JPEDAV (2004) 25:471-478
DOI: 10.1361/15477030420214
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The Cu-Mg-Ni (Copper-Magnesium-Nickel) System

K.P. Gupta, The Indian Institute of Metals

The Cu-Mg-Ni system has been studied by several investigators, and phase equilibria have been established through the determination of several isopleths, a liquidus projection, and an isothermal section.

Binary Systems

The Cu-Mg system [Massalski2] (Fig. 1) has two intermediate phases, $Cu_2Mg(\lambda_2)$ and $CuMg_2$ (ρ), both of which melt congruently at 797 and 568 °C, respectively. Three eutectic reactions, L $\leftrightarrow$ $\gamma + \lambda_2$, L $\leftrightarrow$ $\lambda_2 + \rho$, and L $\leftrightarrow$ $\rho + \epsilon$, occur at 725, 532, and 485 °C, respectively. γ and ϵ are the terminal solid solutions of face-centered-cubic (fcc) Ni and close-packed hexagonal (cph) Mg, respectively. The $CuMg_2$ is a single-composition stoichiometric phase, and Cu_2Mg has a small solubility range of ~3 at.% at the higher temperatures.

The Cu-Ni system [1991Nas] (Fig. 2) is a simple iso-

Table 1 Structure Data of the Binary Phases in Cu-Mg-Ni System

Phase Designation	Composition	Pearson Symbol	Space Group	Type	Lattice Parameters, nm a	b	c
γ	(Cu), (Ni), (Cu, Ni)	*cF*4	$Fm\bar{3}m$	Cu	…	…	…
ϵ	(Mg)	*hP*2	$P6_3/mmc$	Mg	…	…	…
λ_2	Cu_2Mg	*cF*24	$Fd\bar{3}m$	Cu_2Mg	0.7043(a)	…	…
ρ	$CuMg_2$	*oF*48	*Fddd*	Related to Al_2Cu	0.9052	1.8216	0.5296(b)
λ_3	$MgNi_2$	*hP*24	$P6_3/mmc$	$MgNi_2$	0.48147	…	1.58019(c)
δ	Mg_2Ni	*hP*18	$P6_222$	…	0.5212	…	1.322(c)

(a) Lattice parameter from [1963Nev]
(b) Lattice parameter from [1995Ips]
(c) Lattice parameter from [1991Nas]

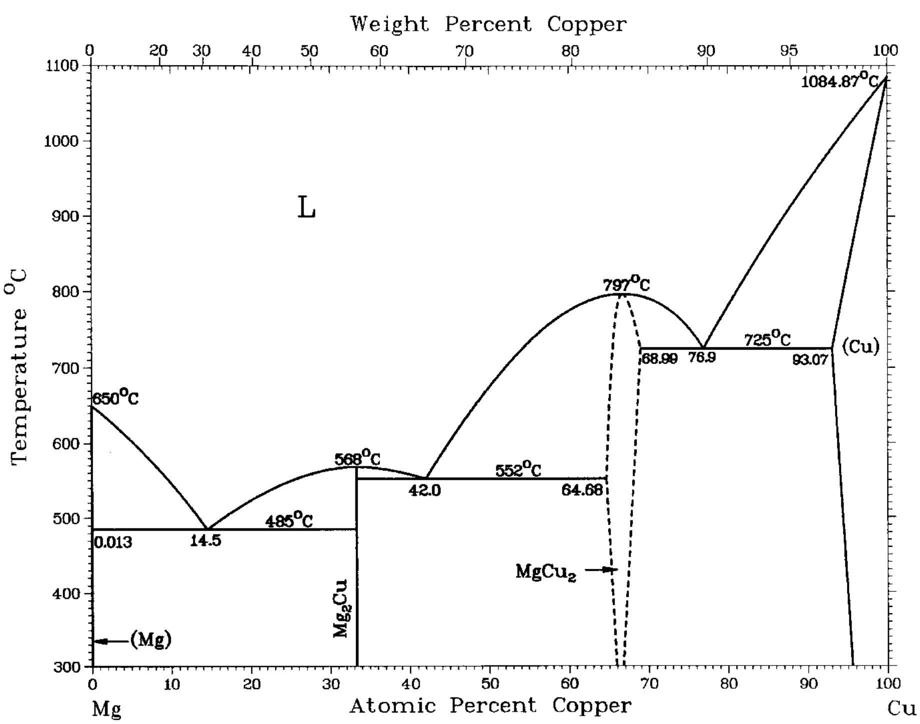

Fig. 1 Cu-Mg binary phase diagram [Massalski2]

