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Al-Cu-Ru (Aluminum-Copper-Ruthenium)

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Recently, [2004Mi] determined six isothermal sections for Al-rich alloys of this system between 1100 and 600 °C, which depict a number of ternary phases.

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. There are five intermediate phases in the Al-Ru system [2004Oka]. $RuAl_6$ is orthorhombic and Ru_4Al_{13} is Fe_4Al_{13}-type monoclinic. $RuAl_2$ has the *C*54, $TiSi_2$-type orthorhombic structure. Ru_2Al_3 is a high-temperature phase stable between 1705 and 970 °C. RuAl is a *B*2, CsCl-type cubic structure. There are no intermediate phases in the Cu-Ru system. The mutual solubility between Cu and Ru is negligible [Massalski2].

Ternary Phases

There are four established ternary phases in this system [2004Mi]. Around the composition $Al_{70}Cu_{20}Ru_{10}$, a tetragonal phase (isostructural with Al_7Cu_2Fe and labeled ω) forms peritectically and has the lattice parameters a = 0.6433 nm and c = 1.489 nm. [2004Mi] found a smaller homogeneity range for this phase than that reported by [1993Shi]. Around the composition $Al_{58}Cu_{30}Ru_{12}$, a cubic phase labeled *C* (space group $Pm\bar{3}$) is found at 800 and 600 °C and has a lattice parameter of 1.2386 nm. The third ternary phase around the composition $Al_{70.5}Cu_{8.5}Ru_{21}$ labeled C_1 (space group $Fm\bar{3}$) has a face-centered cubic structure with a = 1.5511 nm [2004Mi]. The face-centered icosahedral phase (labeled *I*) has a composition range of $Al_{61}Cu_{26}Ru_{13}$-$Al_{70.5}Cu_{12.5}Ru_{17}$. It forms peritectically at 1057 °C and is stable down to at least 600 °C [2004Mi].

The third component solubility in the binary phases is significant in some cases. The CsCl-type *B*2 phase found by [2004Mi] with the copper range of 31-50 at.% is probably an extension of the binary phase RuAl into the ternary region, with Cu substituting for most of Ru. $RuAl_6$ dissolves up to 5 at.% Cu. Ru_4Al_{13} and $RuAl_2$ dissolve about 2.5 and 1.5 at.% Cu, respectively.

Liquid-Solid Equilibria

[1996Log] and [2002Guo] investigated the liquid-solid phase equilibria of this system in the region surrounding the icosahedral phase. With starting metals of 99.999% purity, [2002Guo] arc-melted under Ar atm about 20 alloys with the composition range of 55-70Al, 22.5-42.5Cu, and 2.5-25Ru (all at.%). The phase equilibria were studied with differential thermal analysis, x-ray diffraction, and transmission electron microcopy. The compositions were determined by energy dispersive spectroscopy. The partial vertical section at 62.5 at.% Al constructed by [2002Guo] is redrawn in Fig. 1. The phase at $Al_{68}Cu_{12}Ru_{20}$ that forms peritectically at 1090 °C appears to be the C_1 phase reported by [2004Mi]. In Fig. 1, a second peritectic reaction between liquid and C_1 (?) occurs at 1020 °C, which yields the icosahedral phase *I*. This is in fair agreement with the observation of [2004Mi] that *I* forms peritectically at 1057 °C. [2002Guo] presented this vertical section as a pseudobinary section, which needs confirmation. By bracketing the narrow composition range (2.5-4 at.% Ru), where *I* forms as a primary phase, [2002Guo] obtained large grains of *I* from a partially solidified and quenched alloy.

