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Al-Mg-Mn (Aluminum-Magnesium-Manganese)

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The early experimental data on this system reviewed by [1995Vil] presented a partial liquidus projection and partial isothermal sections at 750, 710, 670, 500, 450, 425 and 400 °C for compositions near the Al-Mg side. Subsequently, [2005Ohn] developed a thermodynamic description of this system with emphasis on Mg-rich alloys. A liquidus projection and an isothermal section at 710 °C were presented in the update of [2007Rag] from the computed results of [2005Ohn]. Very recently, two detailed thermodynamic assessments of this ternary system by [2007Du] and [2009Shu] were published. Both assessments use descriptions of the Al-Mn system, which yield the phase equilibria in Al-rich alloys different from the currently accepted Al-Mn diagram.

Binary Systems

The Al-Mn phase diagram [1987Mur, 1996Liu, 2006Pre, 2007Du, 2008Gru] 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), $Al_{11}Mn_4$(LT) ($Al_{11}Mn_4$-type triclinic), Al_8Mn_5 (Al_8Cr_5-type rhombohedral), γ (34.5-52 at.% Mn; bcc) and ε (55-72 at.% Mn; cph). Recent versions of the diagram [1996Liu, 2007Du] exclude the intermediate phase γ_1 (Cu_5Zn_8-type cubic). Also, there is no unanimity about the nature of the phase relationships at the Al-end. The currently accepted diagram in this region [1987Mur, 2006Pre, 2008Gru] is shown in Fig. 1. Al_6Mn forms peritectically at 705 °C from liquid (L) and μ. The λ phase forms peritectoidally at 695 °C from Al_6Mn and μ. In their experimental investigation of this region, [2007Du] presented a different result. According to them, the λ-phase forms peritectically at 721 °C from L and μ. Al_6Mn also forms peritectically at 703 °C from L and λ. Nucleation difficulties pose problems in identifying the correct equilibria. Opinion about the relative ease or difficulty with which Al_6Mn or λ nucleates has been divided.

[2007Du] reassessed the Al-Mn phase diagram, using their new experimental results along with the literature data. Figure 2 shows their computed diagram in full. [2009Shu] also carried out a new assessment of the Al-Mn system, using the modified quasichemical model for the liquid phase. Their computed diagram is compared with that of [2007Du] in Fig. 2. In both the diagrams, the λ-phase forms peritectically, which is at variance with the version in Fig. 1.

The Al-Mg phase diagram [1998Lia] has the following intermediate phases: Al_3Mg_2 (Al_3Mg_2-type cubic, labeled β), R or ε (rhombohedral) and $Al_{12}Mg_{17}$ ($A12$, αMn-type cubic, denoted γ). There are no intermediate phases in the Mg-Mn system, see [2007Du] for the computed diagram.

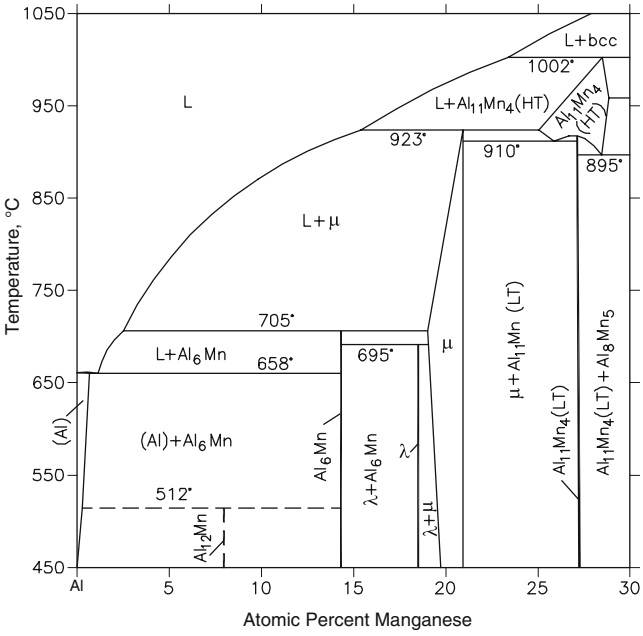

Fig. 1 Al-Mn binary phase diagram in the Al-rich region [2006Pre]

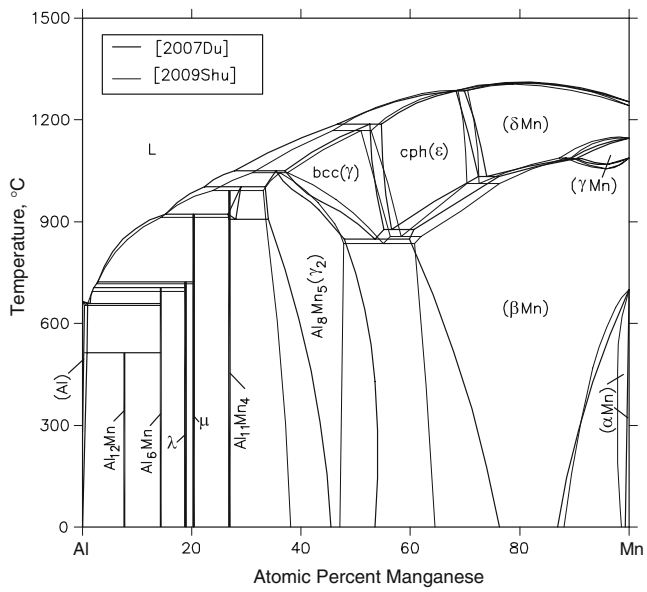

Fig. 2 Al-Mn computed binary phase diagram [2007Du, 2009Shu]

