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Al-Cu-Mg (Aluminum-Copper-Magnesium)

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The pre-1990 experimental results of this ternary system were evaluated by [1991Pri]. The reviewed data were presented as a liquidus projection, a reaction scheme, an isothermal section at 400 °C, and as solubility limits for the solutes in (Al) and in (Cu). The main developments since then have been two thermodynamic assessments of the system by [1997Che] and [1998Buh].

Binary Systems

The Al-Cu phase diagram [1992Sau, Massalski2] depicts a number of intermediate phases: $CuAl_2$ (*C*16-type tetragonal, denoted θ), CuAl (monoclinic, η), Cu_5Al_4(LT) (monoclinic, ζ), ε_2 (NiAs-type hexagonal), ε_1 (bcc), Cu_3Al_2 (rhombohedral, δ), Cu_9Al_4(HT) (γ_0), Cu_9Al_4(LT) ($D8_3$-type cubic, γ_1), and Cu_3Al (bcc, β). In the above, HT = high-temperature and LT = low-temperature. The Al-Mg phase diagram [2003Cze] has the following intermediate phases: Mg_2Al_3 (cubic, denoted β), R or ε (rhombohedral) and $Mg_{17}Al_{12}$ (*A*12-type cubic, denoted γ). The Cu-Mg diagram [1992Oka] has two intermediate phases: $MgCu_2$ (*C*15-type cubic) and Mg_2Cu (C_b-type orthorhombic).

Ternary Phases

[1991Pri] listed the structural details of the four ternary phases of this system: $Al_7Cu_3Mg_6$ (cubic, denoted Q), Al_2CuMg (BRe_3-type orthorhombic, denoted S), $(Al_xCu_{1-x})_{49}Mg_{32}$ $(0.76 < x < 0.91)$ (cubic, denoted T), and $Al_5Cu_6Mg_2$ (Mg_2Zn_{11}-type cubic, denoted V). In addition, all three Laves modifications occur. The $MgCu_2$ binary cubic phase extends into the ternary region with Al substituting for Cu up to 23 at.% [1998Buh]. With more Al substitution, $MgNi_2$-type hexagonal Laves phase is stable. With further Al substitution, $MgZn_2$-type hexagonal form is stable [1991Pri]. Also, polytype structures with variations in the stacking sequence have been found. [1991Pri] summarized the known results of the phases found along the 33.3 at.% Mg line. There is no general agreement among different workers regarding the homogeneity ranges of these Laves phases or their polytypes. [1997Che] clubbed these modifications together as one phase U, denoted λ here. Due to the assumptions made by [1997Che] in the computed equilibria, U (or λ) appears as a separate phase from a nearly pure $MgCu_2$.

Thermodynamic Description

In their optimization, [1997Che] used the experimental results of the liquidus projection from [1949Bro], [1951Mir] and [1952Ura] and of the isothermal section at 400 °C from [1952Ura], supplemented by the reviewed data of [1991Pri]. The thermochemical data used were of [1965Sli] and [1972Pre] on specific heats and enthalpies of formation of alloys along the Cu_2Mg-'Al_2Mg' section, of [1986Not] on the enthalpy of formation of the S phase and of [1995Kim] on the enthalpy of mixing of the liquid phase. Among the recent studies, the results of [1995Hua] on the phase equilibria in Al-rich alloys were included.

The following thermodynamic descriptions for the binary systems were accepted: Al-Cu [1992Sau], Al-Mg [1993Zuo1], and Cu-Mg [1993Zuo2]. The S, Q and V ternary phases were treated as stoichiometric compounds. The T and λ phases were approximated as semi-stoichiometric phases corresponding to the formulae $(Al_xCu_{1-x})_{49}Mg_{32}$ and $(Al_xCu_{1-x})_2Mg$ respectively. No distinction was made between the three Laves modifications. The liquid, fcc, cph, and bcc solid solutions were treated as disordered ternary solution phases. The optimized interaction parameters were listed.

[1998Buh] considered the three Laves modifications of λ separately with the composition variation of 0-23.3 Al at.% for $MgCu_2$, 30.7-43.3 at.% Al for $MgZn_2$-type, and 26.7-43.3 at.% Al for $MgNi_2$-type. Based on the details of the crystal structures, the three modifications were modeled and an elaborate set of interaction parameters was derived for each case. The other ternary phases were treated either as stoichiometric compounds, semi-stoichiometric phases, or disordered solution phases as described above. Binary descriptions from the literature (modified as found necessary) were used. The temperatures and compositions of the invariant reactions as evaluated by [1991Pri] were included in the optimization. In addition, phase diagram data from [1981Mel], [1993Zuo3], and [1995Hua] were used. For thermochemical data, enthalpies of formation of alloys along the Cu_2Mg-'Al_2Mg' section from [1972Pre], the enthalpy of fusion for the reaction $L \leftrightarrow fcc + S + \theta$ from [1986Rod], the enthalpy of formation of the S phase from [1986Not], enthalpies of mixing in the liquid phase from [1995Kim], and Mg activities from [1995Soa] were used in the optimization.

