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Al-Cu-Li (Aluminum-Copper-Lithium)

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The early results on the phase equilibria of this ternary system compiled by [1995Vil] presented two isothermal sections at 500 and 350 °C and three vertical sections at Cu/Li mass ratio of 4/1, Cu/Li atom ratio of 9/1 and along the $CuAl_2$-AlLi join respectively. Subsequent studies by [1991Che1] and [1991Che2] presented a liquidus projection for Al-rich alloys and computed phase equilibria and solidification paths of Al-rich alloys. More recently, [2002Mos] determined the thermodynamic properties of the system by emf and calorimetric studies and calculated isothermal sections at 615 and 555 °C for Al-rich alloys.

Binary Systems

The Al-Cu phase diagram [2004Ria] depicts the following intermediate phases: $CuAl_2$ (*C*16-type tetragonal, denoted θ), CuAl(HT) (η_1, orthorhombic) CuAl(LT) (η_2, monoclinic), Cu_5Al_4(HT) (ζ_1, orthorhombic, space group *Fmm*2), Cu_5Al_4(LT) (ζ_2, orthorhombic, space group *Imm*2), ε_1(HT) (cubic?), ε_2(LT) ($B8_1$, NiAs-type hexagonal), Cu_3Al_2 (rhombohedral, denoted δ), Cu_9Al_4(HT) (γ_0, $D8_2$, Cu_5Zn_8-type cubic), Cu_9Al_4(LT) (γ_1, $D8_3$, Cu_9Al_4-type cubic), and Cu_3Al (β, bcc). The Al-Li phase diagram [2007Hal] depicts the following intermediate phases: AlLi (45-55 at.% Li; *B*32, NaTl-type cubic), Al_2Li_3 (Bi_2Te_3-type rhombohedral), and Al_4Li_9 (stable below 335 °C; monoclinic and another form). The Cu-Li phase diagram [Massalski2] is a simple eutectic system, with a maximum terminal solubility of Li in Cu of about 22 at.% and no solubility of Cu in Li.

Ternary Phases

Four ternary phases are known in this system: Al_2CuLi (denoted T_1), ~Al_5CuLi_3 or Al_6CuLi_3 (T_2), ~Al_5CuLi_3 (R), and Al_7Cu_4Li (T_B). The structural characteristics of these phases are listed in Table 1. The T_2 and R phases are very close in composition, with a slightly lower Al content in R than in T_2 [2002Mos]. Two other ternary phases labeled P and Q were also reported [1956Har, 1991Che1] (not listed in Table 1).

Ternary Phase Equilibria

[1991Che1] used 55 Al-rich alloys containing up to 42.5 at.% Cu and 27.5 at.% Li. The phase equilibria were studied with optical and scanning electron metallography, x-ray powder diffraction and electron probe microanalysis. Differential thermal analysis was carried out at a heating/cooling rate of 2 °C per min for equilibrium studies and 20 °C per second for studying the effect of faster cooling rate on the phase distribution. The reaction temperatures were obtained from heating experiments by extrapolating different scanning rates to zero rate. The observed phases and the thermal arrests were listed for all the samples. The liquidus projection for Al-rich alloys constructed by [1991Che1] is shown in Fig. 1. Six U-type transition reactions are seen on the liquidus surface: U_1 (570 °C), U_2 (567 °C), U_3 (547 °C), U_4 (543 °C), U_5 (543 °C) and U_6 ($543 > T > 522$ °C). The final solidification is through the ternary eutectic reaction E (522 °C): $L \leftrightarrow (Al) + T_1 + T_B$.

