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Al-Cu-Ho (Aluminum-Copper-Holmium)

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Recently, [2005Ria] investigated in detail this ternary system and constructed an isothermal section at 500 °C, which depicts nine ternary compounds.

Binary Systems

The Al-Cu phase diagram [Massalski2] depicts a number of intermediate phases. $CuAl_2$ (θ) is a *C*16-type tetragonal phase. CuAl (η) has two crystal modifications, the high-temperature orthorhombic and the low-temperature monoclinic forms. The two forms of the ζ phase occur in the composition range of 55.2-59.8 at.% Cu and are stable below 590 °C. Two modifications of the ε phase occur around the composition Cu_3Al_2 and are stable above 560 °C. The structures of the phases, δ, γ_1 (Cu_9Al_4), and γ_0, which are stable between 58 and 70 at.% Cu, are based on the γ-brass structure. The β phase (70.6-82 at.% Cu) is body-centered cubic (bcc) and is stable above 567 °C. Copper dissolves up to 20 at.% Al. [2005Ria] accepted the more recent results of [1996God] and [1998Liu] on some parts of the Al-Cu system. The Al-Ho phase diagram [1988Gsc] depicts five line compounds: $HoAl_3$ (rhombohedral), $HoAl_2$ (*C*15, $MgCu_2$-type cubic), HoAl (ErAl-type orthorhombic), Ho_3Al_2 (Al_2Zr_3-type tetragonal), and Ho_2Al (*C*23, Co_2Si-type orthorhombic). [1988Sub] calculated the Cu-Ho phase diagram using data derived from thermodynamic considerations and the systematics of Cu-lanthanide systems. The diagram depicts the following compounds: Cu_5Ho ($C15_b$, $AuBe_5$-type cubic), Cu_9Ho_2, Cu_2Ho ($CeCu_2$-type orthorhombic), and CuHo (CsCl-type cubic).

Ternary Phases

Table 1 lists the crystal structure data on the nine ternary phases of this system [2005Ria]. $Ho_3(Cu_xAl_{1-x})_{11}$ (τ_1) ($0.12 \leq x \leq 0.185$) is a La_3Al_{11}-type orthorhombic phase. $Ho(Cu_xAl_{1-x})_3$ (τ_2) ($0.215 \leq x \leq 0.41$) is $PuNi_3$-type hexagonal. $Ho(Cu_xAl_{1-x})_2$ (τ_3) ($0.43 \leq x \leq 0.615$) is Fe_2P-type

Table 1 Al-Cu-Ho crystal structure and lattice parameter data

Phase	Composition, at.%	Pearson symbol	Space group	Prototype	Lattice parameter, nm
$Ho_3(Cu_xAl_{1-x})_{11}$ (τ_1)	69.1–64.0 Al 9.4–14.5 Cu 21.4 Ho	*oI*28	*Immm*	La_3Al_{11}	a = 0.4195 b = 1.2384 c = 0.9811(a)
$Ho(Cu_xAl_{1-x})_3$ (τ_2)	58.9–44.25 Al 16.1–30.75 Cu 25 Ho	*hR*36	$R\bar{3}m$	$PuNi_3$	a = 0.5360 c = 2.551(b)
$Ho(Cu_xAl_{1-x})_2$ (τ_3)	38–25.7 Al 28.7–41 Cu 33.3 Ho	*hP*9	$P\bar{6}2m$	Fe_2P	a = 0.6994 c = 0.4015(c)
$Ho(Cu_xAl_{1-x})_{12}$ (τ_4)	59.1–41.5 Al 33.2–50.8 Cu 7.7 Ho	*tI*26	*I*4/*mmm*	$ThMn_{12}$	a = 0.8725 c = 0.5130(d)
$Ho_2(Cu_xAl_{1-x})_{17}$ (τ_5)	51.9–27.7 Al 37.6–61.8 Cu 10.5 Ho	*hR*57	$R\bar{3}m$	Th_2Zn_{17}	a = 0.8826 c = 1.2858(e)
$Ho(Cu_xAl_{1-x})_5$ (τ_6)	45.8–15.4 Al 37.5–67.9 Cu 16.7 Ho	*hP*6	*P*6/*mmm*	$CaCu_5$	a = 0.5248 c = 0.4088(f)
$Ho_6Cu_{15.4}Al_{7.6}$ (τ_7)	26.2 Al 53.1 Cu 20.7 Ho	*cF*116	$Fm\bar{3}m$	Th_6Mn_{23}	a = 1.2277
$Ho(Cu_xAl_{1-x})_6$ (τ_8)	16.7–14.6 Al 69.0–71.1 Cu 14.3 Ho	*tI*14	*I*4/*mmm*	$YbMo_2Al_4$	a = 0.6406 c = 0.4949(g)
$Ho(Cu_xAl_{1-x})_4$ (τ_9)	12.0–8.8 Al 68–71.2 Cu 20 Ho	…	…	…	…

