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Al-Cr-Mn (Aluminum-Chromium-Manganese)

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The experimental data on this system up to 1972 were compiled by [1995Vil]. More recently, [1998Sch] clarified the phase relationships in the Al-rich region. They found a continuous solid solution μ between $CrAl_4$ and $MnAl_4$ and also identified a new ternary phase of monoclinic symmetry. The update of this work by [2008Rag] presented for Al-rich alloys a liquidus projection and three isothermal sections at 800, 750, and 700 °C. Very recently, [2009Gru] and [2009Bal] studied this system in the compositional range of 60-100 at.% Al and presented liquidus and solidus projections and a number of isothermal sections between 1010 and 560 °C. They accepted the version of the Al-Mn phase diagram by [1987Mur], in respect of the peritectoidal formation of λAl_4Mn and the existence of the Cu_5Zn_8-type of cubic phase γ_1. As there is no general agreement in the literature about these features, the results of [2009Gru] and [2009Bal] may be accepted provisionally.

Binary Systems

The intermediate phases in the Al-Cr system [2008Gru1] are: Al_7Cr (V_7Al_{45}-type monoclinic, denoted θ), $Al_{11}Cr_2$ ($CrAl_5$-type monoclinic, denoted η), Al_4Cr (hexagonal, $P6_3/mmc$, denoted μ), Al_3Cr (triclinic), $AlCr_2$ ($MoSi_2$-type tetragonal), and an unconfirmed low-temperature phase X at ~75 at.% Cr. Between 30 and 41 at.% Cr, five phases were reported earlier: αAl_9Cr_4, βAl_9Cr_4, γAl_9Cr_4, αAl_8Cr_5, and βAl_8Cr_5, with no well-established phase boundaries between them. The work of [2008Gru1] shows only two phases in this region. The high-temperature phase denoted γ_1 is cubic (Cu_5Zn_8-type) and transforms on cooling to γ_2, the transition temperature decreasing from 1140 to 1060 °C with increasing Al content. The γ_2 phase is rhombohedral (Al_8Cr_5-type). The Al-Mn phase diagram [1987Mur, 1996Liu, 2008Gru2] depicts the following intermediate phases: $Al_{12}Mn$ ($Al_{12}W$-type cubic, denoted G), Al_6Mn (Al_6Mn-type orthorhombic), λAl_4Mn (hexagonal, space group $P6_3/m$), μAl_4Mn (hexagonal, $P6_3/mmc$), $Al_{11}Mn_4$(HT) (Al_3Mn-type orthorhombic, denoted T), $Al_{11}Mn_4$(LT) ($Al_{11}Mn_4$-type triclinic, denoted ν), Al_8Mn_5 (~31.4-50 at.% Mn; $D8_{10}$, Al_8Cr_5-type rhombohedral, denoted γ_2), γ (34.5-52 at.% Mn; bcc) and ε (55-72 at.% Mn; cph). Following [1987Mur], [2009Gru] and [2009Bal] accepted the existence of γ_1 ($D8_2$, Cu_5Zn_8-type cubic), showing three phases in the ternary phase equilibria: γ_2, γ_1, and γ (bcc γ redesignated as β by [2009Gru] and [2009Bal]).

Ternary Phase Equilibria

With starting metals of 99.999% Al, 99.98-99.99% Cr, and 99.95% Mn, [2009Gru] and [2009Bal] levitation-melted a number of alloys in the region of 60-100 at.% Al. For determining the liquidus and solidus surfaces,

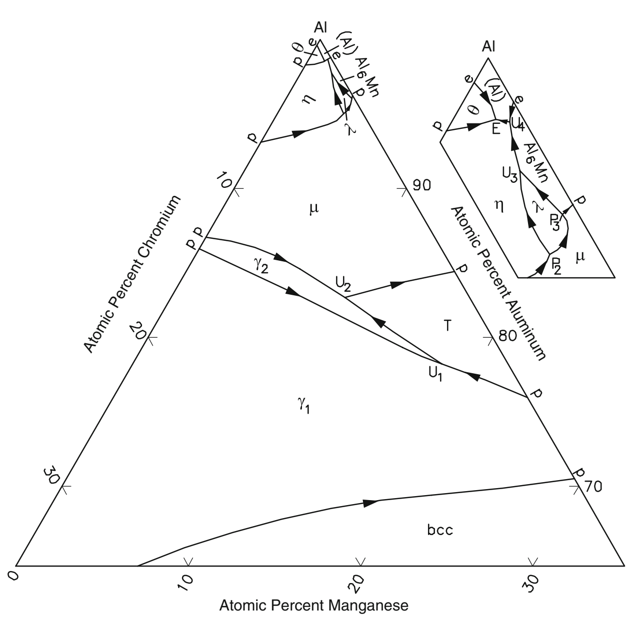

Fig. 1 Al-Cr-Mn liquidus projection for Al-rich alloys [2009Bal]