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

Phase	Composition, at.%	Pearson symbol	Space group	Prototype	Lattice parameter, nm
Al_2CuLi (T_1)	50 Al 25 Cu 25 Li	*hP*?	*P6/mmm*	…	*a* = 0.496 *c* = 0.935
~Al_5CuLi_3 (T_2)	57 Al 11 Cu 32 Li	*cI*162	$Im\bar{3}$	$Al_6Mg_{11}Zn_{11}$	*a* = 1.3914
~Al_5CuLi_3 (R)	55 Al 11.7 Cu 33.3 Li	*cI*160	$Im\bar{3}$	CuLiSi	*a* = 1.39056
Al_7Cu_4Li (T_B)	58.3 Al 33.3 Cu 8.3 Li	*cF*12	$Fm\bar{3}m$	CaF_2	*a* = 0.58328

In their thermodynamic modeling, [1991Che2] reassessed the Al-Cu and Cu-Li binary systems. The Al-Cu phase diagram adopted by [1991Che2] is somewhat different from recent experimental data [2004Ria]. However, in the Al-rich region, the description of [1991Che2] agrees with the experimental data. The liquid, fcc and bcc phases were treated as solution phases and ternary interaction parameters were considered. The binary and ternary compounds (except AlLi) were assumed to be of fixed composition. The P phase was not modeled. The phase equilibrium data of [1956Har] and [1991Che1] and the limited literature data on the thermodynamic properties were used as inputs. The optimized binary and ternary parameters were listed. The computed liquidus projection agrees with the experimental projection shown in Fig. 1. Isothermal sections were computed at 500 and 350 °C. At both these

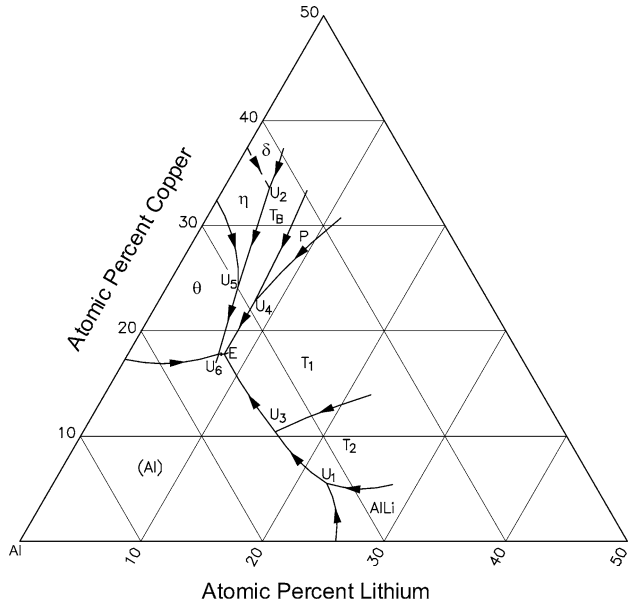

Fig. 1 Al-Cu-Li partial liquidus projection in the Al-rich region [1991Che1]

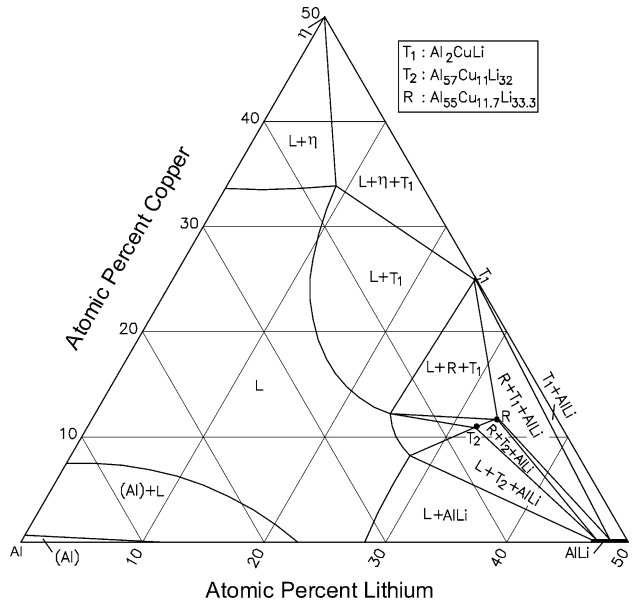

Fig. 3 Al-Cu-Li computed isothermal section at 615 °C in the Al-rich region [2002Mos]. Narrow two-phase regions are omitted

