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Al-Cu-Fe (Aluminum-Copper-Iron)

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The review of this ternary system by [1992Rag] presented liquidus projections for Al- and Cu-rich alloys from [1953Phi] and [1941Yut], respectively, and an isothermal section at 600 °C from [1971Pre]. In an update, [2005Rag] reviewed the more-recent studies of [1998Wan] and [2003Zha1, 2003Zha2] and presented a liquidus projection and several isothermal sections between 1200 and 560 °C. The system was also reviewed by [2005Wan]. Most recently, [2009Che] investigated the region above 40 at.% Al at 600 °C and carried out a detailed thermodynamic analysis. This work will be reviewed here briefly.

Binary Systems

The Al-Cu phase diagram [2004Ria] depicts the following intermediate phases: $CuAl_2$ ($C16$-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) (bcc), ε_2(LT) ($B8_1$, NiAs-type hexagonal), Cu_3Al_2 (rhombohedral), 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).

In the Fe-Al phase diagram [Massalski2], the solid solution γ based on face-centered cubic (fcc) Fe is restricted by a loop. The solid solution based on the body-centered cubic (bcc) Fe (α) exists in both the disordered $A2$ and ordered $B2$ and $D0_3$ forms. The high-temperature phase ε is stable between 1232 and 1102 °C and has the $D8_2$, Cu_5Zn_8-type cubic structure, with a = 0.89757 nm [2010Ste]. There are three other intermediate phases in the system with restricted ranges of homogeneity: $FeAl_2$(triclinic), Fe_2Al_5 (orthorhombic), and $FeAl_3$ or Fe_4Al_{13} (monoclinic). There are no intermediate phases in the Cu-Fe system. A metastable liquid miscibility gap is known.

Ternary Phases

Three established ternary phases are known in this system [1992Rag, 2009Che]. $FeCu_2Al_7$ (denoted ω by [2009Che] and τ_2 by [1992Rag]) is tetragonal, space group *P*4/*mnc*, with lattice parameters a = 0.63417 – 0.63499 nm and c = 1.48498 – 1.48377 nm [2009Che]. $FeCu_2Al_6$ (denoted τ_i by [2009Che] and as I here) is the stable icosahedral quasicrystalline phase [1987Tsa]. [2004Tur] studied

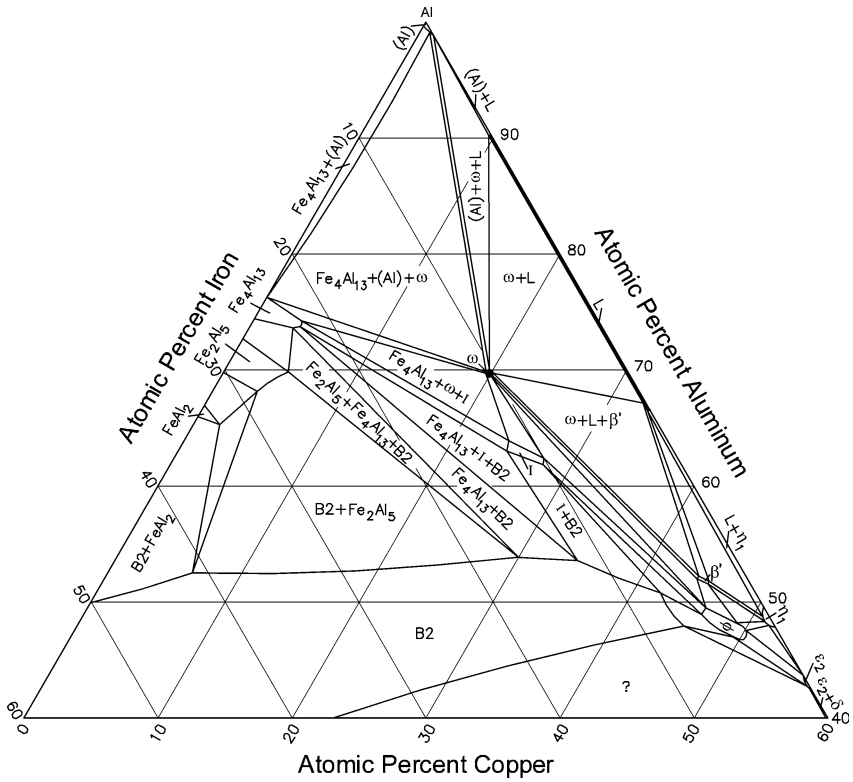

Fig. 1 Al-Cu-Fe experimental isothermal section at 600 °C [2009Che]

the effect of pressure up to ~1.6 GPa on the formation of I. The formation temperature was between 750 and 800 °C and changed little with pressure [2004Tur]. $FeCu_{10}Al_{10}$ (denoted φ by [2009Che] and as τ_3 by [1992Rag]) forms in the solid state and is present at 600 °C. The presence of a fourth phase Fe_4CuAl_{23} (labeled α in earlier reports and as τ_1 by [1992Rag]) was discounted by [2009Che] and was not included in their thermodynamic analysis.