Lattice parameter values are at x = (a) 0.185, (b) 0.413, (c) 0.435, (d) 0.37, (e) 0.42, (f) 0.457, and (g) 0.80, where x is the fraction in (Cu_xAl_{1-x})

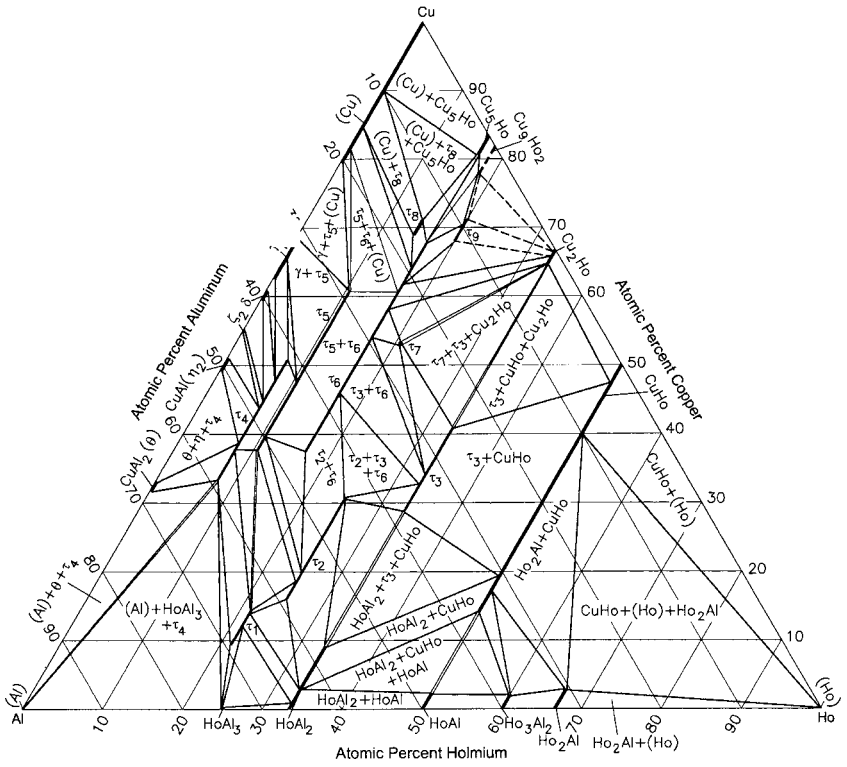

Fig. 1 Al-Cu-Ho isothermal section at 500 °C [2005Ria]

hexagonal. $Ho(Cu_xAl_{1-x})_{12}$ (τ_4) ($0.36 \leq x \leq 0.55$) is $ThMn_{12}$-type tetragonal. $Ho_2(Cu_xAl_{1-x})_{17}$ (τ_5) ($0.42 \leq x \leq 0.69$) is Th_2Zn_{17}-type rhombohedral. $Ho(Cu_xAl_{1-x})_5$ (τ_6) ($0.45 \leq x \leq 0.815$) is $CaCu_5$-type hexagonal. $Ho_6Cu_{15.4}Al_{7.6}$ (τ_7) is Th_6Mn_{23}-type cubic. $Ho(Cu_xAl_{1-x})_6$ (τ_8) ($0.805 \leq x \leq 0.83$) is $YbMo_2Al_4$-type tetragonal. The structure of $Ho(Cu_xAl_{1-x})_4$ (τ_9) ($0.85 \leq x \leq 0.89$) is not known. The homogeneity ranges and the lattice parameters listed in Table 1 are those determined by [2005Ria].

Isothermal Section

With starting metals of 99.999 wt.% Al, 99.99+ wt.% Cu, and 99.9 wt.% Ho, [2005Ria] arc-melted or induction-melted more than 110 alloy samples. These were annealed at 500 °C for one month and quenched in water. The phase equilibria were studied with x-ray diffraction, metallography, and electron probe microanalysis. The isothermal section at 500 °C constructed by [2005Ria], which improves upon and updates the literature data on this system, is redrawn in Fig. 1. As seen in Table 1, the ternary phases τ_1 through τ_9 (with the exception of τ_7) have significant homogeneity ranges, with mutual substitution between Al and Cu at constant Ho content. Around the τ_9 region, the phase equilibria could not be ascertained fully by [2005Ria]. The triangulation indicated in this region in Fig. 1 is schematic. Among the binary compounds, HoAl, Ho_3Al_2, and Ho_2Al dissolve about 2 at.% Cu. $HoAl_2$ dissolves 9 at.% Cu. CuHo, Cu_5Ho, and Cu_2Ho dissolve 36, 3, and 2 at.% Al, respectively. The solubility of Ho in Al-Cu phases is very small.

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