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Al-Cr-Ti (Aluminum-Chromium-Titanium)

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The review of this system by [2005Rag1] presented a schematic liquidus projection, full isothermal sections at 1000, 800 and 600 °C, partial isothermal sections at 1200 and 497 °C and a tentative reaction sequence. Subsequently, [2009Che1] reinvestigated this system and presented a liquidus projection for Al-rich alloys, a reaction sequence and the solid-state equilibria between 900 and 600 °C. This work was briefly reviewed in an update by [2010Rag]. More recently, [2011Che] made a detailed a thermodynamic assessment of the system and computed several isothermal sections between 1300 and 800 °C and a liquidus projection. The phase equilibria in the Al-rich region were investigated by [2009Rus].

Binary Systems

The Al-Cr phase diagram was calculated by [2009Che2]. The intermediate phases in the system are: $CrAl_7$ (V_7Al_{45}-type monoclinic, denoted θ), Cr_2Al_{11} ($CrAl_5$-type monoclinic, denoted η), $CrAl_4$ (hexagonal, $P6_3/mmc$, denoted μ), $CrAl_3$ (ν), Cr_2Al ($MoSi_2$-type tetragonal) and an unconfirmed low-temperature phase X at 75 at.% Cr. Between ~30 and ~41 at.% Cr, the high-temperature phase denoted γ_1 (Cu_5Zn_8-type cubic) transforms on cooling via a second-order transition to γ_2 (Cr_5Al_8-type rhombohedral). The Al-Ti phase diagram [2006Sch] has the following intermediate phases: Ti_3Al ($D0_{19}$, Ni_3Sn-type hexagonal, denoted α_2), TiAl ($L1_0$, AuCu-type tetragonal, denoted γ), $TiAl_2$ ($HfGa_2$-type tetragonal), $TiAl_3$(HT) ($D0_{22}$-type tetragonal), and $TiAl_3$(LT) (tetragonal, space group $I4/mmm$). In a new assessment, [2008Wit] included two previously-known compounds: $Ti_{2+x}Al_{5-x}$ (tetragonal, space group $P4/mmm$, denoted ζ) and Ti_3Al_5 (Ti_3Ga_5-type tetragonal, space group $P4/mbm$). These were excluded by [2006Sch] in their assessed diagram. A second-order transition of (βTi) ↔ $B2$ suggested in the data reviewed by [2005Rag2] appears to be supported by recent results. The Cr-Ti phase diagram [2002Gho] depicts a continuous bcc solid solution between βTi and Cr. The only intermediate phase of this system Cr_2Ti exists in all three Laves modifications. At 1370 °C, γCr_2Ti ($C14$, $MgZn_2$-type hexagonal) forms congruently at 66 at.% Cr from the bcc phase. It transforms at 1270 °C to βCr_2Ti ($C36$, $MgNi_2$-type hexagonal), which decomposes eutectoidally at 801 °C. αCr_2Ti ($C15$, $MgCu_2$-type cubic) forms peritectoidally at 1220 °C and is stable at low temperatures.

Computed Ternary Phase Equilibria

[2011Che] adopted the thermodynamic descriptions of the binary systems from [2009Che2] (Al-Cr), [2008Wit] (Al-Ti), and [2002Gho] (Cr-Ti). The literature experimental data on the ternary system were reviewed and the basis for selection of data as inputs for optimization was outlined. The liquid, bcc and cph phases were modeled as substitutional solutions. The binary intermetallic compounds and the Laves phases were described with appropriate sublattice models, with provision for ternary solubility. The binary compounds in the Al-rich region of the Al-Cr system with ≤25 at.% Cr were assumed to have no Ti solubility. The $B2$ phase was extrapolated from the binary description of [2008Wit] in the Al-Ti system. The ternary phase with the $L1_2$ structure (denoted here as $L1_2$ and as τ by [2010Rag]) was modeled as a $TiAl_3$-based intermetallic, in which Cr atoms occupy both Al and Ti sites [2011Che]. Three sublattices were used: $(Al,Cr,Ti)_{0.25}(Al,Cr)_{0.08}(Al,Cr,Ti)_{0.68}$. The interaction parameters obtained by optimization were listed.

Isothermal sections were computed by [2011Che] at 800, 900, 1000, 1150, 1200 and 1300 °C. Comparison with the corresponding experimental information showed satisfactory agreement. Here, the computed sections at 800, 1000, 1200 and 1300 °C are shown in Fig. 1-4. At 800 °C (Fig. 1), the $C14$ Laves phase and the ordered $B2$ phase are stable only in the ternary region. The ternary phase $L1_2$ is present. At 1000 °C (Fig. 2) and at 900 °C (figure not shown here), the $B2$ region is contiguous with the (βTi) region, separated by a second-order transition boundary. At 1200 °C (Fig. 4) and 1300 °C (Fig. 5), the computed

