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Al-Mn-Pd (Aluminum-Manganese-Palladium)

V. Raghavan

Recently, [2008Rag] reviewed the experimental data on this system, based mainly on the studies of [1995God] and [2000Kle]. The review presented a liquidus projection and three isothermal sections at 875, 840, and 600 °C for Al-rich alloys. [2005Dov] also reviewed the liquidus projection, several isothermal and vertical sections mainly from [1995God] and [2000Kle]. By about the same time as [2008Rag] was published, [2008Bal] reported a detailed experimental study of the system, giving a number of isothermal sections, liquidus and solidus projections, and a reaction scheme for the Al-rich region. This update highlights primarily the new results, comparing them with the previously updated data.

Binary Systems

The Al-Mn phase diagram [1997Oka] has a number of intermediate phases: $MnAl_6$ ($D2_h$-type orthorhombic), λ (16.8-19 at.% Mn), $MnAl_4$ (denoted μ, hexagonal, $P6_3/mmc$), Mn_4Al_{11} (a high-temperature orthorhombic form and a low-temperature triclinic form), γ-MnAl (34.5-51.3 at.% Mn; bcc), γ_1 (30-38.2 at.% Mn), γ_2 (31.4-47 at.% Mn; $D8_{10}$, Cr_5Al_8-type rhombohedral), and ε-Mn_3Al_2 (53.2-60 at.% Mn; cph). The Al-Pd phase diagram [2001Yur] shows the following intermediate phases: $PdAl_4$ (hexagonal, space group $P6_322$), $PdAl_3$ (denoted ε_6, orthorhombic), ε_{28} (∼$PdAl_3$, orthorhombic), Pd_8Al_{21} (Pt_8Al_{21}-type tetragonal), Pd_2Al_3 (denoted δ, $D5_{13}$, Ni_2Al_3-type hexagonal), PdAl ($B2$, CsCl-type cubic and two low-temperature forms: rhombohedral and $B20$-type cubic), Pd_5Al_3 (Rh_5Ge_3-type orthorhombic), Pd_2Al ($C23$, Co_2Si-type orthorhombic), and Pd_5Al_2 (Pd_5Ga_2-type orthorhombic). A partial phase diagram of the Mn-Pd system in the solid state was recently determined by [2004Mii] for the Pd range of 60-76 at.% and for temperatures between 400 and 800 °C. It depicts the following intermediate phases: Pd_3Mn ($D0_{23}$, Al_3Zr-type tetragonal), Pd_2Mn, Pd_5Mn_3, and PdMn ($L1_0$, AuCu-type tetragonal). The high temperature form of PdMn (38-66 at.% Pd) has the cubic CsCl-type structure [Massalski2].

Ternary Phases

An icosahedral phase I (Icosahedral $Pm35$) and a decagonal phase D_3 (Decagonal $P10_5/mmc$) with b parameter = 1.240 nm are stable in this system [2008Bal]. Two other