Computed Phase Equilibria

In Fig. 1, the liquidus projection computed by [1998Buh] is compared with the evaluated projection of [1991Pri]. The agreement is quite satisfactory. In Fig. 2, the computed liquidus projections of [1997Che] and [1998Buh] are compared. The two projections are strikingly similar, in spite of the somewhat-different data used in the optimization. The agreement seen in Fig. 1 and 2 is in a large

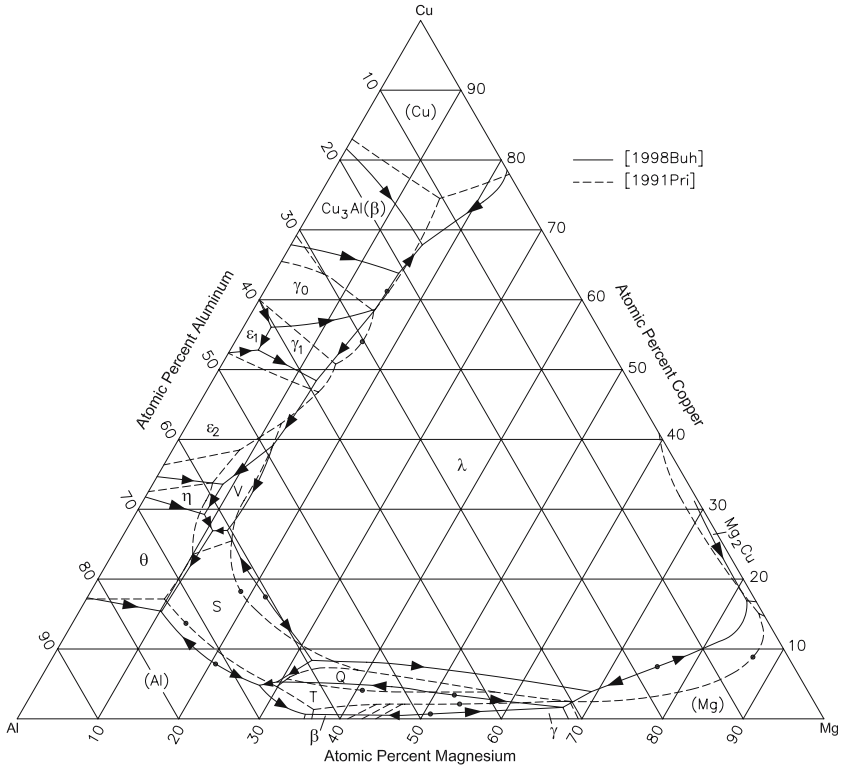

Fig. 1 Al-Cu-Mg comparison of liquidus projections evaluated by [1991Pri] and computed by [1998Buh]

