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

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Silver additions can modify the formation of the ternary phases in Al-Cu-Mg alloys. In this respect, the phase diagram in the Al-rich region of this quaternary system is of interest. [2008Gab] studied the effect of small additions of Ag on the phase equilibria of this system in the Al-rich region. Earlier, [1997Lim2] computed the phase equilibria in the Al-rich region.

Binary Systems

The Ag-Al phase diagram [Massalski2] depicts three intermediate phases: β_2 (20.5-29.8 at.% Al; bcc), δ (22.9-41.9 at.% Al; close-packed hexagonal; denoted ζ to avoid confusion with δAlCu), and μ (~21-24 at.% Al; *A*13, βMn-type cubic). The Ag-Cu phase diagram is of the simple eutectic type, with the terminal phases (Ag) and (Cu) dissolving up to about 14 at.% Cu and 5 at.% Ag respectively. The Ag-Mg phase diagram [1997Lim1] has the following intermediate phases: Ag_3Mg (denoted α′; $L1_2$, $AuCu_3$-type cubic, stable below 392 °C), AgMg (denoted β′; *B*2, CsCl-type cubic), $Ag_{17}Mg_{54}$ [denoted ε′(HT) and ε(LT)]. 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_1, bcc). The Al-Mg phase diagram has the following intermediate phases: Mg_2Al_3 (denoted β; cubic), R or ε (rhombohedral) and $Mg_{17}Al_{12}$ (denoted γ; α-Mn type cubic). The Cu-Mg phase diagram [Massalski2] has two intermediate phases: $MgCu_2$ (*C*15-type cubic) and Mg_2Cu (C_b, Mg_2Cu-type orthorhombic).

Ternary Systems

The Ag-Al-Cu system was updated by [2008Rag], who presented, from the computed results of [2005Wit], a liquidus projection, two isothermal sections at 350 and 500.6 °C and three vertical sections at 50 and 70 mass% Al and along the $CuAl_2$-Ag_2Al join respectively. The Ag-Al-Mg system [1995Vil] has two ternary compounds: AlMgAg (*C*14, $MgZn_2$-type hexagonal) and $(Al,Ag)_{49}Mg_{32}$ (denoted T; cubic, space group $Im\bar{3}$). In a thermodynamic assessment of this system, [1997Lim2] computed a liquidus projection, an isothermal section at 300 °C and a pseudobinary section along the Al-AgMg join. The computed isothermal section

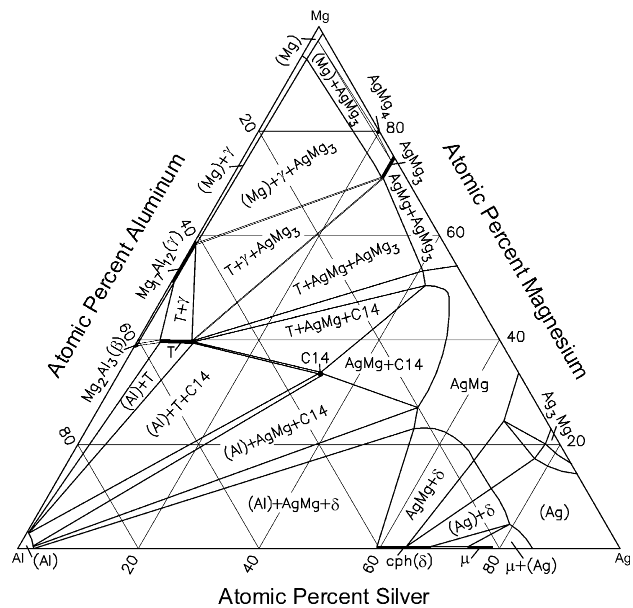

Fig. 1 Ag-Al-Mg computed isothermal section at 300 °C [1997Lim2]

at 300 °C is shown in Fig. 1. [1997Lim2] also assessed the Ag-Cu-Mg system and presented a computed liquidus projection for Mg-rich alloys. The Al-Cu-Mg system was updated recently by [2007Rag]. Four ternary phases are known in 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 or their polytypes occur along the 33.3 at.% Mg line (denoted together as U by [1997Che]).

