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The Co-Ni-Y (Cobalt-Nickel-Yttrium) System

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Introduction

The Co-Ni-Y system has been investigated and two isothermal sections were established. The results of these investigations are reported here.

Binary Systems

The Co-Ni system [Massalski2] (Fig. 1) is a simple isomorphous system with solidus and liquidus lines very close to each other. The solid solution, face centered cubic (fcc) γ phase, extends from fcc αCo to Ni. At the Co-end, at temperatures <422 °C, the fcc αCo transforms to close packed hexagonal (cph) ε phase which is the terminal solid solution of cph εCo phase.

The Co-Y system [Massalski2, 1992Oka] (Fig. 2) has 11 intermediate phases: two polymorphic forms of $Co_{17}Y_2$ (π at >1300 °C and π′ at <1300 °C), Co_5Y (ω), Co_7Y_2 (ρ), Co_3Y (ν), Co_2Y (λ_2), Co_3Y_2 (ζ), $Co_{\sim 7}Y_{\sim 6}$ (τ), CoY (θ′), Co_3Y_4 (δ), Co_5Y_8 (ι), CoY_3 (η). A metastable phase Co_2Y_3 (ϕ′) has been reported in the Co-Y system. The π and ω phases melt congruently at 1357 and 1345 °C, respectively. All other phases form through peritectic or peritectoid reactions: $L + \omega \leftrightarrow \rho$ at 1320 °C, $L + \rho \leftrightarrow \nu$ at 1308 °C, $L + \nu \leftrightarrow \lambda_2$ at 1154 °C $L + \lambda_2 \leftrightarrow \zeta$ at 866 °C, $L + \zeta \leftrightarrow \theta'$ at 798 °C, $L + \theta' \leftrightarrow \iota$ at 740 °C, $L + \varepsilon' \leftrightarrow \eta$ at 889 °C, $\theta' + \zeta \leftrightarrow \tau$ at 775 °C, and $\iota + \theta' \leftrightarrow \delta$ at 732 °C. Three eutectic reactions $L \leftrightarrow \gamma + \pi$, $L \leftrightarrow \pi + \omega$, and $L \leftrightarrow \iota + \eta$ occur at 1340, 1300, and 738 °C.

The Ni-Y system [Massalski2] (Fig. 3) has nine intermediate phases, $Ni_{17}Y_2$ (π), Ni_5Y (ω), Ni_4Y (ψ), Ni_7Y_2 (ρ), Ni_3Y (ν), Ni_2Y (λ_2), NiY (θ), Ni_2Y_3 (ϕ), and NiY_3 (η), of which the ω and θ phases melt congruently at 1430 and 1070 °C, respectively. All other phases form through peritectic reactions: $L + \omega \leftrightarrow \pi$ at 1330 °C, $L + \omega \leftrightarrow \psi$ at 1340 °C, $L + \psi \leftrightarrow \rho$ at 1298 °C, $L + \rho \leftrightarrow \nu$ at 1237 °C, $L + \nu \leftrightarrow \lambda_2$ at 1106 °C, $L + \theta \leftrightarrow \phi$ at 820 °C, and $L + \varepsilon' \leftrightarrow \eta$ at 902 °C. Three eutectic reactions, $L \leftrightarrow \gamma + \pi$, $L \leftrightarrow \lambda_2 + \theta$, and $L \leftrightarrow \phi + \eta$ occur at 1285, 950, and 805 °C, respectively. ε′ is the cph terminal solid solution of αγ.