[1996Log] presented a partial liquidus projection around the icosahedral region. This projection depicts a ternary

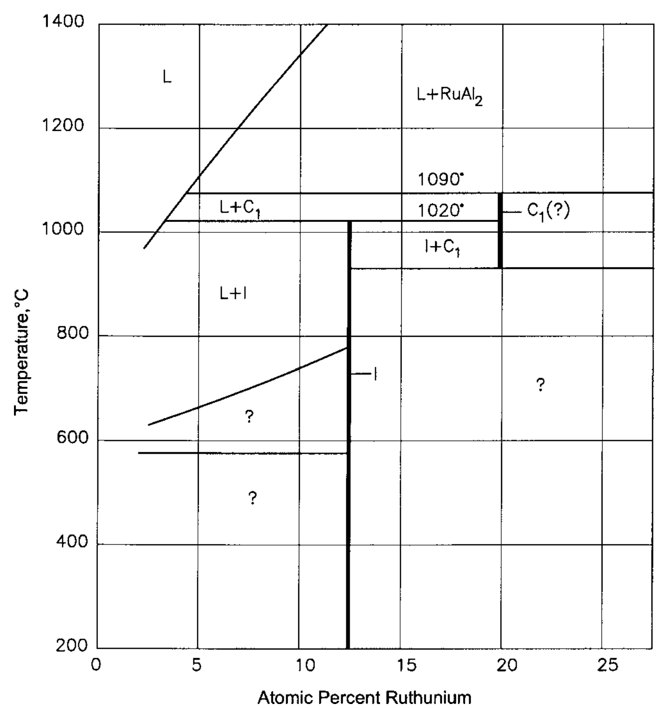

Fig. 1 Al-Cu-Ru partial vertical section at 62.5 at.% Al [2002Guo]

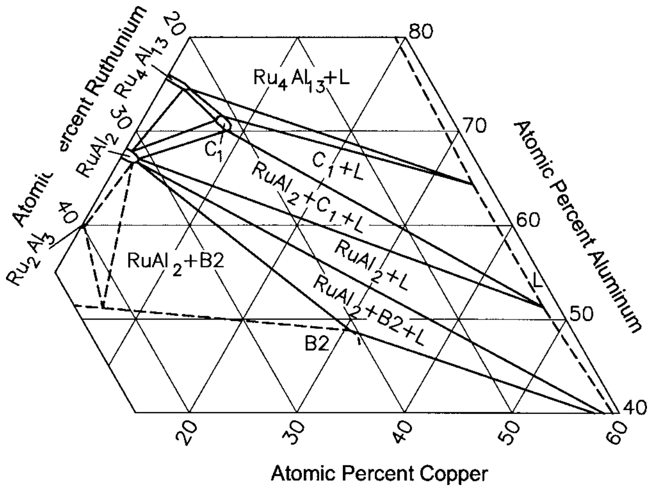

Fig. 2 Al-Cu-Ru partial isothermal section at 1100 °C [2004Mi]

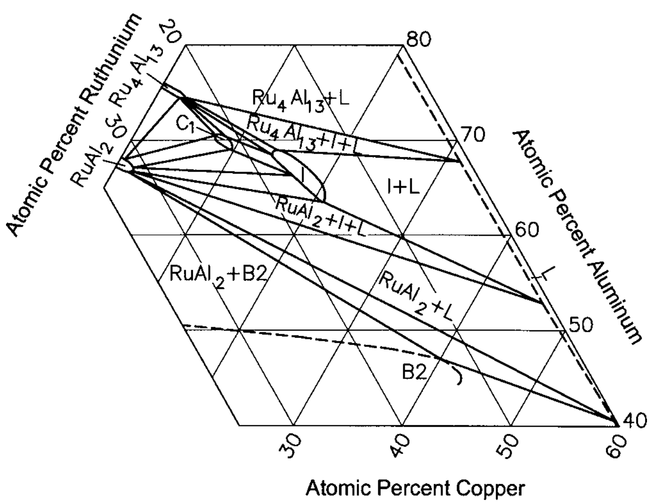

Fig. 3 Al-Cu-Ru partial isothermal section at 1000 °C [2004Mi]