Quaternary Phase Equilibria

For the binary systems, [1997Lim2] used the literature descriptions, except in the case of Ag-Cu. For the Al-Cu-Mg ternary system, they used the assessment of [1997Che]. They made their own assessment of the Ag-Cu, Ag-Al-Cu, Ag-Al-Mg, and Ag-Cu-Mg systems. No quaternary interaction parameters were introduced. No quaternary phases have been reported in the system. The Ag solubility of about 4 at.% in Cu_9Al_4 (γ_1) was ignored in the modeling of the Ag-Al-Cu system. The ternary/quaternary extensions of $AgMg_3$ and $AgMg_4$ were modeled as $(Ag,Cu)(Al,Mg)_3$ and $(Ag,Cu)(Al,Mg)_4$ respectively. The homogeneity range of the T phase was taken into account. The *C*14, $MgZn_2$-type Laves phase (AlMgAg) was assumed to be of fixed composition. By extrapolation of the ternary descriptions, [1997Lim2] calculated a vertical system of this quaternary system at 0.1Ag-1.7Mg (at.%) (Fig. 2) and an isothermal section at 200 °C and at 0.5 mass% Ag (Fig. 3).

With starting metals of 99.9985% Ag, 99.99-99.999% Al, 99.9% Cu and 99.99% Mg, [2008Gab] arc-melted a number of Al-Cu and Al-Cu-Ag master alloys. These were remelted with Mg additions in an induction furnace to produce about 20 quaternary alloys and about 15 Al-Cu-Mg ternary alloys. They were homogenized at 510 °C for 72 h and quenched in water. After solution treatment at 500-525 °C, the alloys were quenched again and aged at 400, 350, 300, 250, 200 and 150 °C for times up to 1000 h. Differential thermal analysis was performed at a heating/cooling rate of 10 °C per min to determine the liquidus boundary. Electron diffraction on a transmission electron microscope and energy dispersive x-ray analysis were employed to identify the phases. The presence or absence of the S phase was ascertained as a function of composition and ageing temperature.

Six vertical sections of this quaternary system were computed by [2008Gab] at 0.3Ag-1Cu, 0.3Ag-2.5Cu, 0.3Ag-4Cu, 0.6Ag-1Cu, 0.6Ag-2.5Cu and 0.6Ag-4Cu (mass%) respectively. For comparison, three ternary vertical sections without Ag were also computed. The quaternary sections are shown in Fig. 4 and 5, along with the experimental data of [2008Gab] on the liquidus boundary and on the presence or absence of the S phase in the solid state. The agreement is satisfactory. The effect of Ag on the phase distribution appears to be minimal.

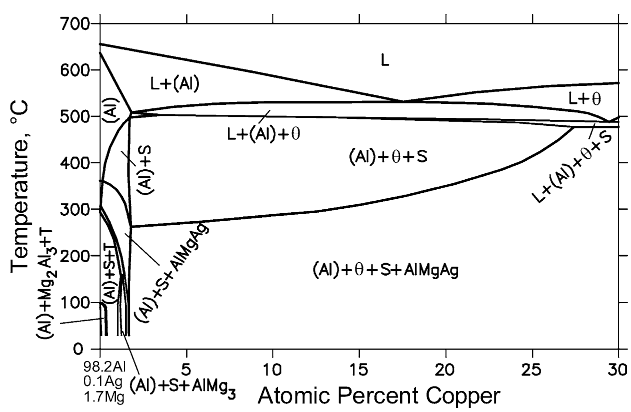

Fig. 2 Ag-Al-Cu-Mg computed vertical section at 0.1Ag-1.7Mg (at.%) [1997Lim2]

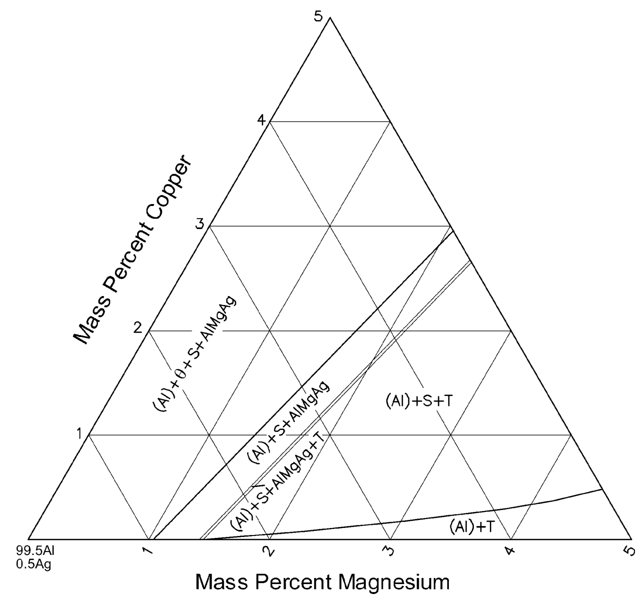

Fig. 3 Ag-Al-Cu-Mg computed isothermal section at 200 °C and at 0.5 mass% Ag [1997Lim2]