Binary and Ternary Phases

The three binaries of the Co-Ni-Y system have 20 intermediate phases. A metastable phase was reported in the

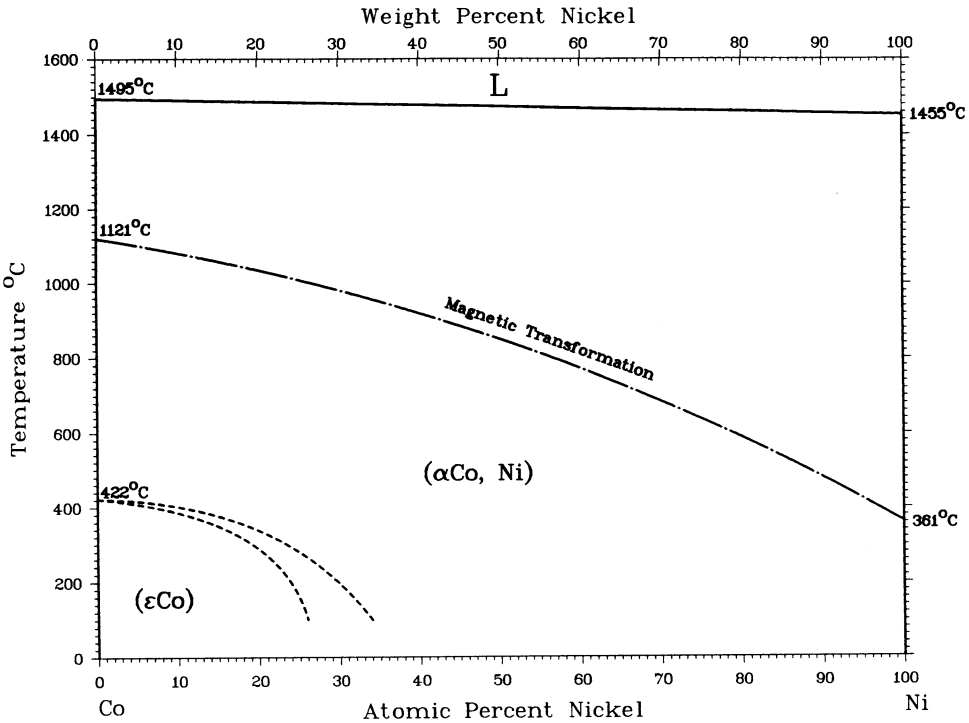

Fig. 1 Co-Ni binary diagram [Massalski2]