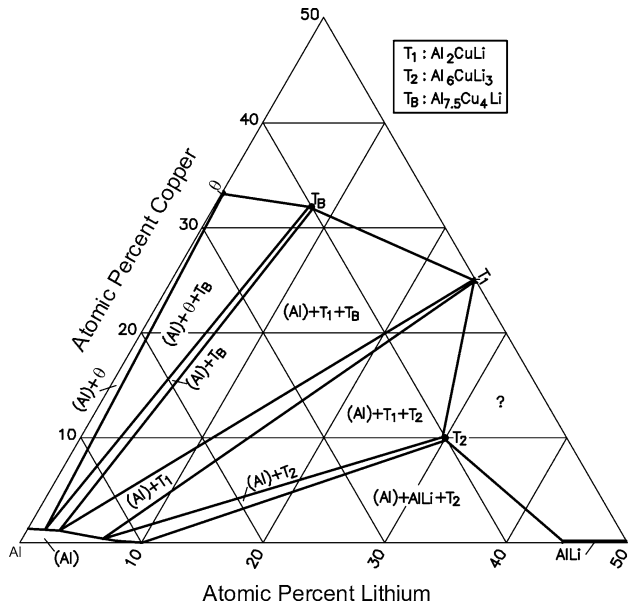

Fig. 2 Al-Cu-Li computed isothermal section at 500 °C in the Al-rich region [1991Che2]

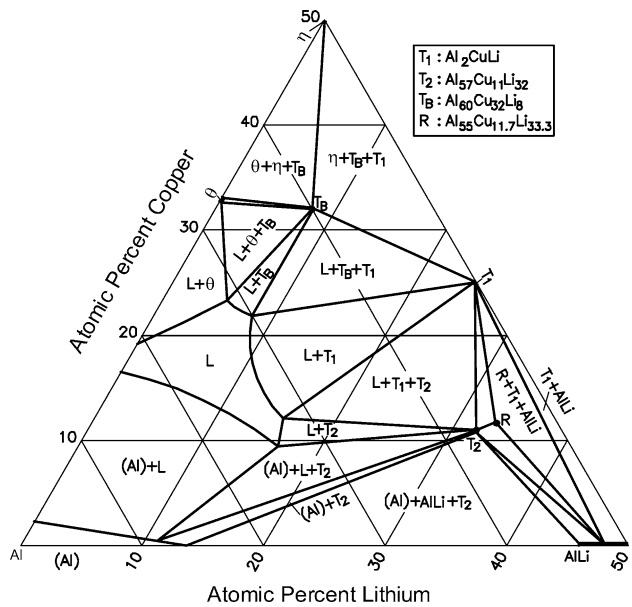

Fig. 4 Al-Cu-Li computed isothermal section at 555 °C in the Al-rich region [2002Mos]. Narrow two-phase regions are omitted

temperatures, (Al) forms tie-lines with θ, T_1, T_2, T_B and AlLi phases. The computed isothermal section at 500 °C shown in Fig. 2 was found to be in satisfactory agreement with the experimental results of [1956Har].

More recently, [2002Mos] determined the thermodynamic properties of liquid and solid ternary alloys of this system from emf measurements in the temperature range of 615-505 °C. Calorimetric measurements were made on liquid alloys at 713 and 672 °C. A new optimization of the phase equilibria was done, using as inputs the emf and calorimetric measurements, enthalpies of formation of T_1, T_2, T_B and R ternary compounds, enthalpies of melting of T_2, R, θ, η, and AlLi (binary/ternary) compounds and updated phase diagram data. The P phase was not considered in the optimization. The isothermal sections computed by [2002Mos] at 615 and 555 °C are shown in Fig. 3 and 4. [2002Mos] stated that the agreement between computed and experimental data was better at 615 °C than at 555 or 505 °C. The computed temperatures of the invariant reactions and the compositions of the participating liquid were listed and compared with literature data. The agreement was found to be satisfactory.

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