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Al-Ce-Ni (Aluminum-Cerium-Nickel)

V. Raghavan

The early report on the phase equilibria of this ternary system by [1983Zar] presented partial isothermal sections at 800, 600, and 500 °C for Ce concentrations up to 33.3 at.%, depicting a number of ternary compounds. Recently, [2008Tan] reinvestigated the system at 800 °C and found two new ternary compounds of unknown structure. The solidification features near the Al corner were studied by [1996Bel].

Binary Systems

The Al-Ce phase diagram was recently reassessed thermodynamically by [2005Gao], using new experimental results as additional input. The intermediate phases in this system are: αCe_3Al ($D0_{19}$, Ni_3Sn-type hexagonal), βCe_3Al ($L1_2$, $AuCu_3$-type cubic), Ce_2Al (stable between 775 and

Table 1 Al-Ce-Ni crystal structure and lattice parameter data [2008Tan]

Phase	Composition, at.%	Pearson symbol	Space group	Prototype	Lattice parameter, nm
AlCeNi (τ_1)	36.4-34.1 Al	*hP*9	$P\bar{6}2m$	Fe_2P	a = 0.69927-0.69745
	33.0-32.7 Ce				c = 0.40276-0.40155
	30.6-33.2 Ni				
Al_2CeNi (τ_2)	53.0-50.7 Al	*oC*16	*Cmcm*	Al_2CuMg	a = 0.40741-0.40774
	24.5-26.9 Ce				b = 1.09631-1.09750
	22.5-22.4 Ni				c = 0.69373-0.69442
$Al_5Ce_2Ni_5$ (τ_3)	41.7 Al	...	...	...	...
	16.7 Ce				
	41.7 Ni				
Al_3CeNi_2 (τ_4)	50.0 Al	*hP*6	*P6/mmm*	$CaCu_5$	a = 0.528
	16.7 Ce				c = 0.404
	33.3 Ni				
Al_4CeNi (τ_5)	66.7 Al	*oC*24	*Cmcm*	Al_4NiY	a = 0.4097
	16.7 Ce				b = 1.547
	16.7 Ni				c = 0.6643
Al_5CeNi_2 (τ_6)	62.5 Al	*oI*16	*Immm*	Al_5Ni_2Pr	a = 0.7030
	12.5 Ce				b = 0.9597
	25.0 Ni				c = 0.3999
Al_7CeNi_2 (τ_7)	70 Al	...	...	...	...
	10 Ce				
	20 Ni				
$Al_{23}Ce_4Ni_6$ (τ_8)	69.7 Al	*mC*66	*C2/m*	$Al_{23}Y_4Ni_6$	a = 1.6042
	12.1 Ce				b = 0.4140
	18.2 Ni				c = 1.8380
					β = 113.24°
$Al_{17}Ce_{40}Ni_{43}$ (τ_9)	17 Al	*oI*?	*Immm*	$MoNi_2B_2$	a = 0.5331
	40 Ce				b = 0.8403
	43 Ni				c = 0.4241
$AlCeNi_4$ (τ_{10})	16.7 Al	*hP*6	*P6/mmm*	$CaCu_5$	a = 0.4943
	16.7 Ce				c = 0.4085
	66.7 Ni	...	...	...	...
τ_{11}	59.8 Al				
	12.1 Ce				
	28.1 Ni				
τ_{12}	40.3 Al	...	...	...	...
	30.4 Ce				
	29.3 Ni				