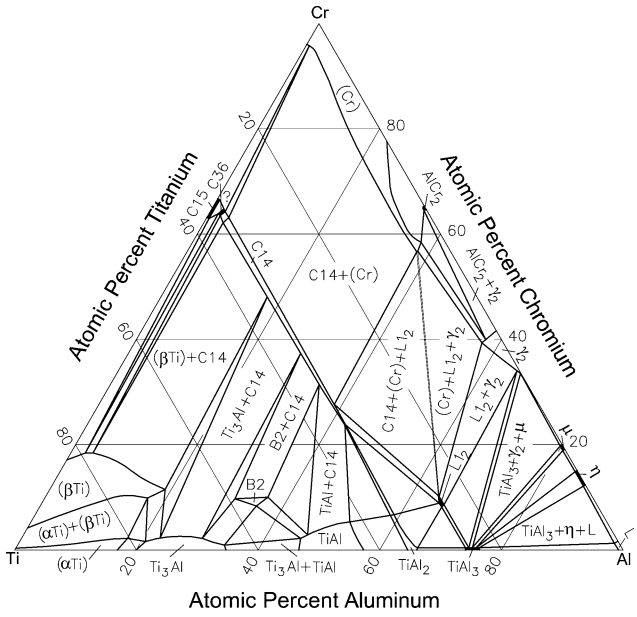

Fig. 1 Al-Cr-Ti computed isothermal section at 800 °C [2011Che]

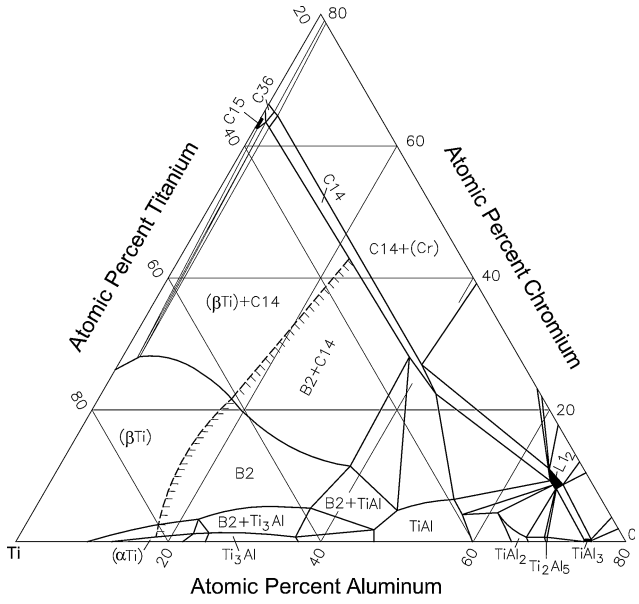

Fig. 2 Al-Cr-Ti computed isothermal section at 1000 °C [2011Che]

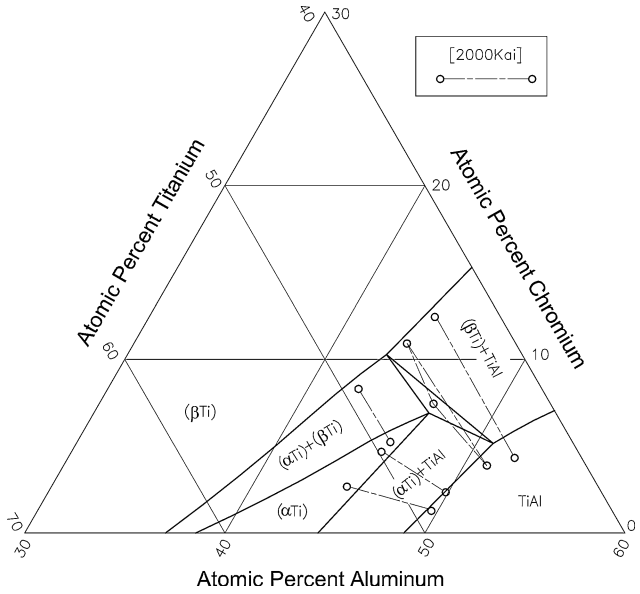

Fig. 4 Al-Cr-Ti computed partial isothermal section at 1300 °C [2011Che]

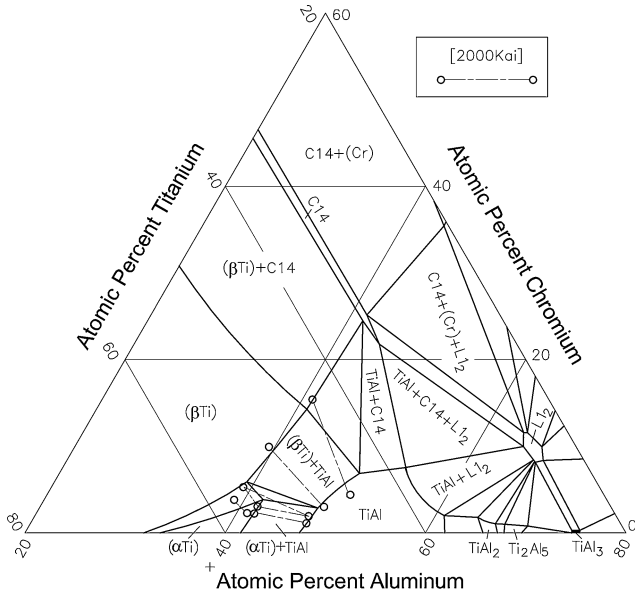

Fig. 3 Al-Cr-Ti computed partial isothermal section at 1200 °C [2011Che]