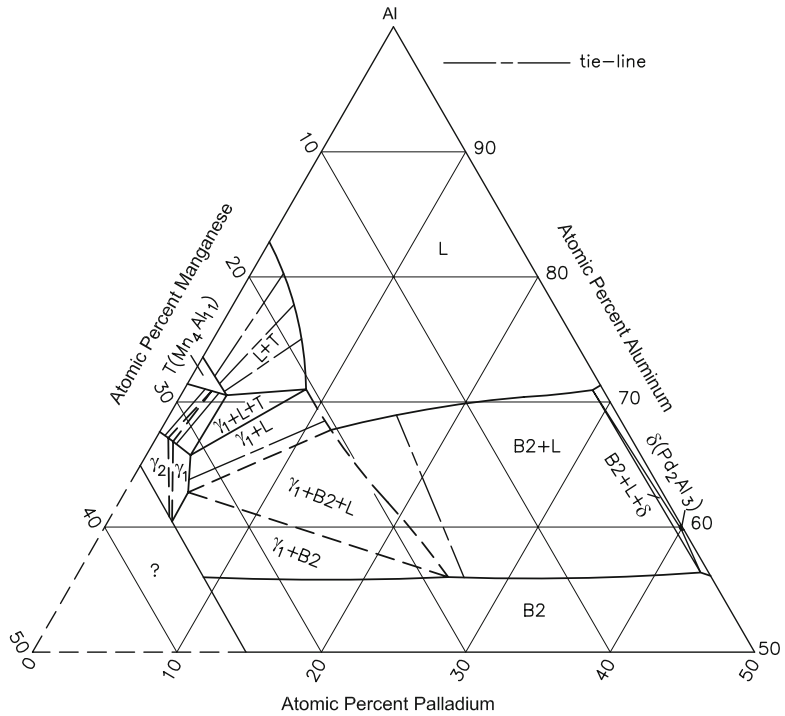

Fig. 1 Al-Mn-Pd isothermal section at 950 °C for Al-rich alloys [2008Bal]

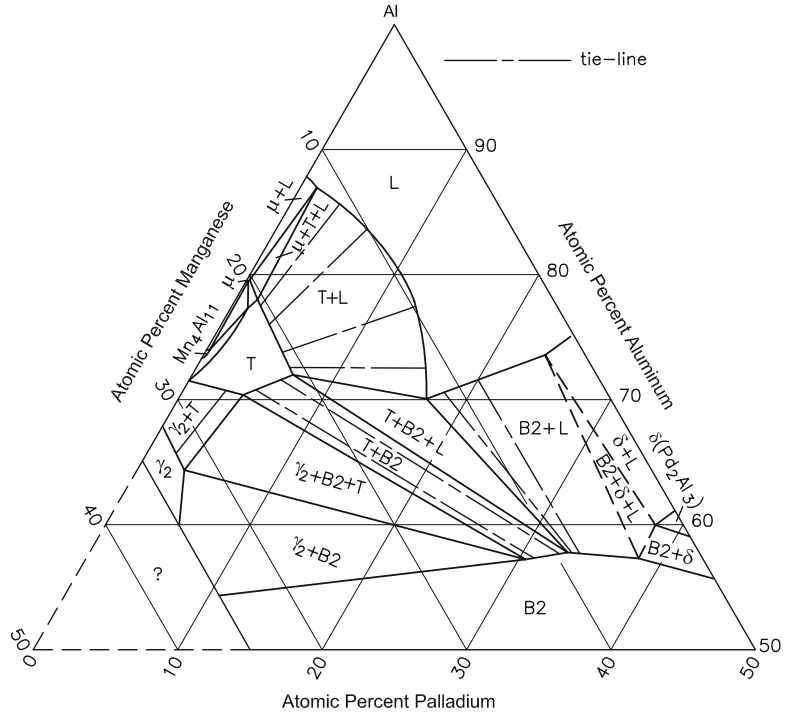

Fig. 2 Al-Mn-Pd isothermal section at 900 °C for Al-rich alloys [2008Bal]

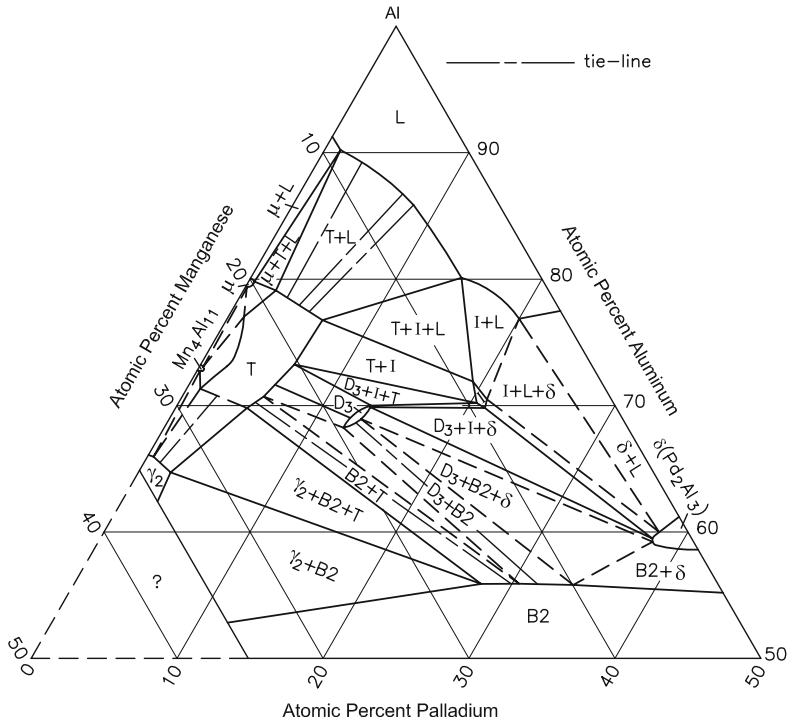

Fig. 3 Al-Mn-Pd isothermal section at 850 °C for Al-rich alloys [2008Bal]