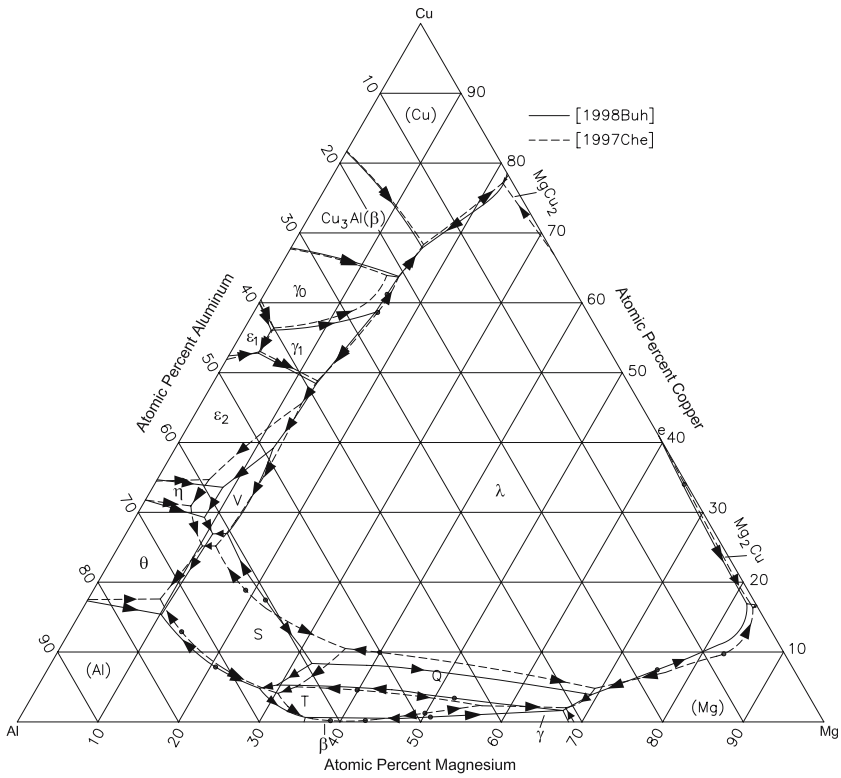

Fig. 2 Al-Cu-Mg comparison of computed liquidus projections of [1997Che] and [1998Buh]

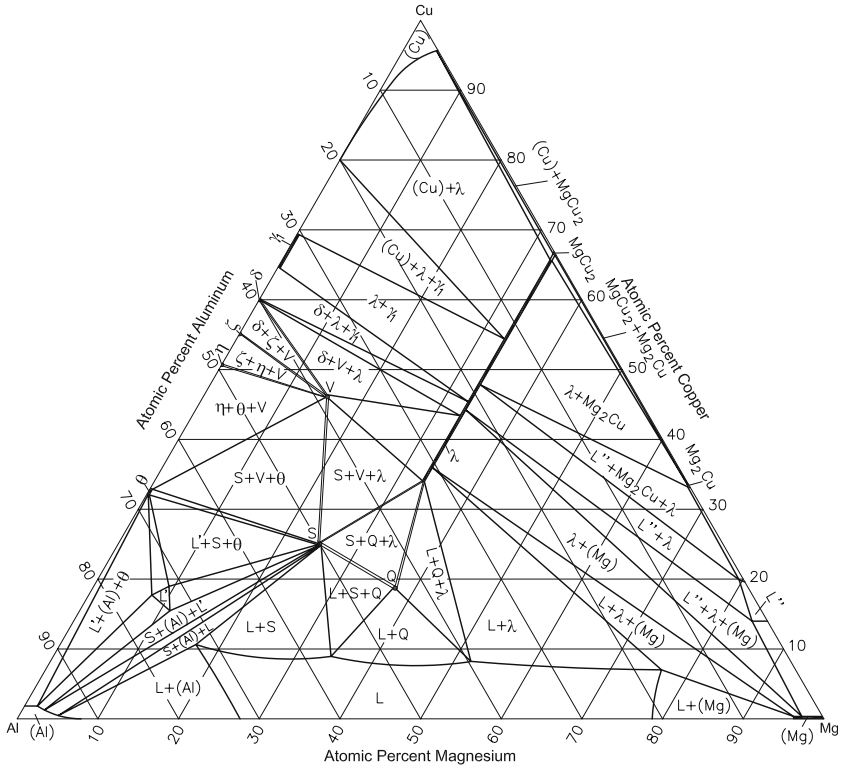

Fig. 3 Al-Cu-Mg computed isothermal section at 512 °C [1997Che]