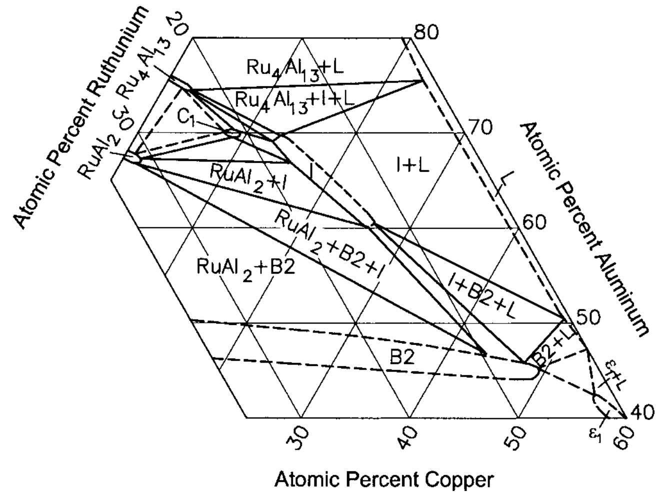

Fig. 4 Al-Cu-Ru partial isothermal section at 890 °C [2004Mi]

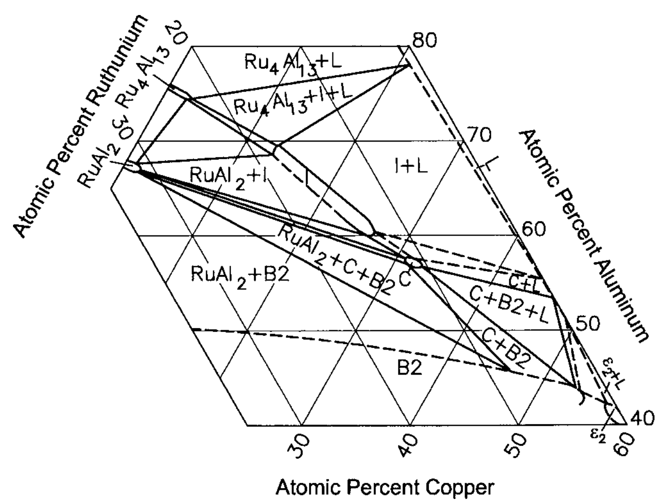

Fig. 5 Al-Cu-Ru partial isothermal section at 800 °C [2004Mi]

peritectic reaction at ~1200 °C, which yields *I*. This appears unlikely, in light of the more recent results of [2002Guo] and [2004Mi], which show that *I* forms at a much lower temperature.

Isothermal Sections

With starting metals of 99.999% Al, 99.99% Cu, and 99.9% Ru, [2004Mi] levitation-melted a number of alloys under Ar atm. The alloys were annealed in the range 1100-600 °C for 40-4392 h. The phase equilibria were studied by transmission electron microscopy, x-ray powder diffraction, and energy dispersive x-ray spectroscopy. The composition of the single phase alloys was determined by inductively coupled plasma optical emission spectroscopy. Differential thermal analysis was performed at a heating rate of 20 °C per min. The six partial isothermal sections constructed by [2004Mi] between 1100 and 600 °C are redrawn in Fig. 2-7 to agree with the accepted binary data. At 1100 °C (Fig. 2), only one ternary phase C_1 is present. The RuAl (*B*2) phase dissolves 31.5 at.% Cu, with Cu substituting for Ru. At 1000 °C (Fig. 3), the icosahedral phase *I* is present and forms tie-lines with Ru_4Al_{13}, C_1, $RuAl_2$, and the liquid. The solubility of Cu in *B*2 is more than 40 at.%. The partial isothermal section at 890 °C is shown in Fig. 4. Between 1000 and 890 °C, the U-type transition reaction: $RuAl_2 + L \leftrightarrow I + B2$ has occurred. At 800 °C (Fig. 5), the C_1 phase is not stable, but the *C* phase is present, forming tie-lines with *B*2, $RuAl_2$, *I*, and *L*. The solubility of Cu in *B*2 has increased to more than 50 at.%, with Cu substituting mostly for Ru. At 680 °C (Fig. 6), the ω phase is present and forms tie-lines with the icosahedral phase *I*. The binary phase $RuAl_6$, which is stable below 724 °C, dissolves 5 at.% Cu at 680 °C, forming tie-lines with ω. At 600 °C (Fig. 7), the binary phase CuAl is stable. [2004Mi] determined a tie-triangle between ω, C, and CuAl at 600 °C.