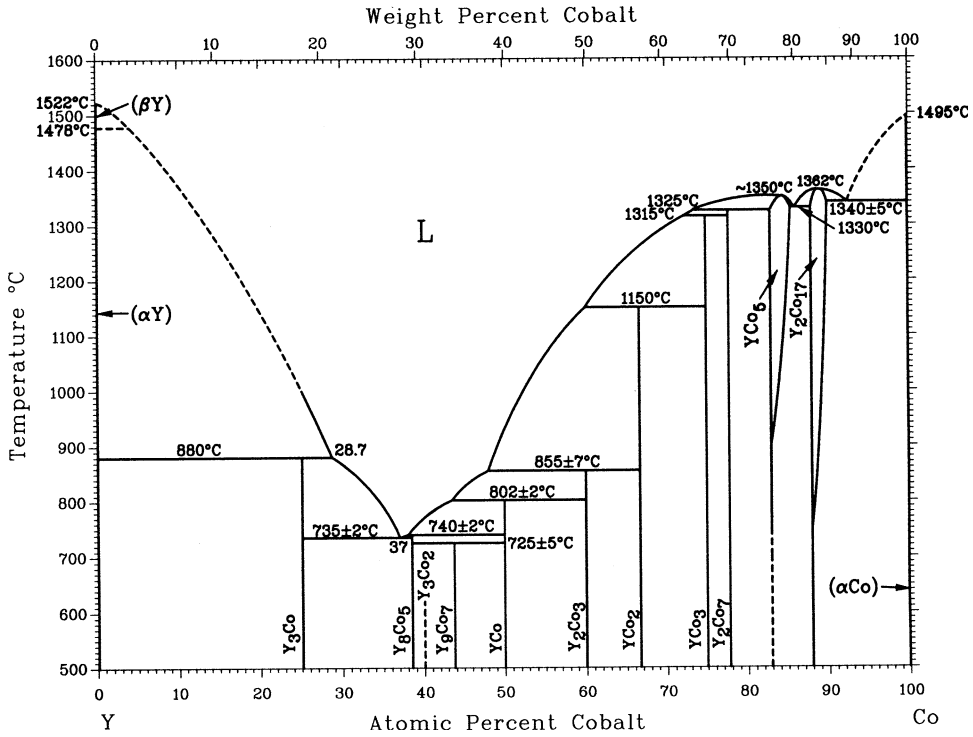

Fig. 2 Co-Y binary diagram [1992Oka]

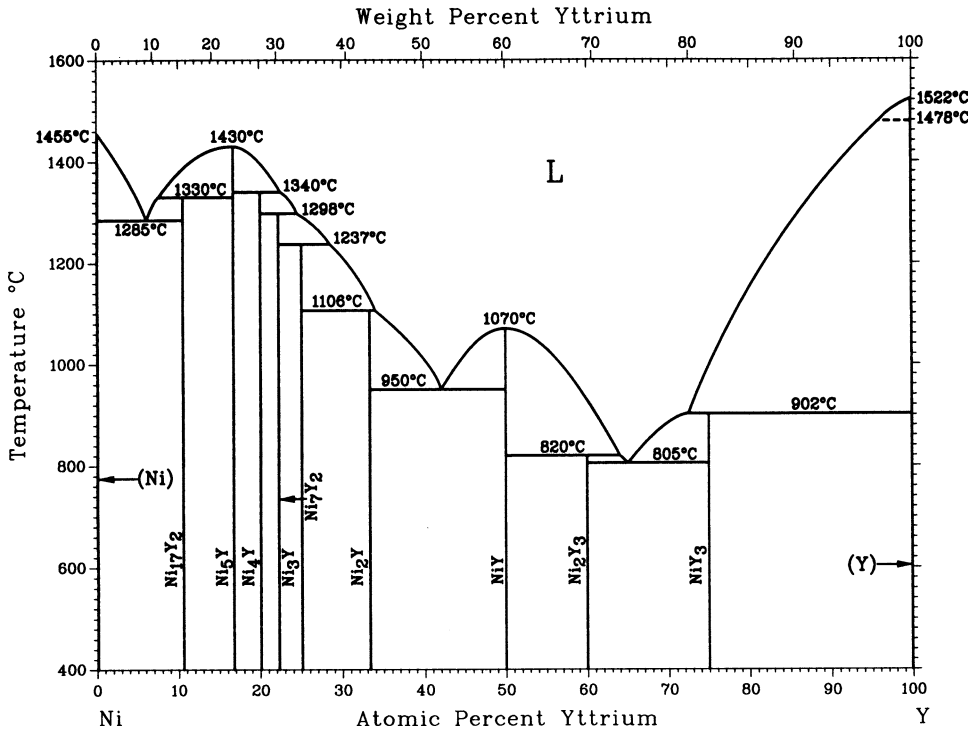

Fig. 3 Ni-Y binary diagram [Massalski2]

Co-Y system. Only one ternary intermediate phase has been reported to form in the Co-Ni-Y system. The phases of the Co-Ni-Y system and their structure data are given in Table 1.

Ternary System

The Co-Ni-Y system was established by [1977Kha] using 126 alloys with Y content up to 66.6 at.% Y. Of these