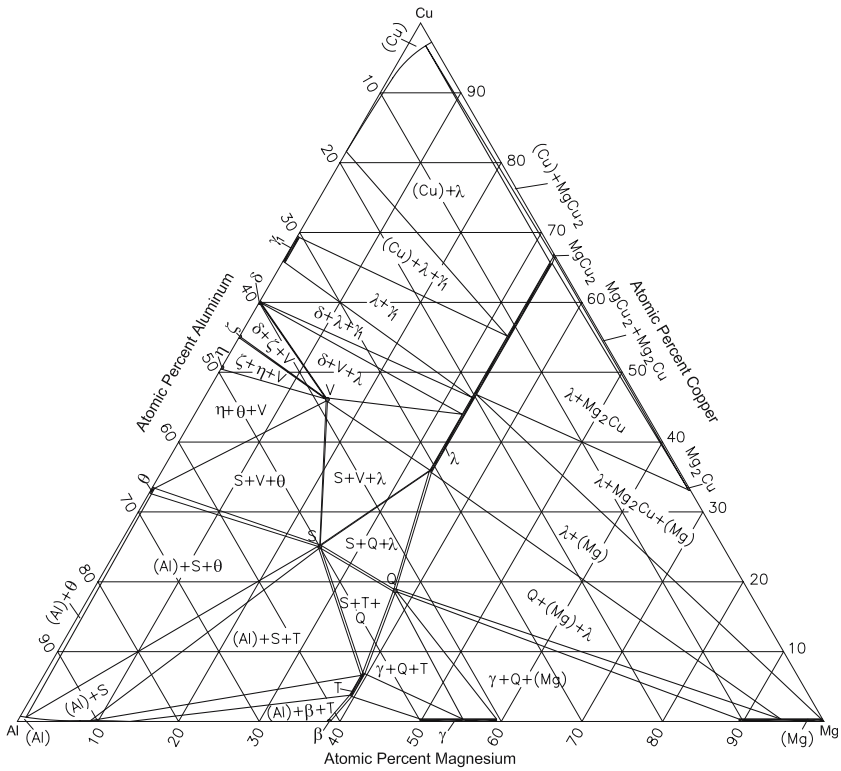

Fig. 4 Al-Cu-Mg computed isothermal section at 400 °C [1997Che]

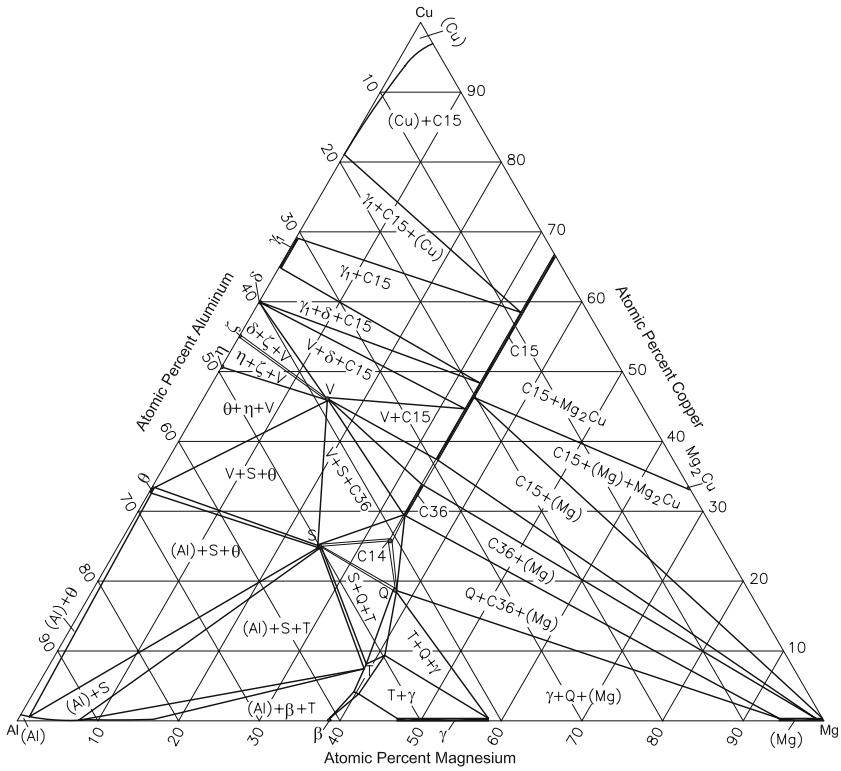

Fig. 5 Al-Cu-Mg computed isothermal section at 400 °C [1998Buh]