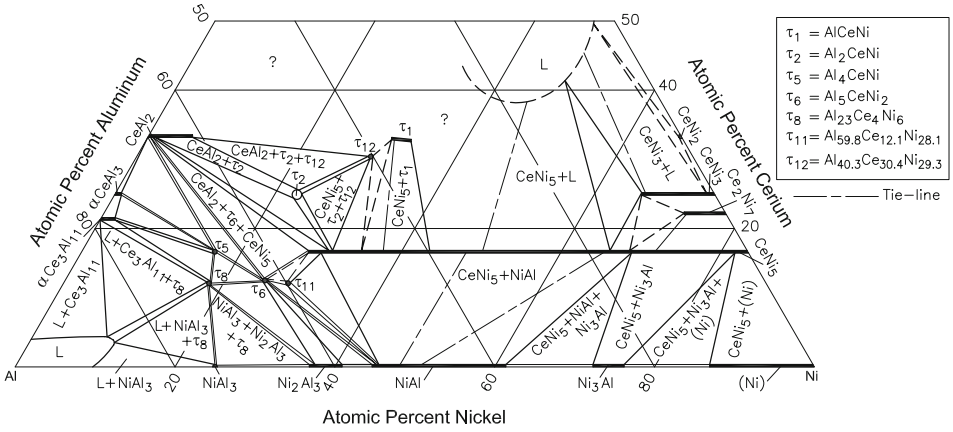

Fig. 1 Al-Ce-Ni isothermal section at 800 °C for Ce-lean alloys [2008Tan]

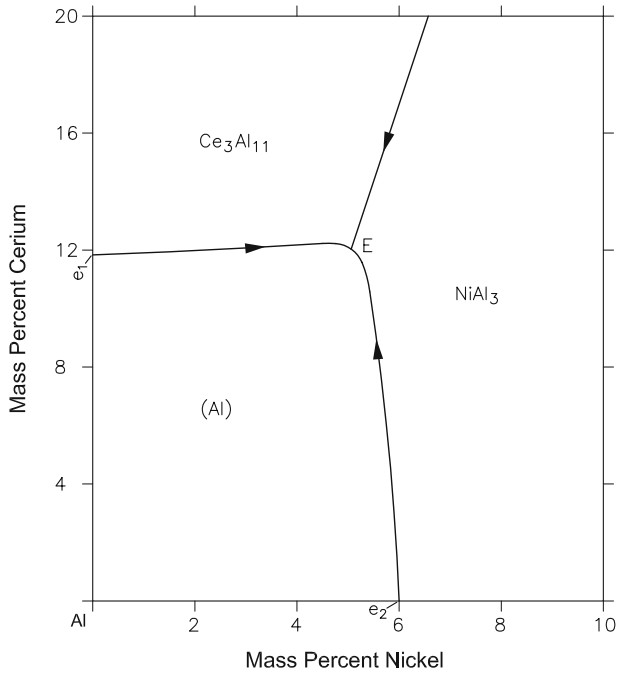

Fig. 2 Al-Ce-Ni liquidus projection near the Al corner [1996Bel]

648 °C; Co_2Si-type orthorhombic?), CeAl (orthorhombic), $CeAl_2$ (*C*15, $MgCu_2$-type cubic), $\alpha CeAl_3$ (Ni_3Sn-type hexagonal), $\beta CeAl_3$ (hexagonal, stable between 1192 and 973 °C), $CeAl_4$ or βCe_3Al_{11} ($D1_3$, Al_4 Ba-type tetragonal), and αCe_3Al_{11} (αCe_3La_{11}-type orthorhombic). The Al-Ni phase diagram [1993Oka] shows five intermediate phases: $NiAl_3$ ($D0_{11}$, Fe_3C-type orthorhombic), Ni_2Al_3 ($D5_{13}$-type hexagonal), NiAl (*B*2, CsCl-type cubic, denoted β), Ni_5Al_3 (Ga_3Pt_5-type orthorhombic), and Ni_3Al ($L1_2$, $AuCu_3$-type cubic, denoted γ′). The Ce-Ni phase diagram [Massalski2] depicts the following binary compounds: Ce_7Ni_3 ($D10_2$, Fe_3Th_7-type hexagonal), CeNi (B_f, CrB-type orthorhombic), $CeNi_2$ (*C*15, $MgCu_2$-type cubic), $CeNi_3$ (hexagonal), Ce_2Ni_7 (hexagonal), and $CeNi_5$ ($D2_d$, $CaCu_5$-type hexagonal).