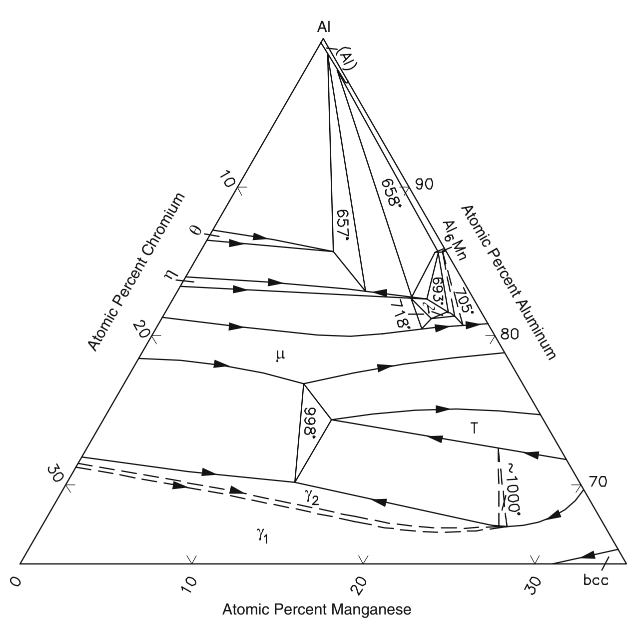

Fig. 2 Al-Cr-Mn solidus projection for Al-rich alloys [2009Bal]

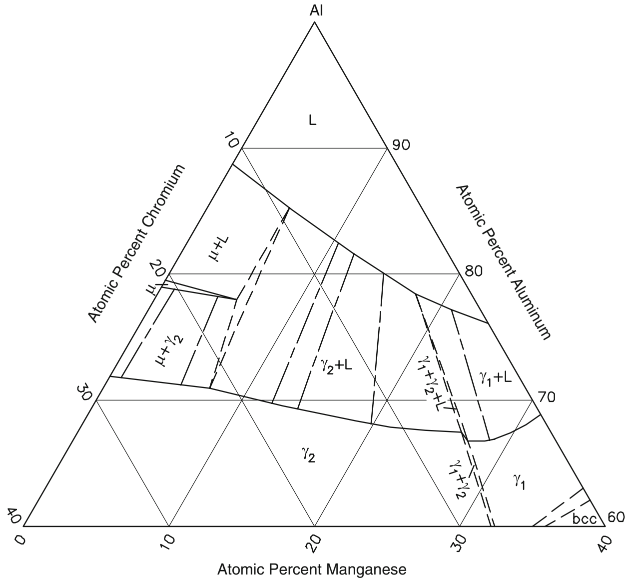

Fig. 3 Al-Cr-Mn isothermal section at 1010 °C for Al-rich alloys [2009Gru]

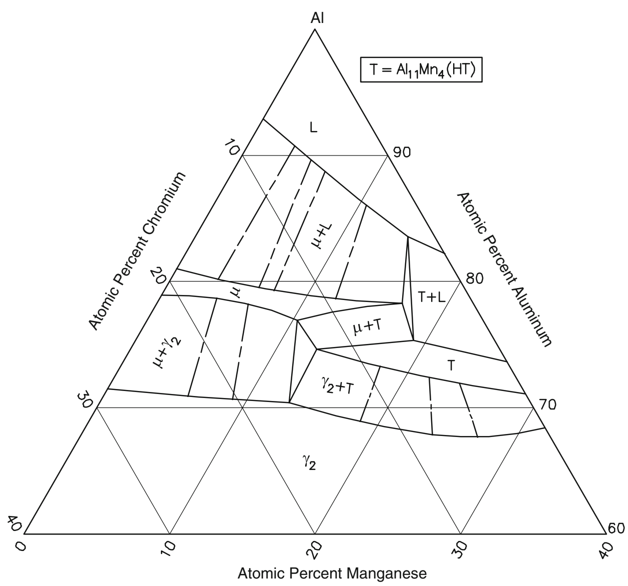

Fig. 4 Al-Cr-Mn isothermal section at 950 °C for Al-rich alloys [2009Gru]