Table 1 Phases of the Co-Ni-Y system and their structure data

Phase designation	Composition	Pearson's symbol	Space group	Type	Lattice parameters, nm		
					a	*b*	*c*
γ	(αCo), (Ni) (αCo,Ni)	*cF*4	$Fm\bar{3}m$	Cu	...	...	...
ε	(εCo)	*hP*2	$P6_3/mmc$	Mg	...	...	...
α	(βY) $T \geq$ 1478-1572 °C	*cI*2	$Im\bar{3}m$	W	...	...	...
ε_1	(αY) $T <$ 1478 °C	*hP*2	$P6_3/mmc$	Mg	...	...	...
π	$Co_{17}Y_2$ $T \geq$ 1300 °C	*hP*38	$P6_3/mmc$	Th_2Ni_{17}	...	...	...
π′	α$Co_{17}Y_2$ $T \geq$ 1300 °C	*hR*19	$R\bar{3}m$	Th_2Zn_{17}	0.8341	...	0.8125
ω	Co_5Y	*hP*6	*Pg/mmm*	$CaCu_5$	0.4956	...	0.3969
ρ	Co_7Y_2	*hR*18	$R\bar{3}m$	Co_7Gd_2	0.5002	...	3.615
ν	Co_3Y	*hR*12	$R\bar{3}m$	Be_3Nb	...	...	...
		*hP*12	$P6_3/mmc$	$CeNi_3$	0.51033	...	...
λ_2	Co_2Y	*cF*24	$Fd\bar{3}m$	Cu_2Mg	0.7217	...	2.4371
ζ	Co_3Y_2	*cP*2	...	...	0.7996	...	...
τ	$Co_{\sim 7}Y_{\sim 6}$	...	...	...	...	...	...
θ′	CoY	*oC*8	*Cmcm*	CrB	...	...	...
			$P6_3/mmc$				
δ	Co_3Y_4	*hP*22	$P6_3/m$	...	1.1521	...	0.4042
ϕ′	Co_2Y_3(a)	*oP*20	*Pnnm*	...	...	...	...
ι	Co_5Y_8	*mP*52	$P2_1/c$	...	0.7058	0.7286	2.4227
						β = 102.11°	
η	CoY_3	*oP*16	*Pnma*	cFe_3	0.7026	0.9454	0.629
π	$Ni_{17}Y_2$	*hP*38	$P6_3/mmc$	Th_2Ni_{17}	0.8307	...	0.804
ω	Ni_5Y	*hP*6	*P6/mmm*	$CaCu_5$	0.4891	...	0.3961
ψ	Ni_4Y	...	...	...	...	...	...
ρ	Ni_7Y_2	*hR*18	$Rm\bar{3}m$(b)	Co_7Gd_2	0.4924	...	3.667
			$P6_3/mmc$(c)	Ce_2Ni_{17}	0.4928		2.441
ν	Ni_3Y	*hR*12	$R\bar{3}m$	Ni_3Pu	0.49782	...	2.4468(f)
		*hP*12					
λ_2	Ni_2Y	*cF*24	$Fd\bar{3}m$	Cu_2Mg	0.7183	...	...(d)
					0.7164	...	... (e)
θ	NiY	*oP*8	*Pnma*	FeB	0.7156	0.4124	0.5515
ϕ	Ni_2Y_3	*tP*80	$P4_12_12_1$	Ni_2Y_3	0.7104	...	3.6597
η	NiY_3	*oP*16	*Pnma*	Fe_3C	0.692	0.949	0.636
Δ	$Co_3Ni_2Y_5$	*tI*16	$I4_1/amd$	Bmo	0.3946	...	2.085

(a) Metastable, (b) at 1100 °C, (c) at 600 °C, (d) Ni-rich, (e) Ni-poor, (f) for hexagonal cell

alloys most of the alloys were prepared along the stoichiometric composition lines of the phases existing in the Co-Y and Ni-Y systems. The alloys were prepared using 99.99 mass% pure electrolytic Co and Ni and 99.8 mass% Y. The alloys were sealed in evaluated quartz capsules for annealing. The alloys with up to 33.3 at.% Y were annealed at 800 °C for 360 h and the alloys with >33.3 at.% Y were annealed at 600 °C for 360 h and after annealing the alloys were quenched in cold water. Characterization of the annealed alloys was done using metallographic and x-ray diffraction (XRD) methods. The results of the characterization of alloys is given in Fig. 4, which is a composite isothermal section at 800 °C (up to 33.3 at.% Y) and at 600 °C (for >33.3 at.% Y).