[1992Shi] and [1993Shi] studied eleven Al-rich alloys in

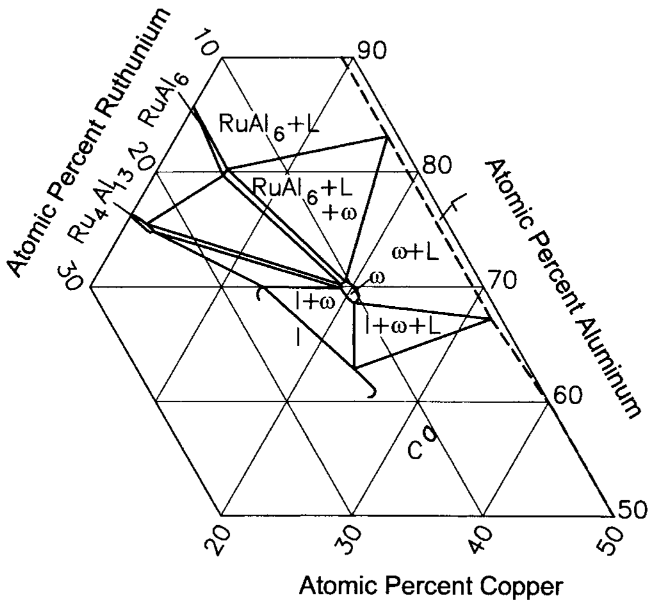

Fig. 6 Al-Cu-Ru partial isothermal section at 680 °C [2004Mi]

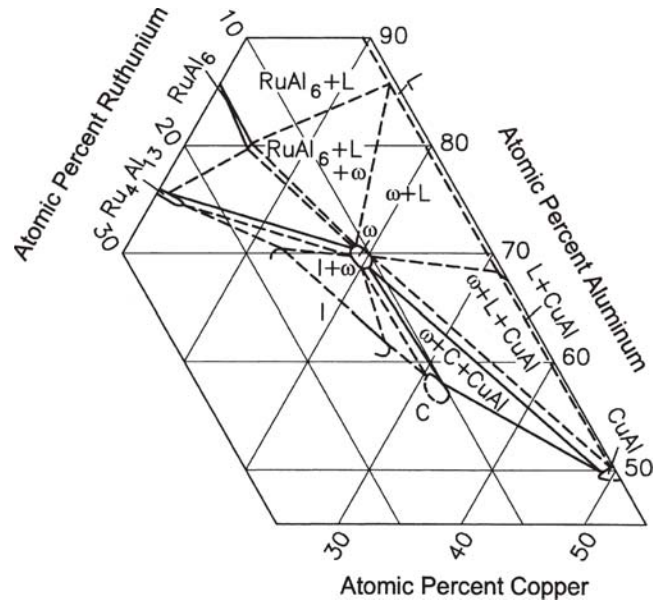

Fig. 7 Al-Cu-Ru partial isothermal section at 600 °C [2004Mi]

the icosahedral region and constructed partial isothermal sections at 800 and 500 °C. Their conclusion that the *I* phase transforms directly to the tetragonal ω phase at lower temperatures appears unlikely. The compositions of the *I* and ω phases are different and there is no convincing evidence for the direct $I \rightarrow \omega$ transition [1994Gru]. Their isothermal section at 500 °C shows only the ω phase, with a rather large composition range. [2004Mi] used an annealing time of 4392 h (6 months) at 600 °C. The attainment of equilibrium at 500 °C in the experiments of [1993Shi] with annealing times not exceeding 10 d is doubtful.

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