ternary phases T and R of orthorhombic symmetry are known. The T phase, variously called Al_3Mn, Al_4Mn_{11}(HT) and H, is isostructural with the binary phase Al_4Mn_{11}(HT) (space group *Pnma*, Pearson symbol *oP*156) and has a composition range of $Al_{72.6}Mn_{27.2}$ to $Al_{72.4}Mn_{21.1}Pd_{6.5}$ and lattice parameters of a = 1.4873-1.4726 nm, b = 1.2420-1.2514 nm and

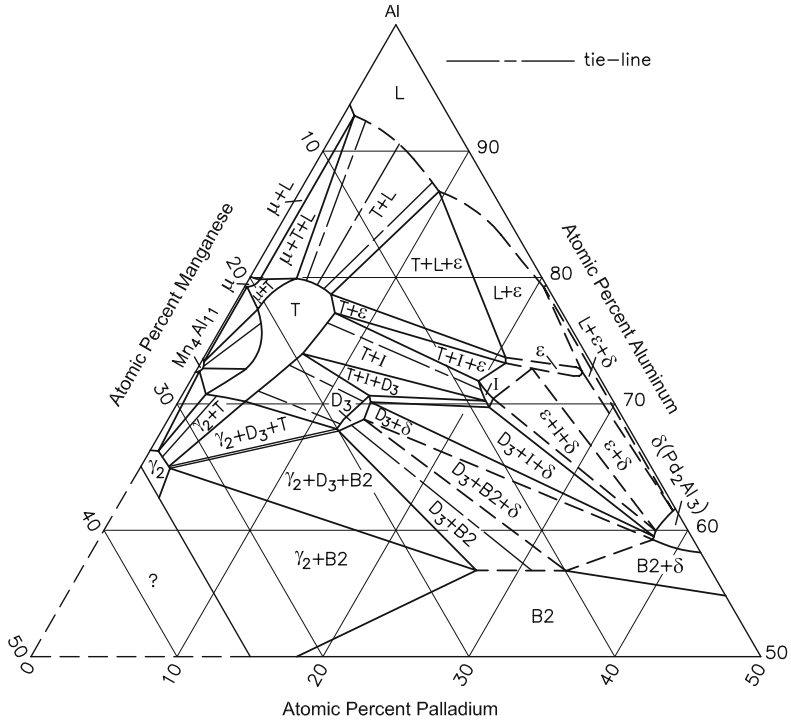

Fig. 4 Al-Mn-Pd isothermal section at 800 °C for Al-rich alloys [2008Bal]