The isothermal section up to 33.3 at.% Y show (Fig. 4) continuous solid solution regions between the Co_5Y-Ni_5Y phases (ω). Co_7Y_2-Ni_7Y_2 phases (ρ), Co_3Y-Ni_3Y phases (ν), and Co_2Y-Ni_2Y phases (λ_2). The extended solid solution regions from the Co-Y to Ni-Y systems suggest the existence of four pseudobinaries but their nature were not established. The ψ phase, even though it exists in the Ni-Y system was not reported by [1977Kha]. The $Co_{17}Y_2$ and $Ni_{17}Y_2$ phases are not isostructural at 800 °C and hence do not form a continuous solid solution region. The $Co_{17}Y_2$ (π′) phase was found to extend up to ~35 at.% Ni whereas the $Ni_{17}Y_2$ (π) phase was found to extend up to about 10 at.% Co. In between the π and π′ phases a 2-phase region γ + ω and two 3-phase regions γ + π + ω and γ + η′ + ω were established. Above 33.3 at.% Y the θ phase extended from the Ni-Y binary up to ~15 at.% Co. A new ternary phase Δ, ideal composition $Co_3Ni_2Y_5$, was found in the composition region between ~20 and 60 at.% Co along the

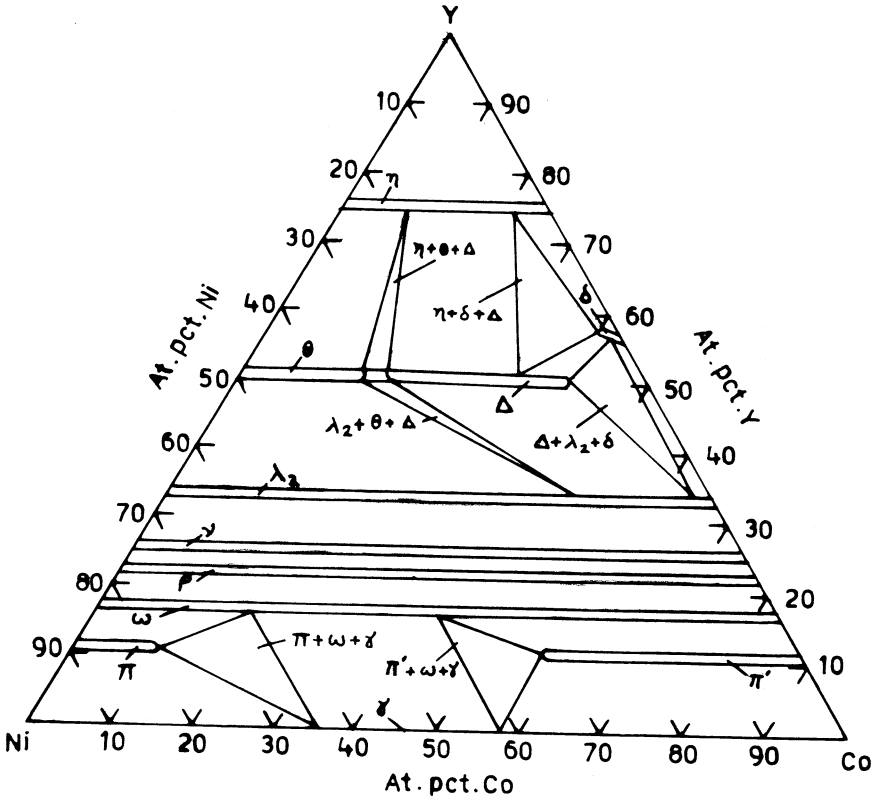

Fig. 4 A composite isothermal section of Co-Ni-Y system at 800 °C up to 33.3 at.% Y at 600 °C above 33.3 at.% Y [1977Kha]