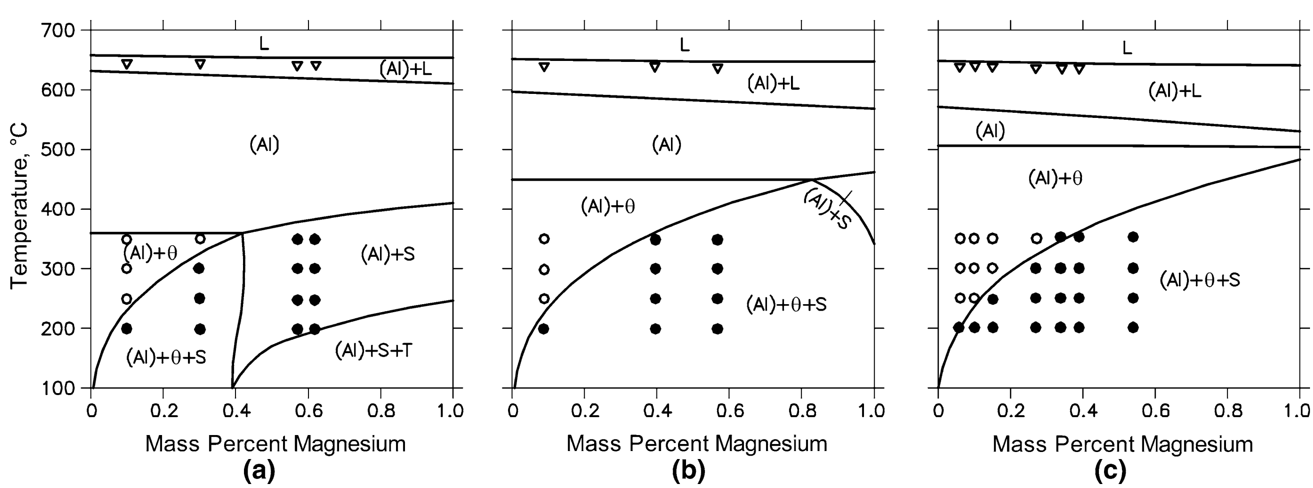

Fig. 4 Ag-Al-Cu-Mg computed vertical sections at (a) 0.3Ag-1Cu, (b) 0.3Ag-2.5Cu, and (c) 0.3Ag-4Cu (mass%). Experimental data: (▽) liquidus; (○) no S phase detected; (●) S phase detected [2008Gab]

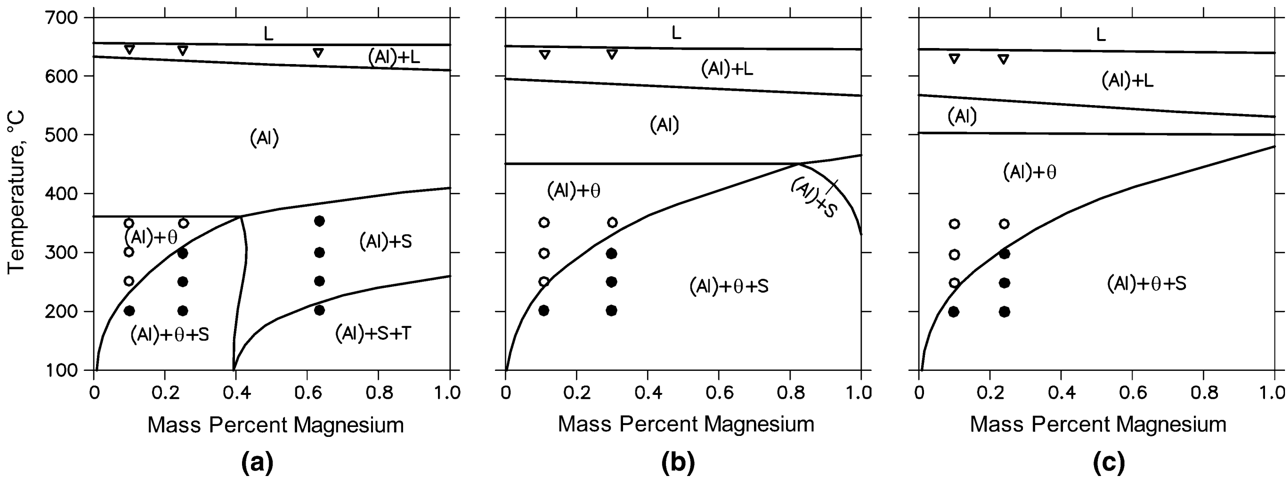

Fig. 5 Ag-Al-Cu-Mg computed vertical sections at (a) 0.6Ag-1Cu, (b) 0.6Ag-2.5Cu, and (c) 0.6Ag-4Cu (mass%). Experimental data: (▽) liquidus boundary; (○) no S phase detected; (●) S phase detected [2008Gab]

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