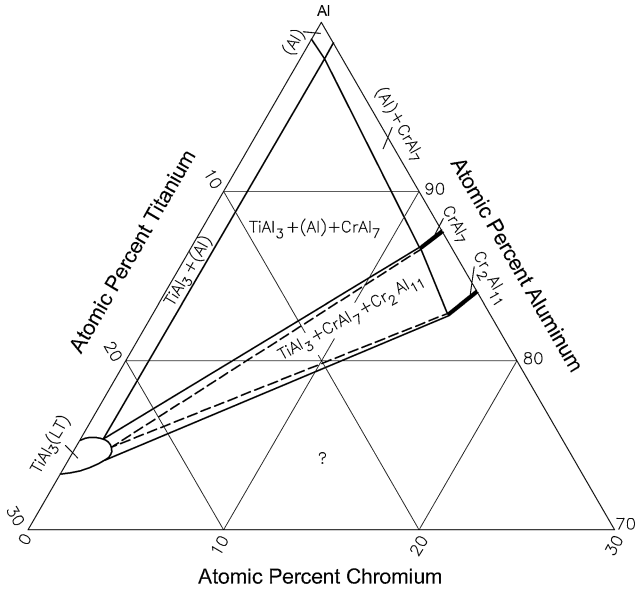

Fig. 5 Al-Cr-Ti partial isothermal section at 497 °C in the Al-rich region [2009Rus]

sections are compared with the experimental results of [2000Kai]. The *B*2 phase is not seen in the composition range depicted in these sections, although it is expected along the Al-Ti side [2008Wit]. [2011Che] calculated a liquidus projection (not shown here), which is in reasonable agreement with the experimental findings of [2009Che1].

In a parallel thermodynamic assessment, [2011Wan] incorporated the presence of the *B*2 phase and recomputed the ternary phase equilibria, using the database of [2005Zha] for the other phases present in the system. Recalculation of the Al-Cr binary phase diagram by [2011Wan] indicated the presence of a very narrow region of *B*2, consistent with the experimental findings of [1999Hel]. The computed liquidus projection and the isothermal sections at 1000, 800 and 600 °C by [2011Wan] agree with the assessed data of [2005Rag].

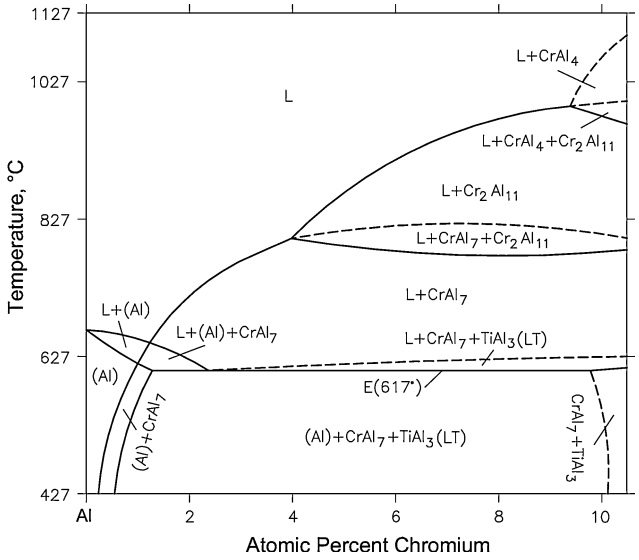

Fig. 6 Al-Cr-Ti vertical section at Cr:Ti atom ratio of 3:1 [2009Rus]

With starting metals of 99.999% Al, 99.98% Cr and 99.5% Ti, [2009Rus] arc-melted 20 Al-rich ternary alloys containing up to 13 at.% Cr and 22.5 at.% Ti. The alloys were annealed at 497 °C for 1000 h and quenched in water. The phase equilibria were studied with optical microscopy, x-ray powder diffraction, electron probe microanalysis and differential thermal analysis at a heating/cooling rate of 25 °C/min. The partial isothermal section constructed by [2009Rus] in the Al-rich region at 497 °C (770 K) is shown in Fig. 5. $TiAl_3$(LT) forms tie-lines with $CrAl_7$ and Cr_2Al_{11}. From the thermal analysis data, two vertical sections were constructed by [2009Rus] at a Cr:Ti atom ratio of 3:1 and along the $TiAl_3$-$CrAl_7$ join. The vertical section at Cr:Ti atom ratio of 3:1 is shown in Fig. 6. The ternary eutectic reaction E: L ↔ (Al) + $TiAl_3$(LT) + $CrAl_7$ is at 617 °C (890 K) [2009Rus].

Since this review was completed, a recent (third) thermodynamic assessment of this ternary system by [2011Cup] has come to the attention of this reviewer.

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