CoY-NiY line but the CoY (θ′) phase was not reported. A continuous solid solution region η was found to extend from the CoY_3 to NiY_3 phases. The τ phase was found to extend up to ~2 at.% Ni. The Δ phase was found in equilibrium with the η, λ_2, θ, and τ phases. Four 3-phase regions $\lambda_2 + \theta + \beta$, $\lambda_2 + \Delta + \delta$, $\theta + \Delta + \eta$, and $\eta + \Delta + \delta$ were established. Above 33.3 at.% Y the ϕ, ϕ′, and ι phases were also not reported at 600 °C even though these phases exist in the Co-Y and Ni-Y systems. All the binary intermediate phases in Fig. 4 are single composition stoichiometric compounds at 600 and 800 °C but they are all shown with small solubility region without giving any experimental evidence for the same. Possibly all the phase regions should be represented by lines extending from the Co-Y to Ni-Y system.

A single crystal X-ray study of the Δ phase showed that it is of Moβ type tetragonal structure with 16 atoms/cell, space group $I4_1$/and with lattice parameters a = 0.3946 nm and c = 2.081 nm and with experimentally determined density of 6.04 g/cm^3. The lattice parameters of the solid solution phases ω, ρ, ν, λ_2, and η were determined and are shown in Fig. 5 as a function of composition. The lattice parameters of the ω phase was also determined by [1975Dwi] and are shown in Fig. 5(a). While the variation of a parameter for the ω phase as a function of Ni content determined by [1975Dwi] and [1977Kha] agree reasonably well, the variation of c parameter as a function of Ni content do not agree. The lattice parameters for the ω phase should be redetermined.

[1995Wen] studied the Co-Ni-Y system using diffusion couples. 99.9 mass% pure Co, Ni, and Y were used to form two types of diffusion couples: (1) Y/(Co,Ni) alloy couple formed by embedding 5 mm diameter Y in four Co-Ni alloys of the following compositions: $Co_{80}Ni_{20}$, $Co_{60}Ni_{40}$, $Co_{40}Ni_{60}$, $Co_{20}Ni_{80}$ and (2) Co-Ni-Y couple formed by a Y plate sandwiched between two Co plates and then the Co-Y-Co block was sandwiched between two Ni slabs. The Y/(Co,Ni) alloy couples were annealed for 20 days at 1000 °C whereas the Co-Ni-Y couple was annealed for 15 days at 1000 °C in argon filled quartz capsules. Characterization of the diffusion zones of the diffusion couples were done by electron probe micro analysis (EPMA) method supplemented by optical microscopy as well as scanning electron microscopy (SEM).

The Co-Ni-Y couple was analyzed by EPMA across the Co/Y, Ni/Y boundaries and the Co-Ni-Y region formed between the Co/Y and Ni/Y region. Across the Co/Y boundary region the sequence of phases observed were Co/$Co_{17}Y_2$/Co_5Y/Co_7Y_2/Co_3Y/Co_2Y. Across the Ni/Y boundary the sequence of phases found were Ni/$Ni_{17}Y_2$/Ni_5Y/Ni_4Y/Ni_7Y_2/Ni_3Y/Ni_2Y. For the Co-Ni-Y region the sequence of phases found were Ni/17:2/5:1/4:1/7:2/3:1/2:1/3:1/7:2/5:1/17:2/Co. The sequence of phases found across the Co/Y and Ni/Y boundaries were the same as