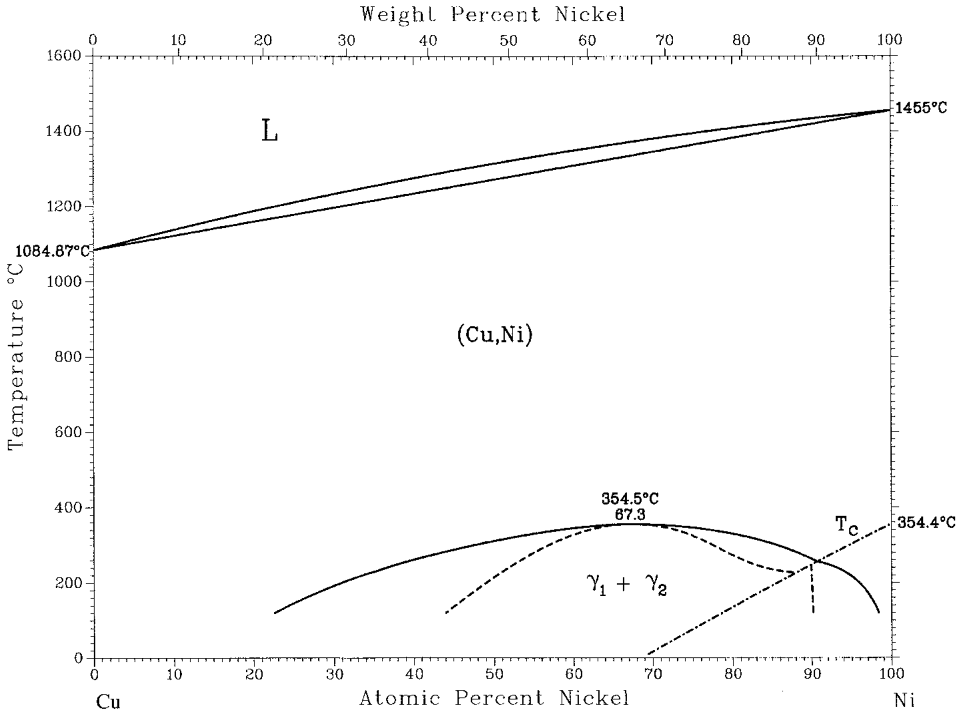

Fig. 2 Cu-Ni binary phase diagram [1991Nas]

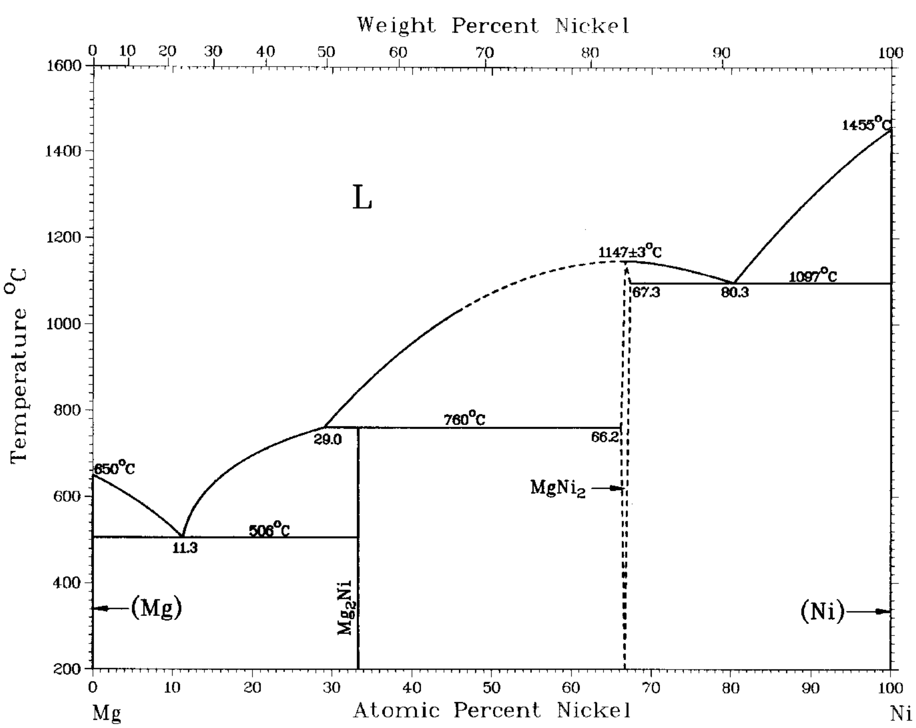

Fig. 3 Mg-Ni binary phase diagram [1991Nas]

morphous system. The fcc γ-phase possibly has a separation of Cu-rich and Ni-rich phases at temperatures <354 °C.

The Mg-Ni system [1991Nas] (Fig. 3) has two intermediate phases, Mg_2Ni (δ) and $MgNi_2$ (λ_3); latter phase melts congruently at 1147 °C. The Mg_2Ni phase forms through a peritectic reaction, L + $\lambda_3 \leftrightarrow \delta$, at 760 °C. Two eutectic reactions, L $\leftrightarrow \epsilon + \delta$ and L $\leftrightarrow \delta + \gamma$, occur at 504 and 1007 °C, respectively. The Mg_2Ni phase is a single-composition stoichiometric phase, whereas the $MgNi_2$ phase has a very narrow solubility range of ~1 at.%.

Binary and Ternary Phases

The three binary systems of the Cu-Mg-Ni system have only four intermediate phases. No ternary phase is known to occur in the Cu-Mg-Ni system. The structure data for the binary phases are given in Table 1.