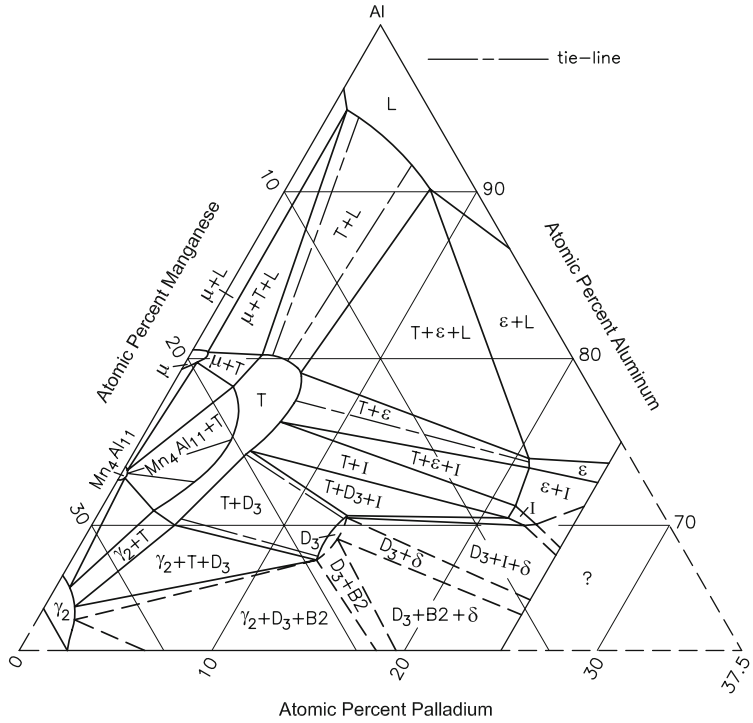

Fig. 5 Al-Mn-Pd isothermal section at 750 °C for Al-rich alloys [2008Bal]

c = 1.2547-1.2605 nm [2008Bal]. The orthorhombic R phase (space group *Bbmm*, Pearson symbol o*S*156, structure type $Al_{31}Mn_6Ni_2$) has lattice parameters of a = 2.388 nm, b = 1.243 nm and c = 0.778 nm and occurs around the composition $\sim Al_{80}Mn_{15}Pd_5$. The literature data on the ternary phases of this system were reviewed by [2008Bal].

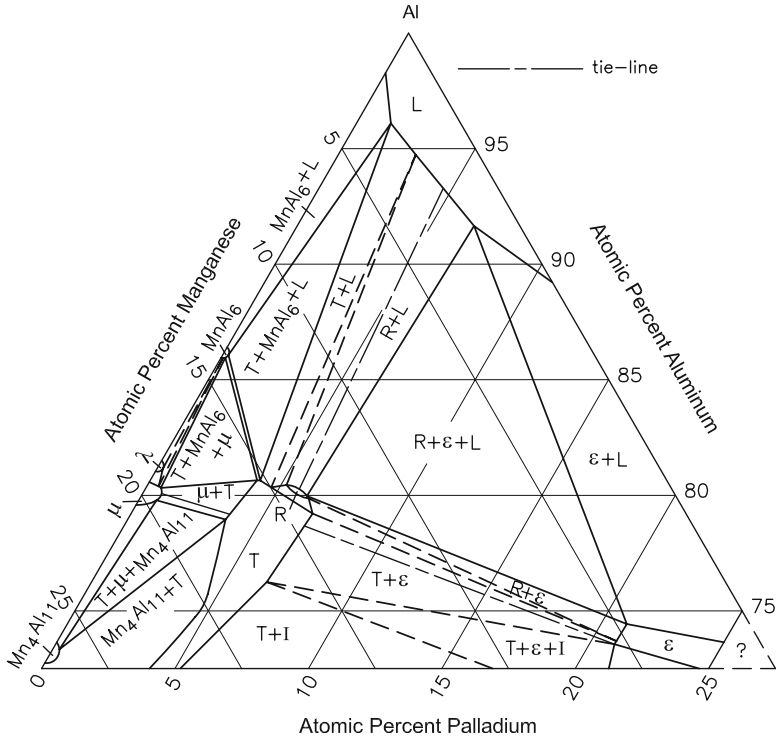

Fig. 6 Al-Mn-Pd isothermal section at 680 °C for Al-rich alloys [2008Bal]