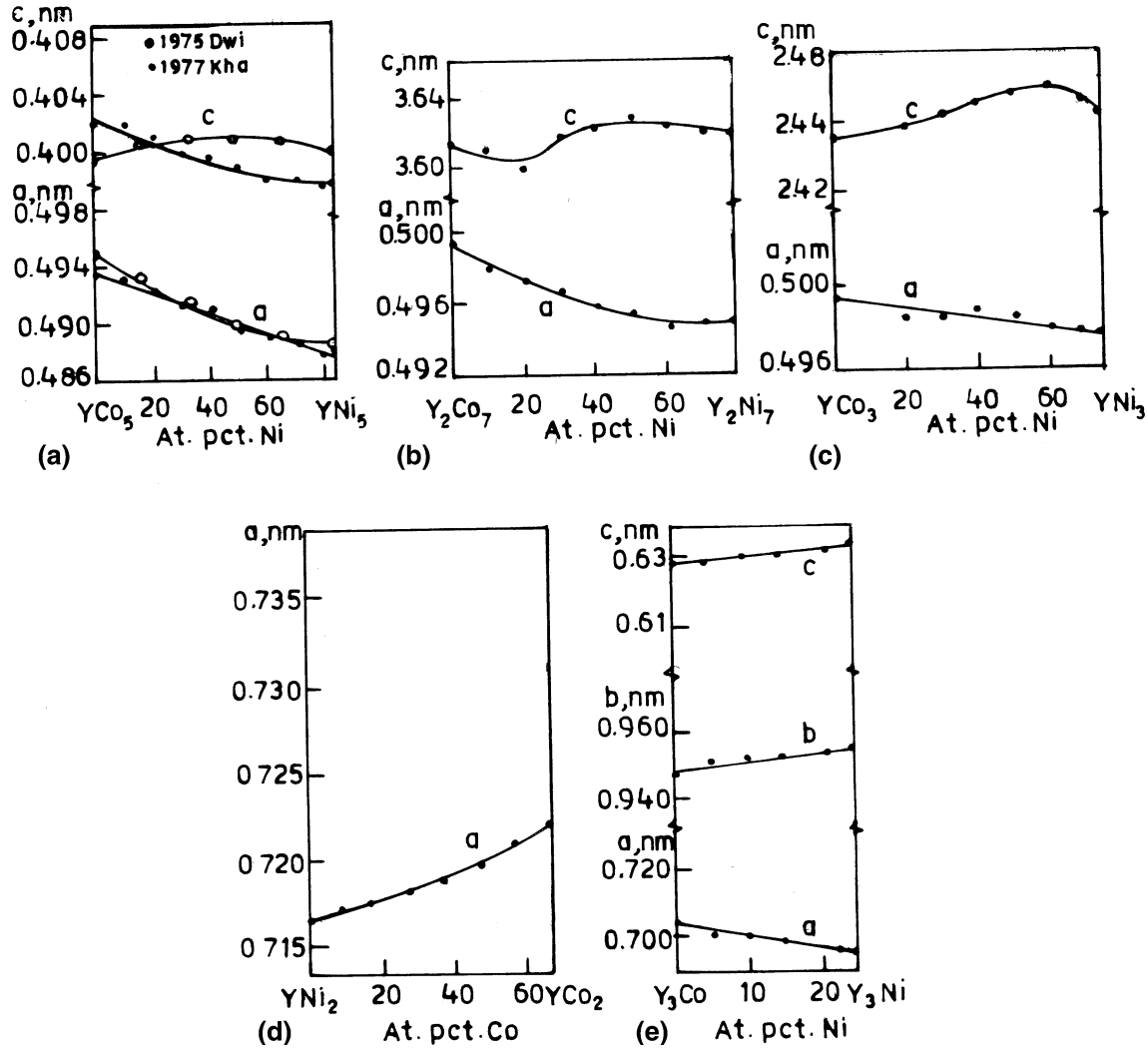

Fig. 5 Lattice parameters of several phases of the Co-Ni-Y system as a function of composition [1977Kha]: (a) ω phase, (b) ρ phase, (c) ν phase, (d) λ_2 phase, and (e) η phase

those reported for the Co-Y and Ni-Y binaries. The Y/(Co_pNi_q) alloy diffusion couples with Co:Ni ratios of 80:20 and 60:40 showed the sequence of phases (Co,Ni)/17:2/5:1/7:2/3:1/1:2 and for the couples with Co:Ni ratio of 40:60 and 20:80 the sequence of phases found were (Co,Ni)/17:2/5:1/4:1/7:2/3:1/2:1. The results of the characterization of diffusion zones were used to establish a partial isothermal section of 1000 °C and is given in Fig. 6.