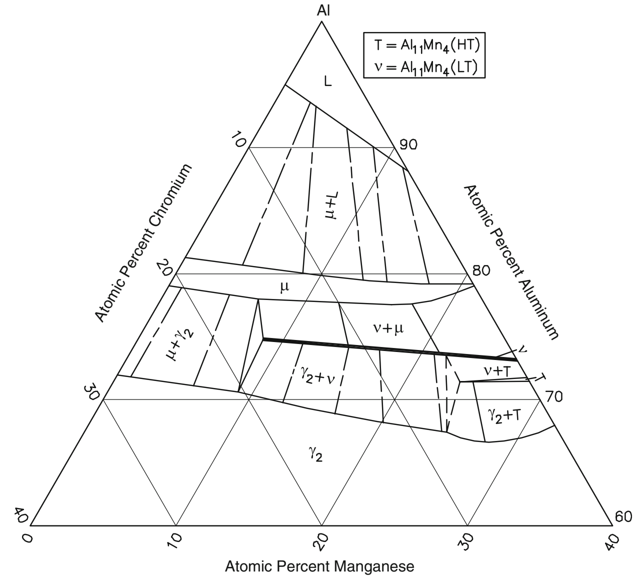

Fig. 5 Al-Cr-Mn isothermal section at 900 °C for Al-rich alloys [2009Gru]

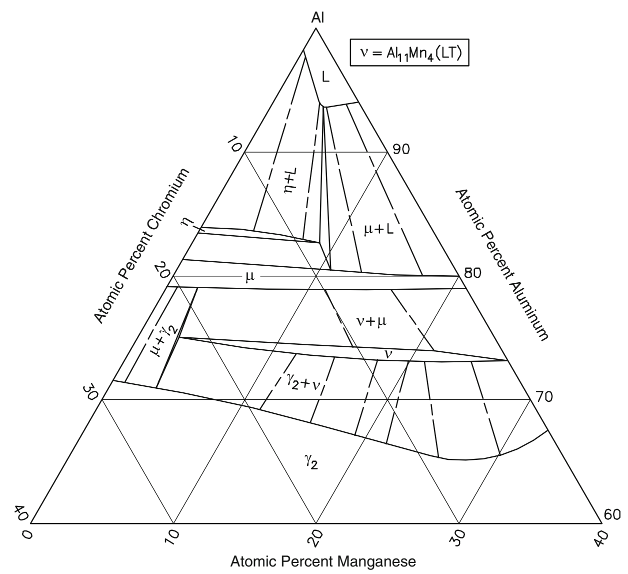

Fig. 6 Al-Cr-Mn isothermal section at 800 °C for Al-rich alloys [2009Gru]

differential thermal analysis was carried out at heating/cooling rates of 1-10°C/min [2009Bal]. For isothermal studies, the samples were annealed between 1010 and 560 °C for durations up to 94-1490 h [2009Gru]. The phase equilibria were studied with x-ray powder diffraction and electron diffraction in a transmission electron microscope. Local compositions were measured with the energy dispersive x-ray analyzer attached to the scanning electron microscope.

The liquidus projection constructed by [2009Bal] is shown in Fig. 1. An enlarged view of the surface near the Al corner is shown. The primary fields of crystallization are marked. Four U-type transition reactions U_1 (~1000 °C), U_2 (998 °C), U_3 (693 °C), and U_4 (658 °C), two ternary peritectic reactions P_2 (718 °C) and P_3 (~705 °C) and a ternary eutectic reaction E_1 (657 °C) are the solid-liquid reactions seen in Fig. 1 [2009Bal]. The binary phases λ and Al_6Mn nucleate in the ternary region through the peritectic reactions P_2 and P_3, respectively. The solidus projection constructed by [2009Bal] is shown in Fig. 2. The temperatures marked in the three-phase fields are those

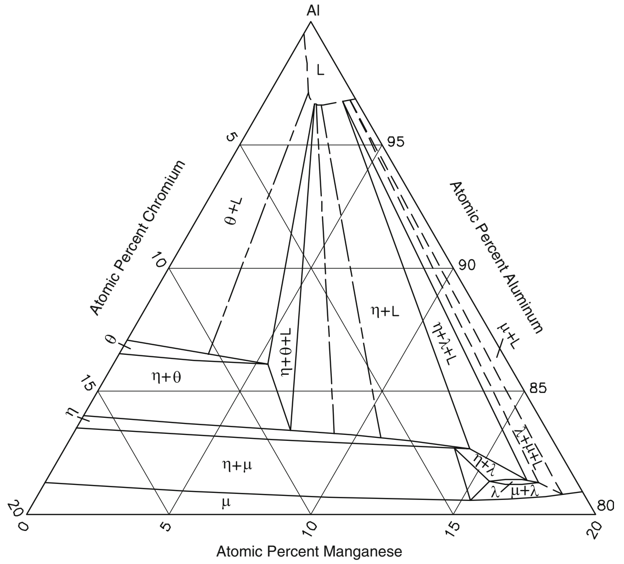

Fig. 7 Al-Cr-Mn isothermal section at 715 °C for Al-rich alloys [2009Gru]