Ternary Phase Equilibria

With starting metals of 99.99% Al, 99.99% Cu, and 99.99% Fe, [2009Che] arc-melted under Ar atm 14 Al-rich ternary alloys. The alloys were annealed at 600 °C for 35 days and quenched in water. The phase equilibria were studied with x-ray powder diffraction, scanning electron microscopy, and energy dispersive x-ray spectroscopy. Differential thermal analysis was carried out at a heating rate of 5 °C per min. The identified phases and their compositions were listed. The isothermal section at 600 °C for Al-rich alloys constructed by [2009Che] is shown in Fig. 1. The three ternary phases ω, I, and φ are present. In addition, [2009Che] found a phase β′, which appears to arise from a miscibility gap in the *B*2 solid solution.

In their thermodynamic modeling, [2009Che] treated liquid, fcc and bcc (ε_1, Cu_3Al, and αδFe) as substitutional solid solutions. The magnetic contribution to the Gibbs energy of fcc and bcc phases was taken into account. To describe the ordered bcc (*B*2) phase, an ordering energy term was added to the description of the disordered bcc phase. A two sublattice model was used to describe the Fe-Al binary compounds to allow for the solubility of Cu, which mainly substitutes for Al. The Al-Cu phase γ_1 was described similarly to account for the Fe solubility. In cases where no ternary solubility has been reported, the binary phases θ, η, ζ, δ, and ε_2 were described as pure compounds. The ternary compounds $FeCu_2Al_6$ (I) and $FeCu_{10}Al_{10}$(φ)

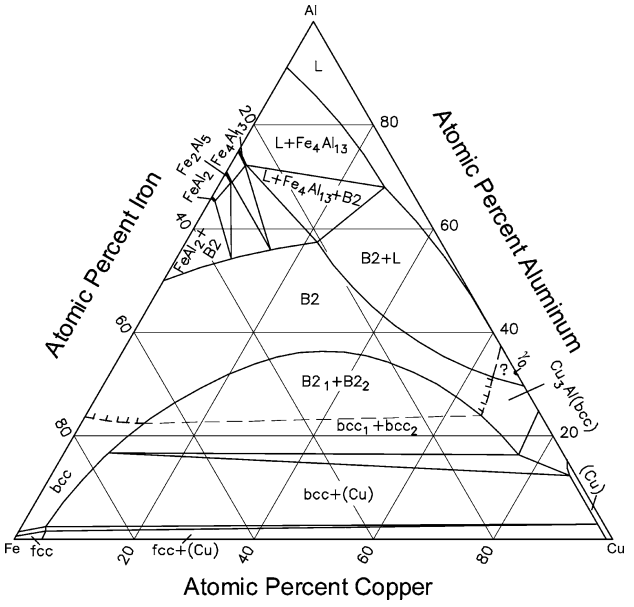

Fig. 3 Al-Cu-Fe computed isothermal section at 1000 °C [2009Che]

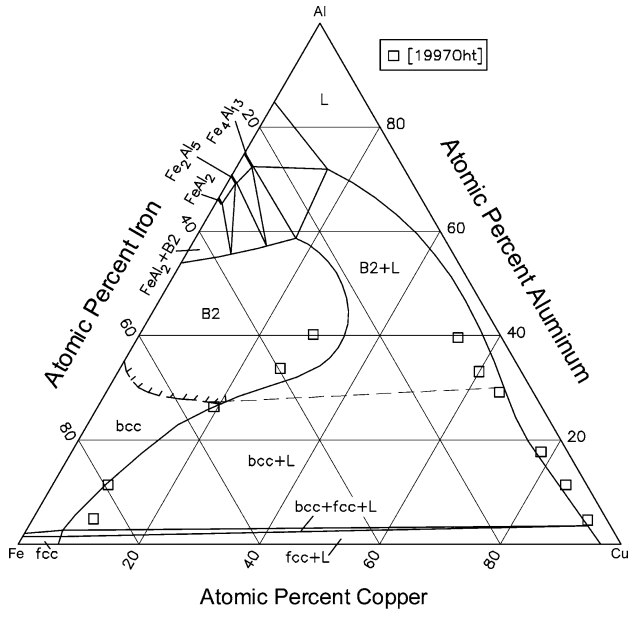

Fig. 2 Al-Cu-Fe computed isothermal section at 1100 °C [2009Che]