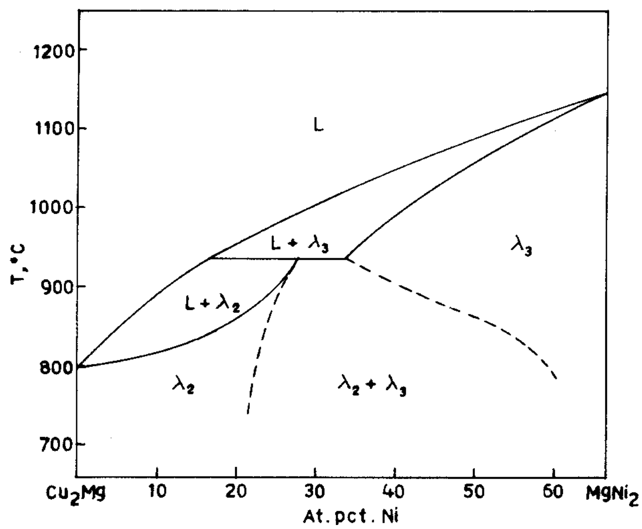

Fig. 4 Pseudobinary section Cu_2Mg-$MgNi_2$ [1979Cha]

Ternary System

The Cu-Mg-Ni system was studied between 1951 and 1972 by various investigators. The results of all these investigators were evaluated by [1979Cha] to compile the phase equilibria data that were available up to 1979. The phase equilibria of the Cu-Mg-Ni system given by [1979Cha] are cited below.

A pseudobinary exists between the two AB_2 Laves phases Cu_2Mg and $MgNi_2$ (Fig. 4). The pseudobinary is a peritectic type, $L + \lambda_3 \leftrightarrow \lambda_2$, with a peritectic temperature of 930 °C. The λ_2 phase forms at a composition of ~28 at.% Ni.

A liquidus projection with temperature isotherms (Fig. 5) was established. The liquidus projection shows the presence of four four-phase reactions: U_1, $L + \lambda_3 \leftrightarrow \gamma + \lambda_2$ at 808 °C; U_2, $L + \lambda_3 \leftrightarrow \lambda_2 + \delta$ at ~650 °C; U_3, $L + \lambda_3 \leftrightarrow \rho + \delta$ at 540 °C; and E, $L \leftrightarrow \epsilon + \rho + \delta$ at 480 °C. The compositions of the liquid at the four four-phase reactions are given in Table 2.

An isothermal section at 475 °C is given in Fig. 6. Besides the equilibrium between the λ_2 and λ_3 phases, the isothermal section also shows equilibrium between the δ and ρ phases. Four three-phase equilibrium triangles, $\gamma + \lambda_2 + \lambda_3$, $\lambda_2 + \lambda_3 + \delta$, $\lambda_2 + \rho + \delta$, and $\rho + \delta + \epsilon$, were also established. In Fig. 6, the binary-phase regions are shown according to whatever data were available through the *Met-*

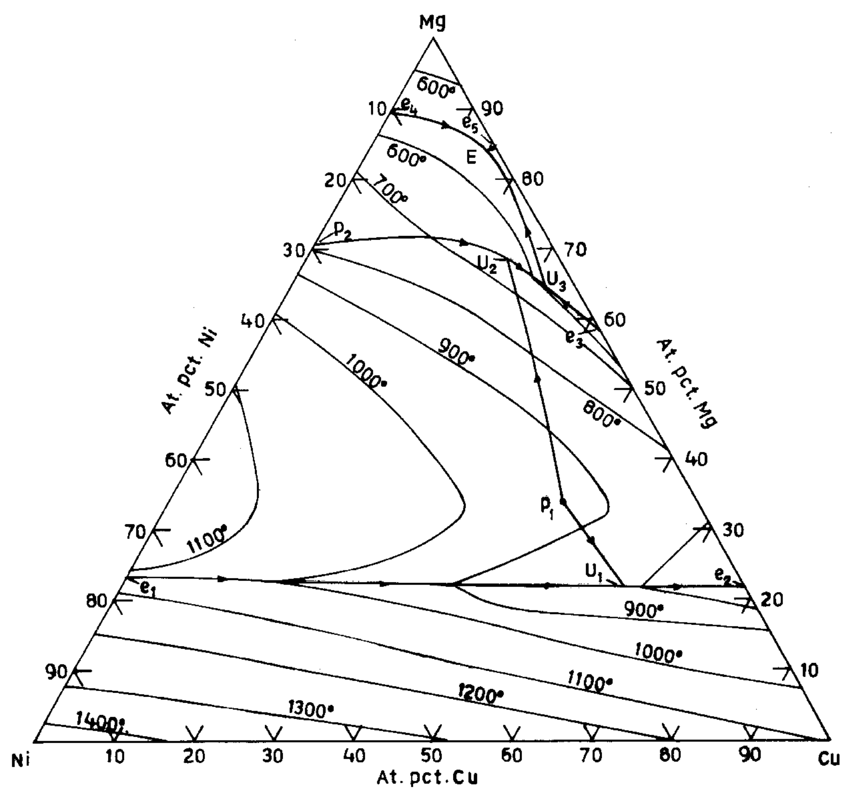

Fig. 5 Liquidus projection with temperature isotherms for the Cu-Mg-Ni system [1979Cha]

als Handbook at the time of compilation of data by [1979Cha]. Since the binary phase diagrams accepted here do not agree with the data available at the time of compilation of the isothermal section data, further phase boundary adjustments will be necessary to conform to the accepted binary data.