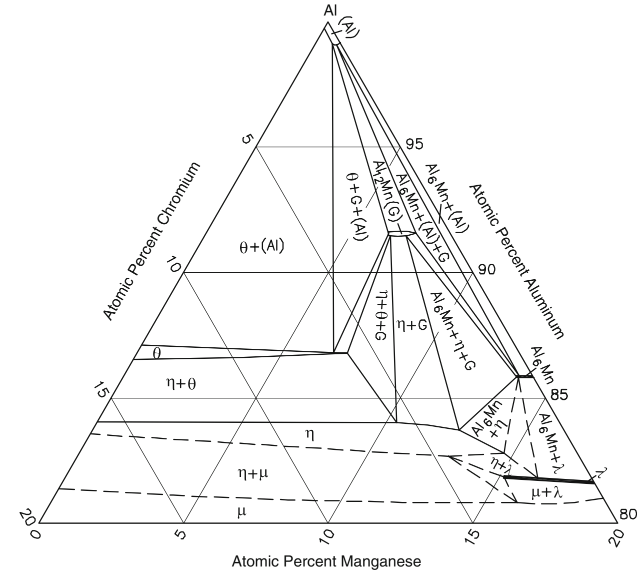

Fig. 9 Al-Cr-Mn isothermal section at 560 °C for Al-rich alloys [2009Gru]

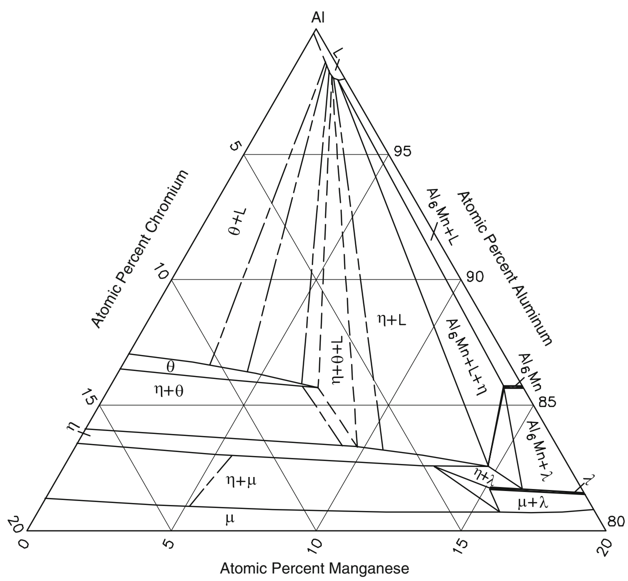

Fig. 8 Al-Cr-Mn isothermal section at 685 °C for Al-rich alloys [2009Gru]

of the invariant reactions which yield the three-phase equilibria.

Isothermal sections in the Al-rich region were constructed by [2009Gru] at 1010, 950, 900, 800 715, 685, 661, 600, and 560 °C. At 1010 °C (Fig. 3), the Al-rich liquid is present over a large area near the Al corner. Al_4Cr (μ) dissolves up to 5.5 at.% Mn. The rhombohedral γ_2 dissolves ~26.5 at.% Mn at the high Al limit. Near the Al-Mn side, the Al-Mn γ phase (bcc) is present. At 950 °C (Fig. 4), the rhombohedral γ_2 phases of the Al-Cr and Al-Mn binaries form a continuous solid solution. $Al_{11}Mn_4$ (HT) (denoted T) is stable and dissolves 12.5 at.% Cr. Al_4Cr (μ) dissolves up to 17 at.% Mn. At 900 °C (Fig. 5), the Al-Cr and Al-Mn μ phases form a continuous solid solution. $Al_{11}Mn_4$ (LT) (denoted ν) is stable and dissolves up to 16.5 at.% Cr. At 800 °C (Fig. 6), the Al-Cr η phase is stable and dissolves up to 9 at.% Mn. The T phase is not stable. The low temperature triclinic form ν dissolves up to 22 at.% Cr. At 715 °C (Fig. 7), the Al-Cr phases θ and η are stable and dissolve up to 5.5 and 14.5 at.% Mn, respectively. The Al_4Mn-λ phase is present in the ternary region [2009Gru]. At 685 °C (Fig. 8), the λ phase has extended up to the binary side and Al_6Mn has appeared. At 560 °C (Fig. 9), $Al_{12}Mn$ (G) is stable in the ternary region. It may be noted that the G phase forms only below 512 °C in the Al-Mn binary system. The G phase forms tie-lines with (Al), θ, η and Al_6Mn. [2009Bal] presented a reaction sequence that incorporates the invariant reactions on the liquidus surface as well as solid-state reactions.

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