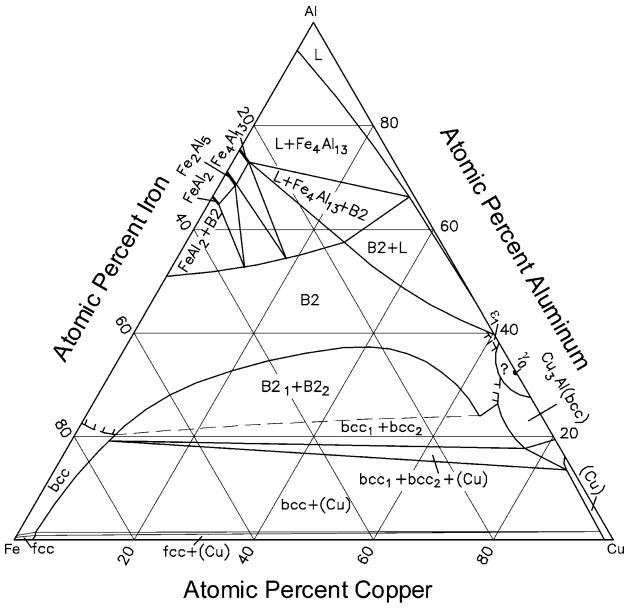

Fig. 4 Al-Cu-Fe computed isothermal section at 900 °C [2009Che]

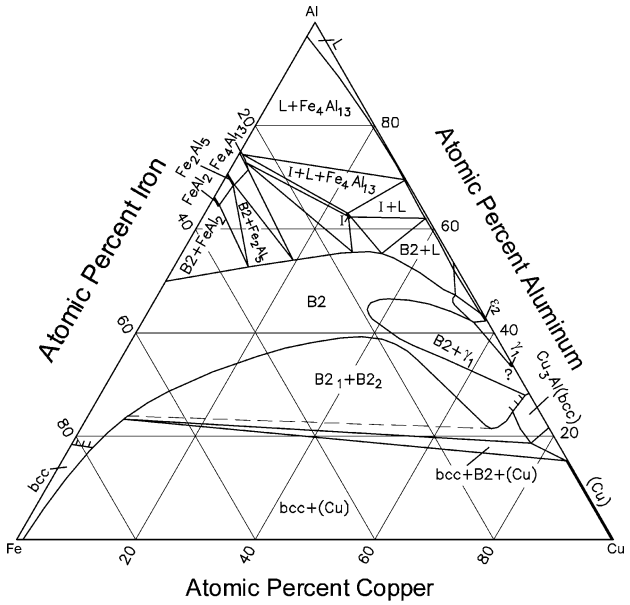

Fig. 5 Al-Cu-Fe computed isothermal section at 800 °C [2009Che]

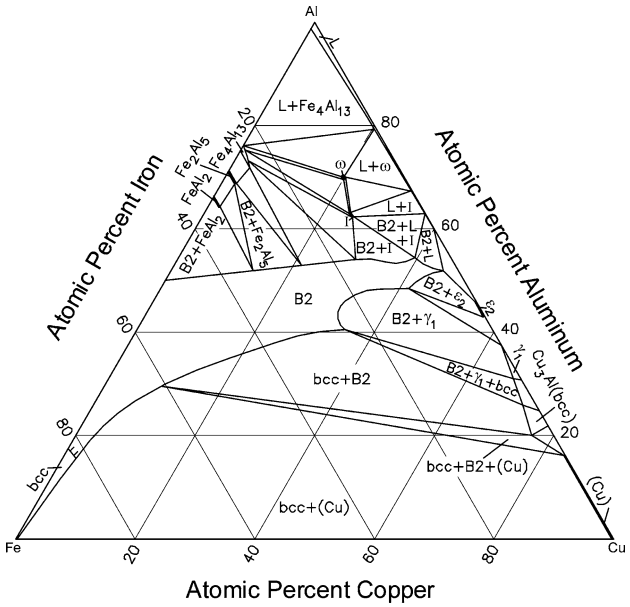

Fig. 6 Al-Cu-Fe computed isothermal section at 700 °C [2009Che]

were assumed to have a homogeneity range at constant Fe content, whereas $FeCu_2Al_7$ (ω) was treated as a stoichiometric compound. The binary descriptions were taken from the literature. The experimental data of [1941Yut], [1997Oht], [1998Wan], [2003Zha1], [2003Zha2], and [2009Che] were used as inputs. The optimized interaction parameters were listed.

[2009Che] computed eight isothermal sections at 100 °C intervals between 1300 and 600 °C. The computed sections were found to be in general agreement with the experimental data. Here, the computed isothermal section at 1100 °C is compared with the experimental data of [1997Oht] in Fig. 2. The computed isothermal sections at 1000, 900, 800, and 700 °C are shown in Fig. 3-6. Due to the low solubility of Fe in some of the Al-Cu intermediate phases and the proximity of the ordering bcc ↔ *B*2 transitions, the phase relationships near the Al-Cu side are not clearly defined in Fig. 3-6. The quasicrystalline phase I, which forms peritectically at 882°C [2003Zha2], is present at 800 °C (Fig. 5). The ω phase, which also forms peritectically at 740 °C [2003Zha2] (762 °C [2009Che]), is present additionally at 700 °C (Fig. 6). The computed isothermal section at 600 °C (not shown here) agrees with the experimental results shown in Fig. 1. The invariant equilibria computed by [2009Che] were found to have some differences with the liquidus projection and reaction scheme presented by [2003Zha1] and reviewed by [2005Rag].

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