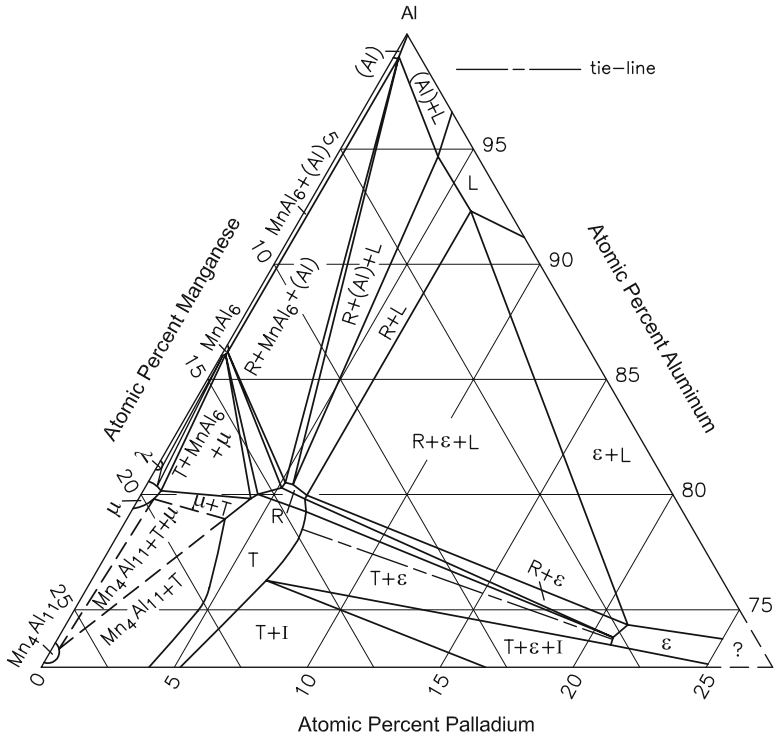

Fig. 7 Al-Mn-Pd isothermal section at 650 °C for Al-rich alloys [2008Bal]

Ternary Phase Equilibria

With starting metals of 99.999% Al, 99.99% Mn, and 99.95% Pd, [2008Bal] levitation-melted under Ar atm 40 Al-rich samples. The alloys were annealed between 950 and 650 °C for durations up to 694 h and quenched in water. The phase equilibria were studied with scanning and transmission electron microscopy, energy dispersive

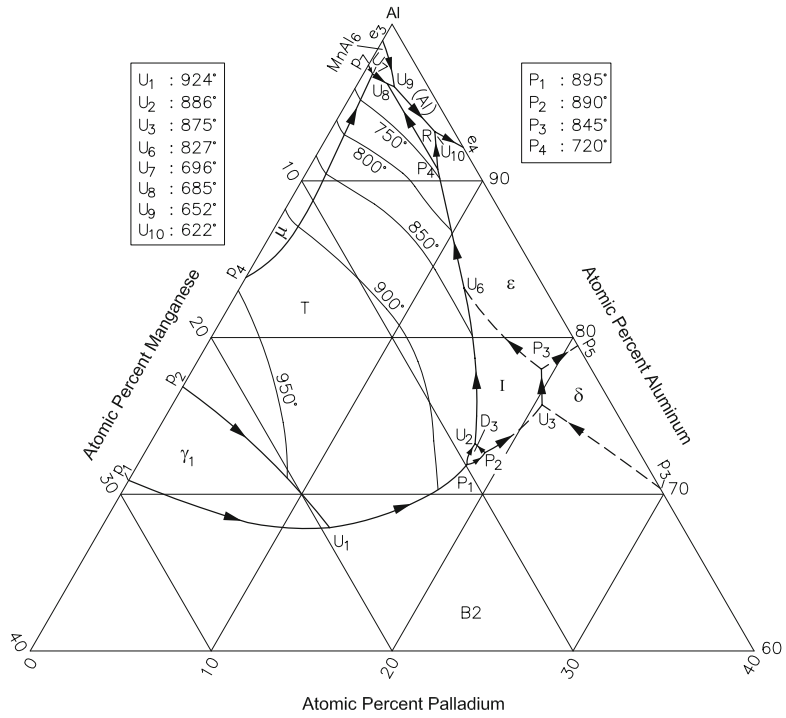

Fig. 8 Al-Mn-Pd liquidus projection for Al-rich alloys [2008Bal]