Table 2 Three-Phase and Four-Phase Equilibria in the Cu-Mg-Ni System

Reaction	Temperature, °C	Phase	Composition, at.%					
			Cu	Mg	Ni(a)	Cu	Mg	Ni(b)
p_1: L + λ_3↔λ_2	930(a)	L	49.7	33.3	17.0	…	…	…
		λ_2	38.7	33.3	28.0	…	…	…
		λ_3	32.7	33.3	34.0	…	…	…
U_1: L + λ_3 ↔ γ + λ_2	808(a)(b)	L	63.0	22.3	14.8	65	20	15
		λ_2	…	…	…	45	32	23
		λ_3	…	…	…	5	32	63
		γ	…	…	…	72	5	23
U_2: L + λ_3 ↔ λ_2 + δ	~650(a)	L	21.1	71.1	7.8	25	67	8
	658(b)	λ_3	…	…	…	5	34	61
		δ	…	…	…	21	67	12
		λ_2	…	…	…	41	34	25
U_3: L + λ_2 ↔ δ + ρ	540(a)	L	30.6	66.2	3.2	29	68	3
		λ_2	…	…	…	65	35	0
		λ_3	…	…	…	25	67	8
		ρ	…	…	…	32	67	1
E: L ↔ ϵ + ρ + δ	480(a)	L	14.9	84.1	1.0	15	84	1
		ϵ	…	…	…	0	100	0
		δ	…	…	…	25	67	8
		ρ	…	…	…	32	67	1

(a) [1979 Cha]
(b) [1995 Ips]

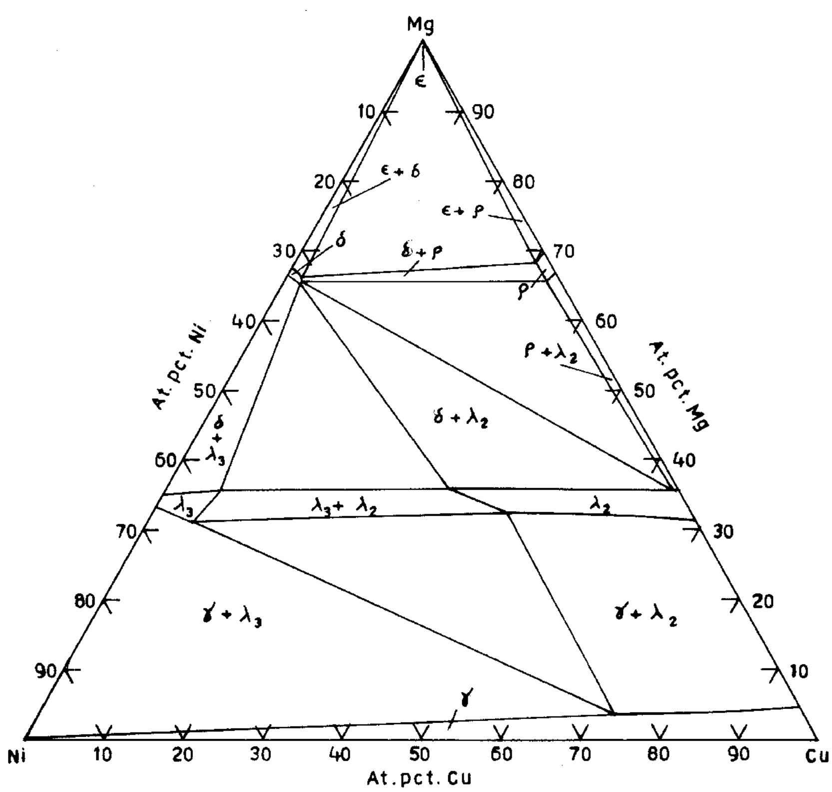

Fig. 6 Isothermal section of the Cu-Mg-Ni system at 475 °C [1979Cha]

Enthalpies of the formation of alloys along the Cu_2Mg-$MgNi_2$ composition line have been measured by [1972Pre] and are given in Fig. 7 [1979Cha] for $Cu_{2-x}Ni_xMg$ alloys as a function of Ni content X. The hump in the enthalpy curve