The partial isothermal section at 1000 °C (Fig. 6) shows the solid solution phases ω, ρ, ν, and λ_2 phases extending from the Co-Y to the Ni-Y binaries without any reasonable solubility region. The ψ phase was found to extend up to ~32 at.% Co. The π phase was found to extend up to ~32 at.% Co. The π′ phase was found to extend little beyond ~43 at.% Ni whereas the π phase was found to extend up to ~15 at.% Co. The three phase regions were not determined experimentally but are shown in Fig. 6 to show that they should exist. The γ phase was found to extend up to ~2 at.% Y near the $Co_{50}Ni_{50}$ composition region. Above 33.3 at.% Y the phase regions were not determined. The dashed lines show the approximate composition region in which a liquid should exist in the Co-Ni-Y system. The Y-corner and the region around $Ni_{50}Y_{50}$ were also not determined. The dash-dot lines show the tie lines determined through the EPMA analysis of Y/(Co_pNi_q) alloy couples.

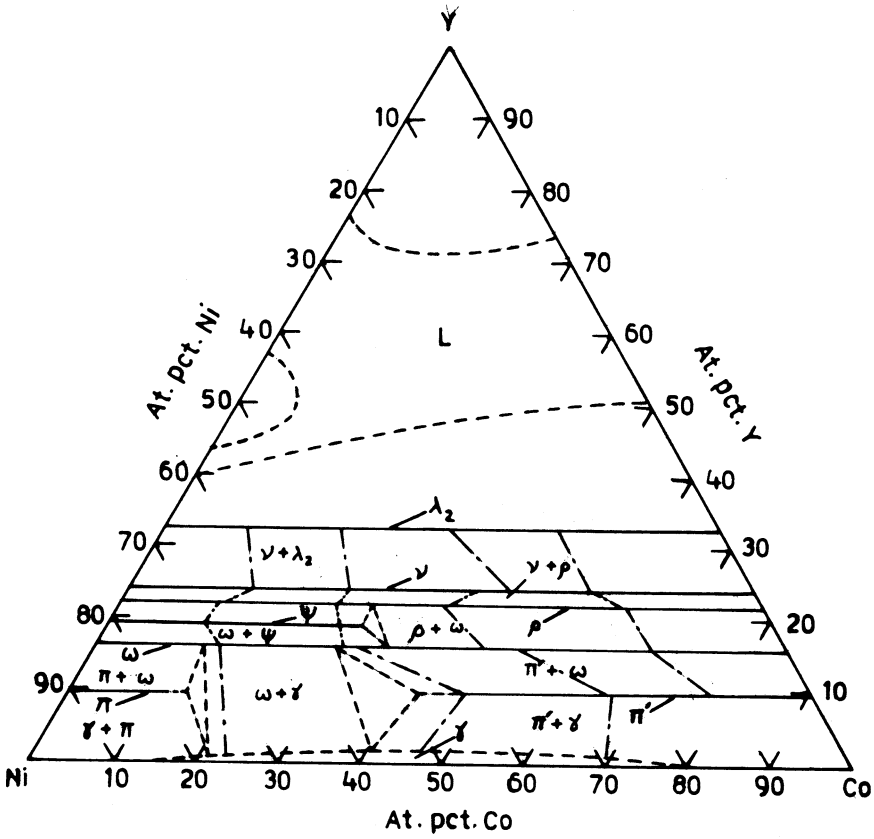

Fig. 6 A partial isothermal section of Co-Ni-Y system at 1000 °C [1995Wen]

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# indicates presence of phase diagram.

Co-Ni-Y 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.