	*C*2/*m*	Ni_7Ze_2	0.4698	0.8235 β = 95.83°	1.2193
κ	Ni_3Zr	*Hp*8	$P6_3/mmc$	Ni_3Sn	0.5309	…	0.4303
θ	$Ni_{21}Zr_8$	*ap*29	$p\bar{1}$	Hf_8Ni_{21}	0.6472 α = 7519°	0.8065 β = 68.04°	0.8588 γ = 75.26°
β	$Ni_{10}Zr_7$	*oc*68(a)	*Aba*2	$Ni_{10}Zr_7$	0.9211	0.9156	1.2386
		*op*68(b)	*Pbca*	$Ni_{10}Zr_7$	1.2497	0.9210	0.9325
ν	$Ni_{11}Zr_9$	*tI*40	*I*4/*m*	$Pt_{11}Zr_9$	0.990	…	0.662
ϕ	NiZr	*oc*8	*Cmcm*	CrB	0.3268	0.9936	0.4101
ξ	$NiZr_2$	*tI*12	*I*4/*mcm*	Al_2Cu	0.6483	…	0.5267

(a) Zr poor
(b) Zr rich

microanalysis (EPMA), and x-ray diffraction (XRD). The 902 °C isothermal section established by [1998Sly] is given in Fig. 1.

The isothermal section at 902 °C shows that no ternary intermediate phase exists in the Ni-Re-Zr system. Six binary phases of the Ni-Zr system, namely the ξ, ϕ, β, θ, π, and ε were found to extend into the ternary to only ~1 at.% Re. The Ni_3Zr(κ) phase, which exists below 920 °C, however, was not detected. The Ni_3Zr phase forms through a peritectoid reaction. The sluggish peritectoid reaction may be the reason for Ni_3Zr phase not forming at 902 °C even after 300 h annealing. The χ, λ_1, and ζ phases of the Re-Zr system were found to extend up to ~2, 13, and 22 at.% Ni, respectively. The ξ phase was found in equilibrium with the βZr, ξ, and, λ_1 phases, and the λ_1 phase was found in equilibrium with the ζ, ξ, ϕ, β, θ, π, and χ phases. The χ phase was found in equilibrium with the π and ε phases, and the ε phase was found in equilibrium with the χ, π, ε, and γ phases. Ten three phase equilibrium triangles were reported: (βZr) + ξ + ζ , ξ + ζ + λ_1 , ξ + ϕ + λ_1, ϕ + β + λ_1, β + θ + λ_1, θ + π + λ_1, π + λ_1 + χ , π + χ + ε , π + ε + ε, and ε + γ + ε.

The ternary system Ni-Re-Zr, established by [1998Sly] (Fig. 1) has certain features which do not agree with the accepted binary diagrams. The solubility of Re in Ni at 902 °C is ~12 at.% Re, the solubility of Ni in Re is ~15 at.% Ni, and the solubility of Zr in Ni at 902 °C is ~1 at.% Zr. Figure 1 shows a wide fcc γ phase field with solubility of Zr in Ni to be ~8 at.% Zr. The probable γ phase field is expected to be small, as indicated in Fig. 1 by a dashed boundary line. The ε phase field at the Ni-Re binary line is also expected to be ~14 to 15 at.% Ni and not ~21 at.% Ni as given in Fig. 1. The probable ε phase boundary is also indicated by a dashed line near the Ni-Re binary line. The βZr phase region is also expected to be smaller, shown by a dashed line, than the wider range indicated by [1998Sly]. Figure 1 also shows all the binary intermediate phases with some solubility ranges, whereas the binary π, ϕ, ξ, and ζ phases are of invariant compositions. Moreover, the locations of the binary χ and λ_1 phases in the Re-Zr system are slightly different than those indicated in the accepted Re-Zr binary diagram. The probable phase boundaries of these phases are indicated in Fig. 1 by dashed lines. Since the κ phase exists below 920 °C, the ternary system should also show the κ phase region and its equilibrium with the other phases. The ternary isothermal section of the Ni-Re-Zr system has been established on the basis of only nine alloys of which only four alloys were in the three phase regions. While the βZr + ξ + ζ , ξ + ϕ + λ_1 , π + λ_1 + χ , and ε + γ + ε regions are well established on the basis of EPMA analysis of three phase alloys, the rest of the three phase regions are shown on the basis of two phase alloys. These three phase regions should be properly established.

References

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Ni-Re-Zr 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.