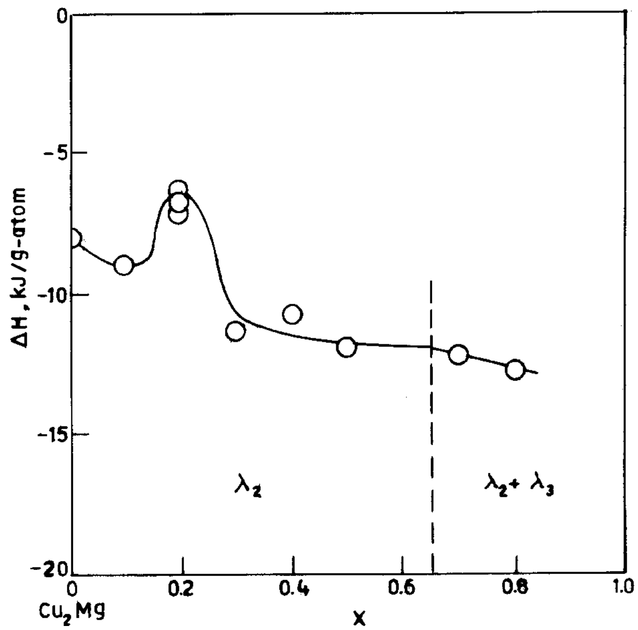

Fig. 7 Variation of enthalpy of formation of Cu_2Mg-$MgNi_2$ alloys as a function of $MgNi_2$ content [1979Cha]

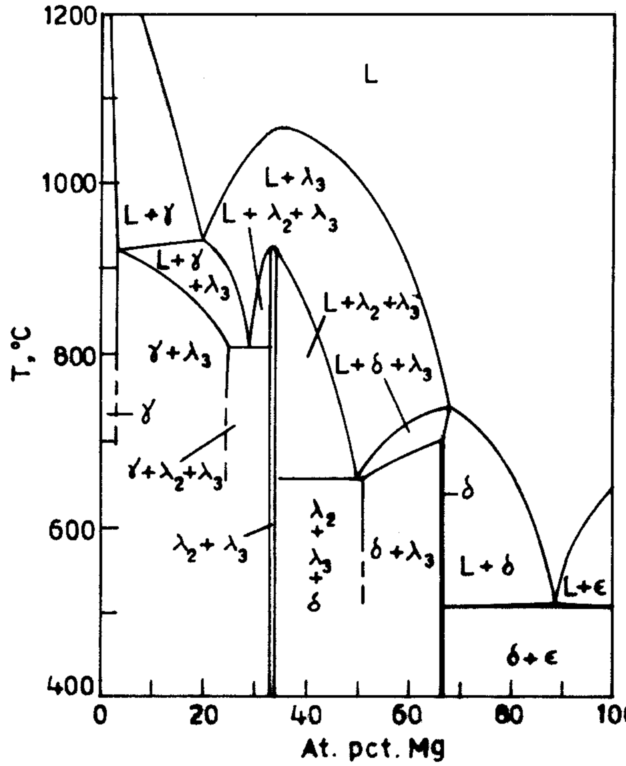

Fig. 9 Isopleth along a line with a constant Cu/Ni ratio of 1.0 [1995Ips]

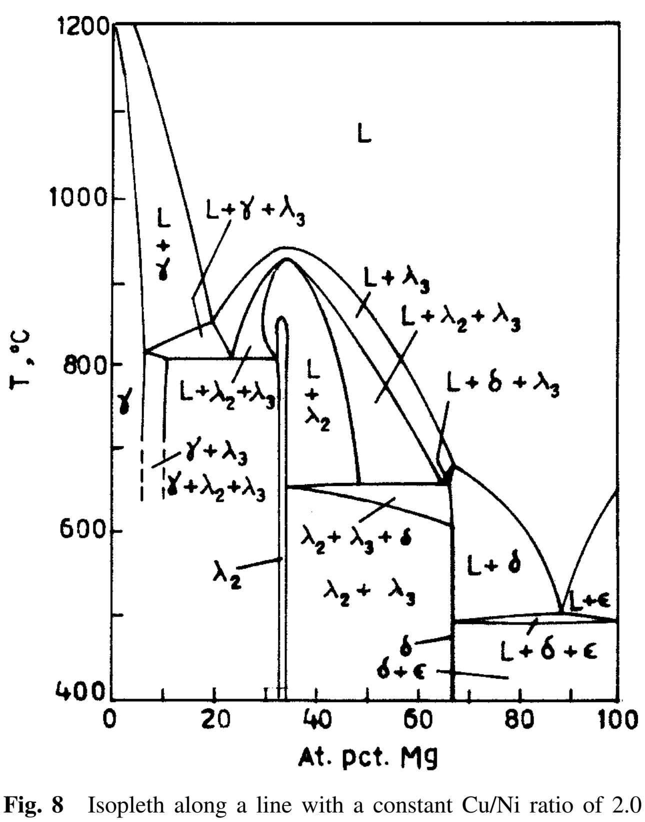

Fig. 8 Isopleth along a line with a constant Cu/Ni ratio of 2.0 [1995Ips]