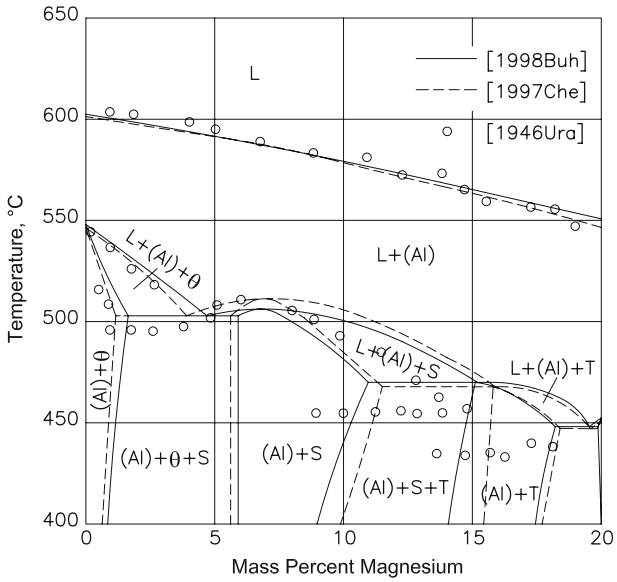

Fig. 6 Al-Cu-Mg computed vertical section 80 mass% Al

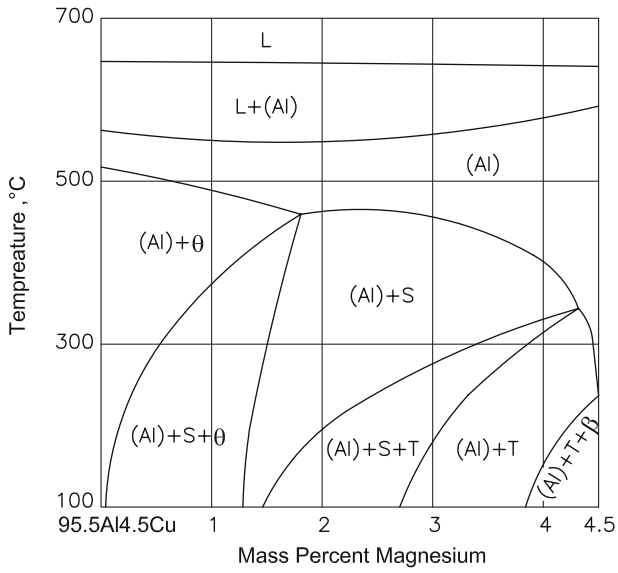

Fig. 7 Al-Cu-Mg computed vertical section at 95.5 mass% Al [1998Buh]

measure due to the use in the optimization of the compositions and temperatures of the evaluated reactions of [1991Pri] by both [1997Che] and [1998Buh].

The computed isothermal sections of [1997Che] at 512 and 400 °C are shown in Fig. 3 and 4. The computed section of [1998Buh] at 400 °C is shown in Fig. 5. The differences between Fig. 4 and 5 are due to the inclusion of the different Laves modifications in the modeling by [1998Buh]. In Fig. 6, the vertical sections at 80 mass% Al computed by [1997Che] and [1998Buh] are compared with the experimental data of [1946Ura]. Both sections agree well with each other and with the experimental data. Fig. 7

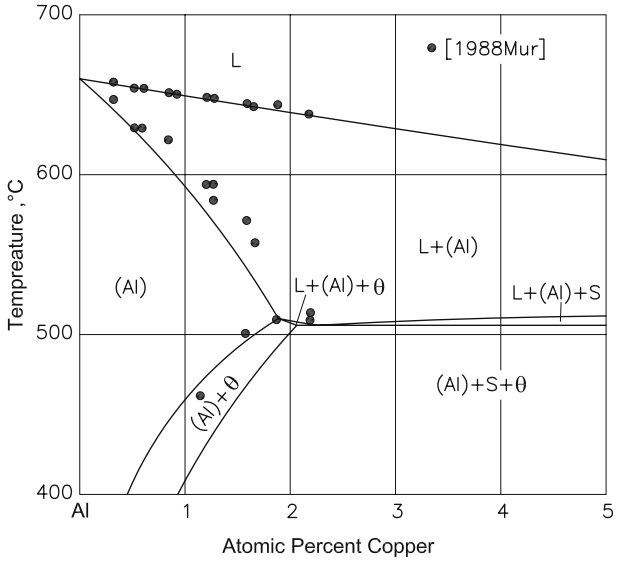

Fig. 8 Al-Cu-Mg computed vertical section along Al-$Cu_{0.5}Mg_{0.5}$ line [2000Lia]

is a computed vertical section at 95.5 mass% of Al from [1998Buh]. The agreement with experimental data from several sources (not shown in Fig. 7) was found to be satisfactory. In addition, [1997Che] presented three vertical sections at 10 at.% Cu, 50 at.% Al, and along the Al-$Cu_{0.7416}Mg_{0.2584}$ line respectively. The computations of [1998Buh] included vertical sections at 70 and 60 mass% Al and solubility limits of Cu and Mg in (Al) at 450, 400 and 300 °C.

[1997Che] could not find satisfactory agreement for the (Al) solidus curve in the computed vertical section along the Al-$Cu_{0.5}Mg_{0.5}$ line. [2000Lia] obtained new experimental results on the distribution coefficients of the solutes (Cu and Mg) in the Al-rich liquid and solid phases at 600, 575 and 550 °C. Using these data in the optimization, [2000Lia] recomputed the vertical section along the Al-$Cu_{0.5}Mg_{0.5}$ line to obtain better agreement with the liquidus and solidus curves, as shown in Fig. 8.

For conditions of restricted or partial equilibrium, such as the assumption of infinite diffusion in the liquid and zero diffusion in the solid phases, phase equilibria calculations have been reported [1990Roo, 1996Zuo, 2000Lia].

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