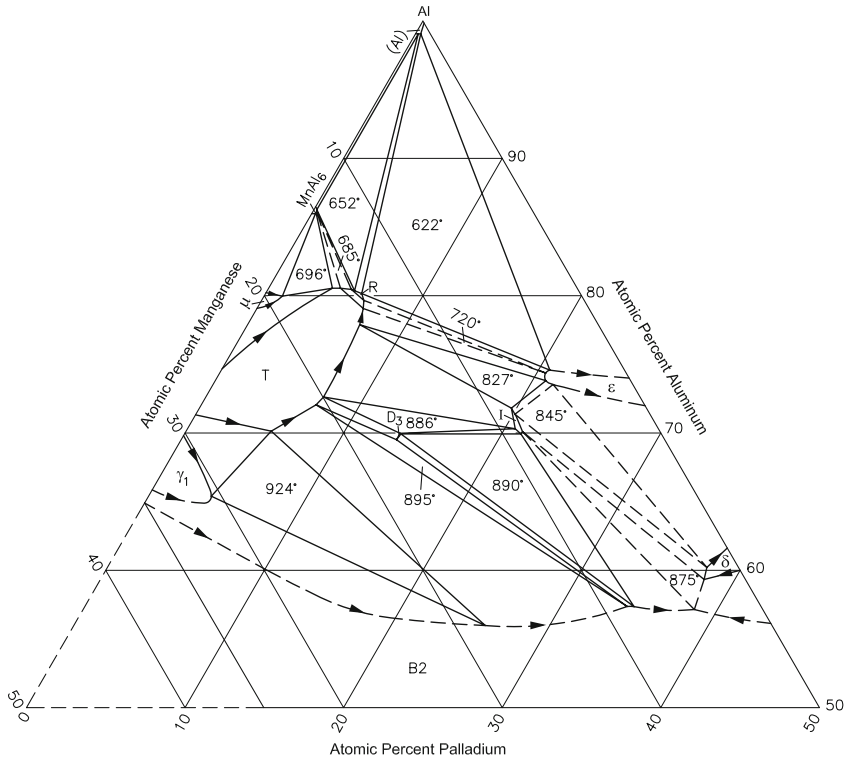

Fig. 9 Al-Mn-Pd solidus projection for Al-rich alloys [2008Bal]

x-ray analysis, inductively-coupled plasma optical emission spectroscopy, and x-ray powder diffraction. Differential thermal analysis was carried out at heating and cooling rates of 2-10 °C/min. The isothermal sections constructed by [2008Bal] for the Al-rich region are shown in Fig. 1-7.

At 950 °C (Fig. 1), the binary T phase extends up to ~3.5 at.% Pd and ~70.5 at.% Al. It forms tie-lines with the liquid, γ_1 and γ_2. At 900 °C (Fig. 2), the T phase dissolves ~7.0 at.% Pd at ~72.0 at.% Al and ~1.5 at.% Pd at ~78.0 at.% Al. It is in two-phase equilibrium with L, γ_2, Mn_4Al_{11}, μ, and β. The γ_2 phase dissolves more than 3 at.% Pd. The PdAl (β) phase dissolves 57.7 at.% Al at 33.5 at.% Pd. At 850 °C (Fig. 3), the T phase is stable only in the ternary region dissolving up to 6.7 at.% Pd at 77.0 at.% Al and 2.3 at.% Pd at 79.4 at.% Al. The decagonal phase D_3 is present in the composition range of $Al_{68.5}Mn_{19.1}Pd_{12.4}$-$Al_{70.2}Mn_{16.5}Pd_{13.3}$. The icosahedral I phase is present in the range of $Al_{70.0}Mn_{8.8}Pd_{21.2}$-$Al_{72.0}Mn_{18.5}Pd_{9.5}$. Pd_2Al_3 (δ) dissolves up to ~4 at.% Mn. At 800 °C (Fig. 4), the T phase recedes further into the ternary region. Also, the Al-rich liquid region decreases in extent. At 750 °C (Fig. 5), the T phase region is elongated along the ~5 at.% Pd line. At 680 °C (Fig. 6) and 650 °C (Fig. 7), the R phase is present in a small composition region around $\sim Al_{80}Mn_{15}Pd_5$. The binary phase $MnAl_6$ is present at 680 and 650 °C and shows negligible solubility for Pd. The ε-related phases are clubbed together as ε in the above figures [2008Bal].

A reaction sequence, a liquidus projection, and a solidus projection for the Al-rich region were also determined by [2008Bal]. The liquidus projection (Fig. 8) depicts four ternary peritectic reactions P_1, P_2, P_3, and P_4 corresponding to the formation D_3, I, ε, and R phases at 895, 890, 845, and 720 °C respectively. Figure 9 shows the projection of the solidus surface. The temperatures indicated in the three-phase triangles in Fig. 9 are those of the respective invariant reactions, which yield the three-phase equilibria.

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