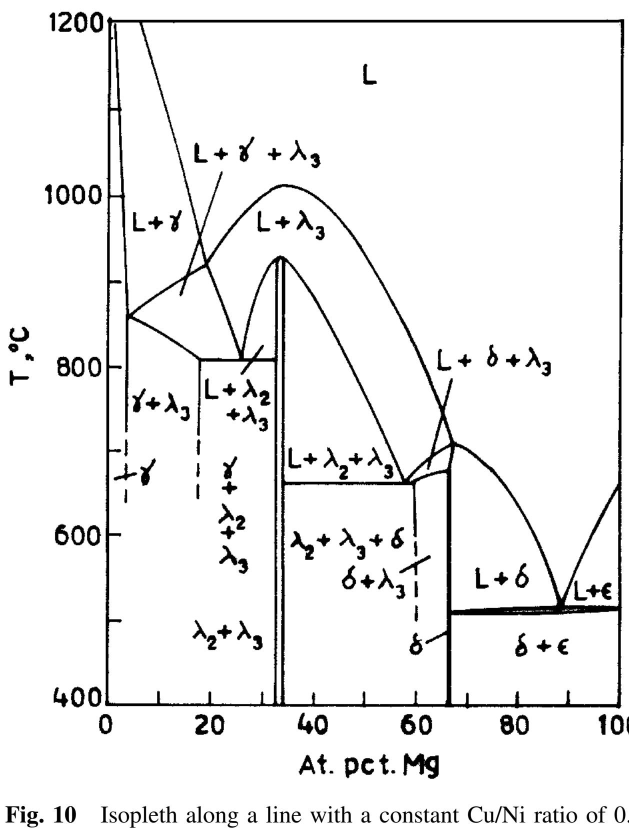

Fig. 10 Isopleth along a line with a constant Cu/Ni ratio of 0.5 [1995Ips]

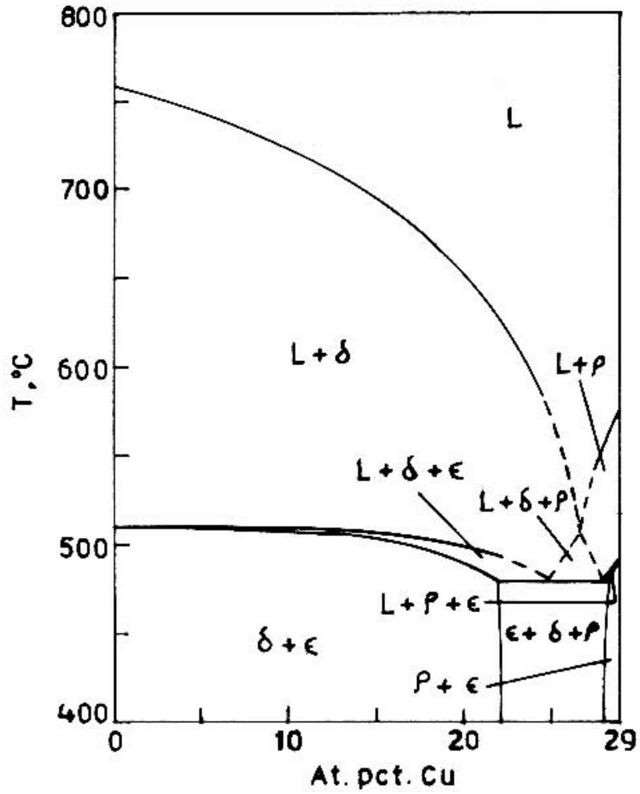

Fig. 11 Isopleth along a line with a constant Mg content of 71 at.% [1995Ips]

near $X = 0.2$ has been attributed to an interaction between the Fermi Surface and the Brillouin zone boundary.

A further study of the Cu-Mg-Ni system has been done more recently by [1995Ips]. With 28 alloy specimens, [1995Ips] studied the Cu-Mg-Ni system by establishing four isopleths, three of which have Cu/Ni ratios of 2.0, 1.0, and 0.5, and the fourth one is along a constant Mg content of 71 at.%. For alloy preparation, high-purity (≥99.95 mass% pure) metals were used. Special care was taken for melting the 71 at.% Mg alloys. All alloys were chemically analyzed to determine their final compositions. The investigation was carried out using differential thermal analysis (DTA) and x-ray diffraction (XRD). Specially designed DTA crucibles (iron crucibles with graphite lining) were used, and the investigation was carried out up to 1060 °C with heating and cooling rates of 2 °C/min. Before DTA measurements, the alloy samples were annealed between 400 and 500 °C for 2-6 weeks. The accuracy of the transformation temperature determination was estimated to be approximately ±3 °C.

The DTA results for the four isopleths are given in Fig. 8-11. The Cu_2Mg phase was found as a narrow phase region in the isopleth for the Cu/Ni ratio of 2.0 (Fig. 8), whereas a narrow two-phase region Cu_2Mg + $MgNi_2$ exists in the isopleths of Cu/Ni ratios of 1.0 and 0.5 (Fig. 9 and 10, respectively). This agrees well with the 475 °C isothermal section given by [1979Cha]. Unlike what is given by [1979Cha], the three isopleths (Fig. 8-11) indicate that the Mg_2Ni phase extends as a very narrow phase region up to about 25 at.% Cu. The isopleth at 71 at.% Mg (Fig. 11) also