Ternary Compounds

A total of 12 ternary compounds are known in this system. The structural details of these are shown in Table 1 [2008Tan]. The ternary compounds AlCeNi (τ_1) and Al_2CeNi (τ_2) show a measurable homogeneity range and a corresponding variation in the lattice parameters, Table 1. The compounds $Al_5Ce_2Ni_5$ (τ_3), Al_3CeNi_2 (τ_4), Al_7CeNi_2 (τ_7), and $Al_{17}Ce_{40}Ni_{43}$ (τ_9) were not found by [2008Tan] at 800 °C. The compound τ_{10} is a solid solution based on the binary compound $CeNi_5$. The composition variation in the compounds Al_4CeNi (τ_5), Al_5CeNi_2 (τ_6), and $Al_{23}Ce_4Ni_6$ (τ_8) was found to be very small [2008Tan]. The compounds τ_{11} and τ_{12} were newly found by [2008Tan], but the crystal structures were not determined.

Ternary Phase Equilibria

With starting metals of 99.999% Al, 99.9% Ce, and 99.9% Ni, [2008Tan] arc-melted under Ar atm 34 ternary alloys with Ce content up to 33.3 at.%. The alloys were annealed at 800 °C for 20 days and quenched in water. The phase equilibria were studied by x-ray powder diffraction, optical and scanning electron microscopy and energy dispersive x-ray spectroscopy. The measured compositions of the identified phases were listed.

The isothermal section for Ce-lean alloys at 800 °C constructed by [2008Tan] is shown in Fig. 1. The ternary compounds τ_1, τ_2, τ_5, τ_6, τ_8, τ_{11}, and τ_{12} are present. The binary phase $CeNi_5$ dissolves up to 55 at.% Al at constant Ce content (denoted τ_{10} by [2008Tan]). The lattice parameters vary nonlinearly from $a = 0.4880$ nm and $c = 0.4013$ nm at 0% Al to $a = 0.53423$ nm and $c = 0.40344$ nm at 55 at.% Al. The other Ce-Ni phases Ce_2Ni_7 and $CeNi_3$ dissolve 5.2 and 13.1 at.% Al. $CeNi_2$ shows no solubility for Al [2008Tan], in contrast to the solubility of 10 at.% reported by [1983Zar]. The Al-Ce compounds $CeAl_2$, Ce_3Al_{11}, $\alpha CeAl_3$, and $\beta CeAl_3$ dissolve 5.5, 1.8, 0.6,

and 3.8 at.% Ni respectively. The Al-Ni phases dissolve very little Ce.

Very recently, [2009Tan] reported a second isothermal section for this system at 500 °C for compositions up to 33.3 at.% Ce. The ternary compounds τ_3, τ_7, τ_{10}, τ_{11} and τ_{12} are not present at 500 °C. A compound found at the composition $Al_{35}Ce_{16.5}Ni_{48.5}$ was labeled as τ_9 by [2009Tan]. This composition is different from $Al_{17}Ce_{40}Ni_{43}$, which was labeled τ_9 by [2008Tan].

The solidification of Al-rich alloys was investigated by [1996Bel]. Starting with high purity metals, [1996Bel] melted in a resistance furnace a number of binary and ternary alloys with Ce and Ni contents up to 16 and 8 mass% respectively. The phase equilibria were studied with optical and scanning electron microscopy, electron probe microanalysis, and differential thermal analysis. The liquidus projection constructed by [1996Bel] near the Al corner is shown in Fig. 2. The solidification is through the ternary eutectic reaction E: $L \leftrightarrow (Al) + Ce_3Al_{11} + NiAl_3$ at 626 °C with the liquid composition at 12Ce-5Ni (mass%).

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