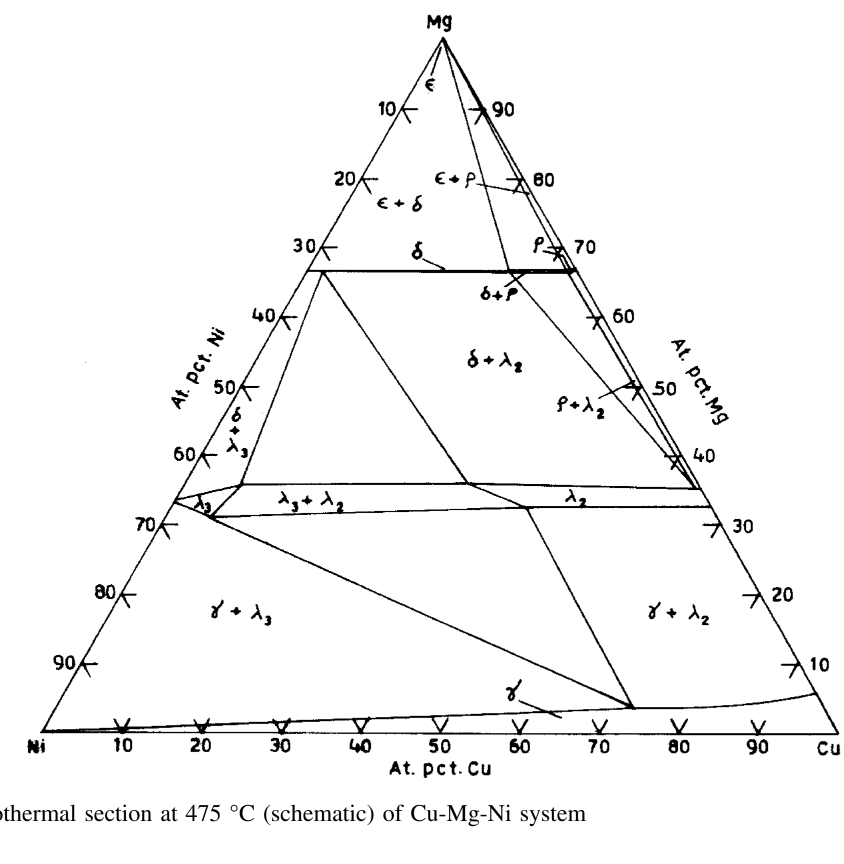

Fig. 12 A probable isothermal section at 475 °C (schematic) of Cu-Mg-Ni system

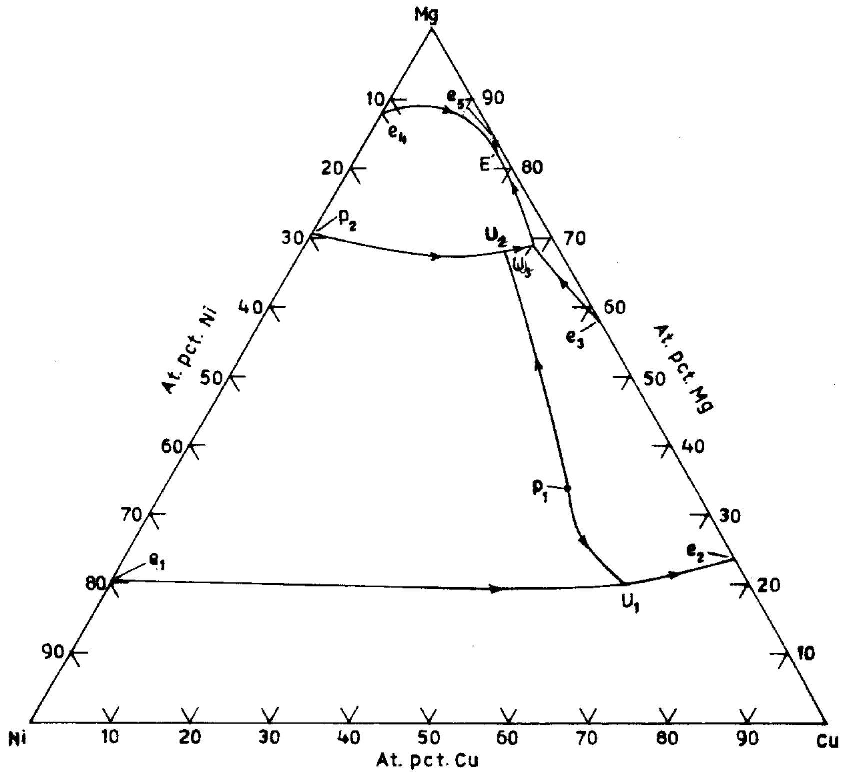

Fig. 13 Liquidus projection of Cu-Mg-Ni system by [1995Ips]

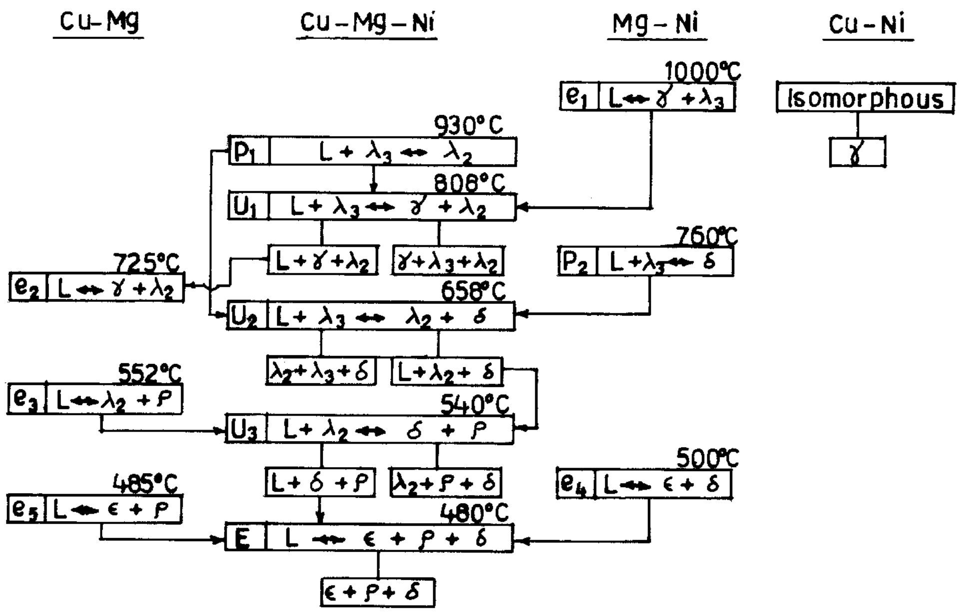

Fig. 14 Reaction scheme for the Cu-Mg-Ni system

shows a wide $\delta + \epsilon$ phase region extending up to ~22 at.% Cu. All this indicates that the three-phase equilibrium triangles $\delta + \lambda_2 + \rho$ and $\delta + \rho + \epsilon$ will be smaller than what was cited earlier by [1979Cha]. A probable 475 °C isothermal section is given schematically (Fig. 12) incorporating the available information through the isopleths and the accepted binary data.

From the liquidus data of the four isopleths (Fig. 8-11), the path of liquid compositions leading to the four four-phase reaction points U_1, U_2, U_3, and E have been redrawn by [1995Ips] and are given in Fig. 13. The corresponding reaction scheme is given in Fig. 14. While most of the four phase reaction points remain practically the same, the new data show that the reaction U_3 occurs at a slightly

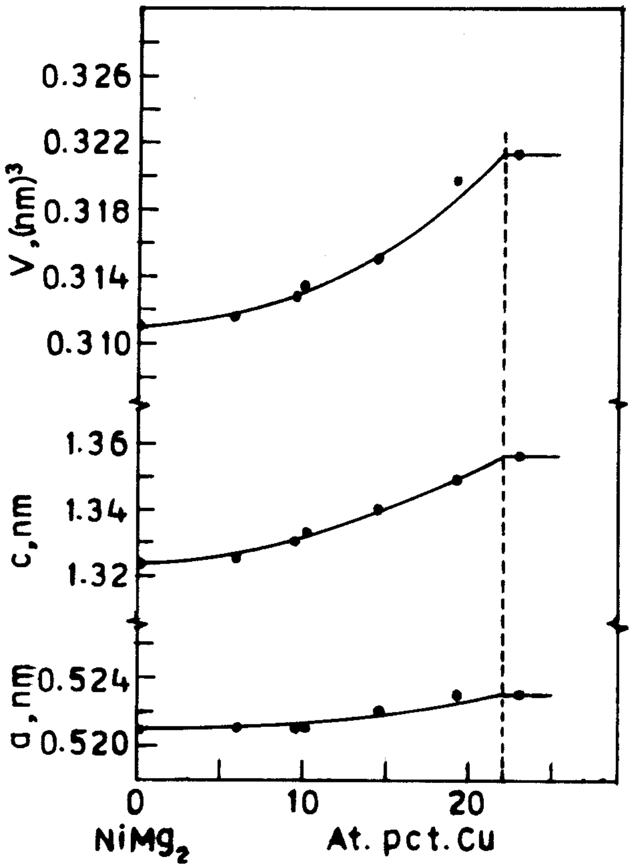

Fig. 15 Variation of the lattice parameter of the Mg_2Ni (δ) phase as a function of Cu content [1995Ips]

higher Mg content. The liquid compositions for the reaction points given by [1995Ips] are also given in Table 2. The estimated compositions for the solid phases in equilibrium with liquid at 808, 658, 540, and 480 °C are also given in Table 2. No details are given as to how these estimations of the compositions of the solid phases in equilibrium with liquid were made. Hence, these compositions of the solid phases in equilibrium with liquid should be treated as tentative.

From the two-phase alloys along the 71 at.% Mg line, [1995Ips] determined the compositional dependence of the lattice parameter of the Mg_2Ni phase with Cu content (Fig. 15) and thereby determined the boundary location between the $\delta + \epsilon$ and $\delta + \epsilon + \rho$ regions. The phase boundary was found to exist at ~22 at.% Cu.

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Cu-Mg-Ni 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.