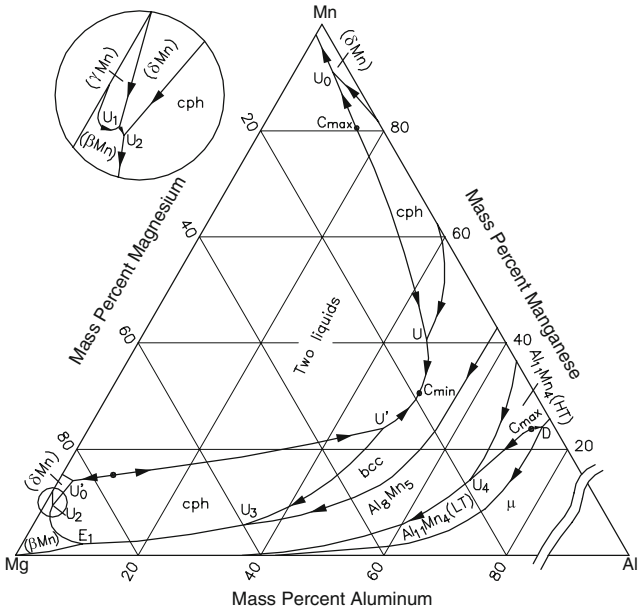

Fig. 3 Al-Mg-Mn computed liquidus projection [2007Du]

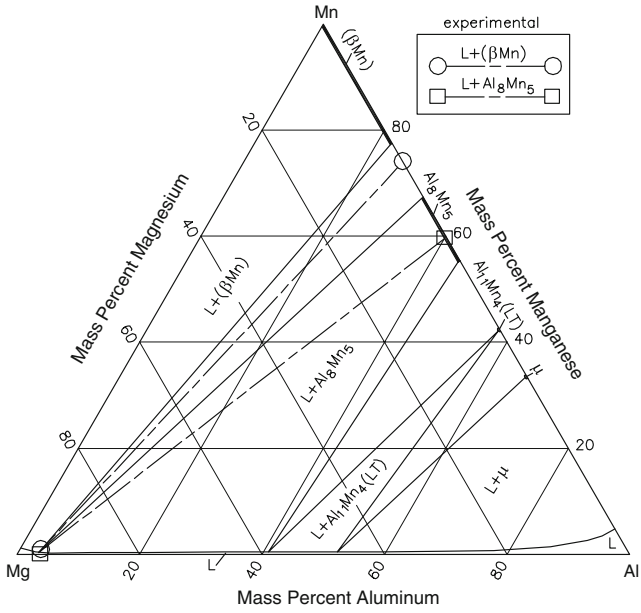

Fig. 5 Al-Mg-Mn computed isothermal section at 710 °C [2007Du]

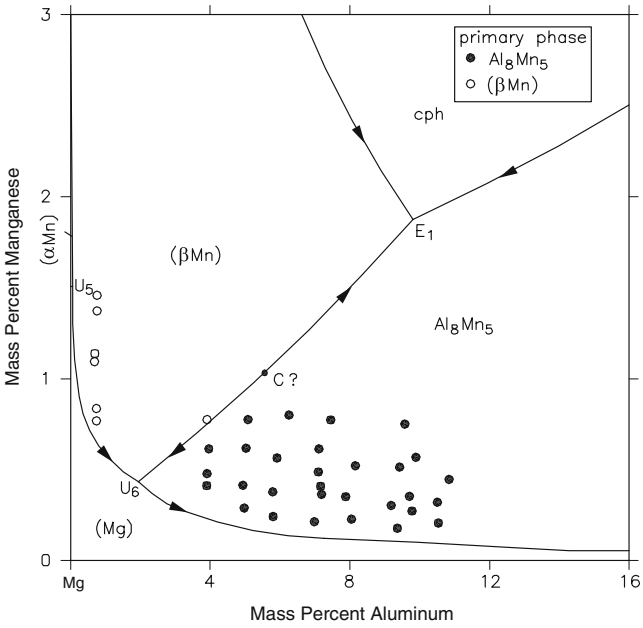

Fig. 4 Al-Mg-Mn computed liquidus projection near Mg corner [2007Du]

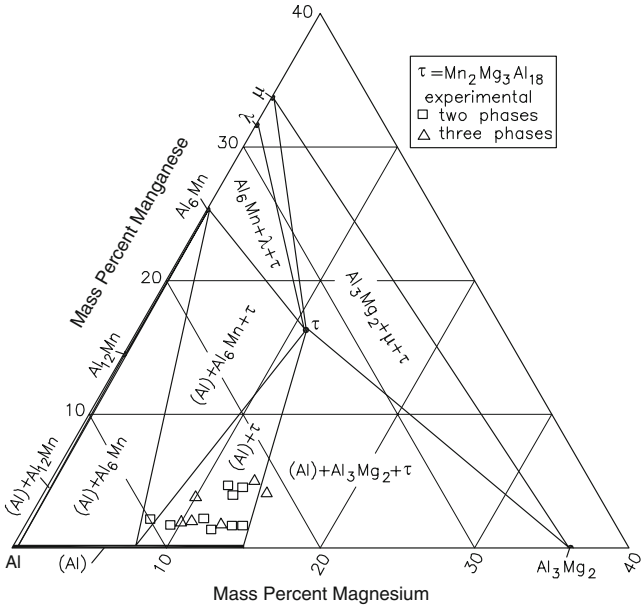

Fig. 6 Al-Mg-Mn computed isothermal section at 450 °C for Al-rich alloys [2007Du]. Narrow two-phase regions are omitted

Ternary Thermodynamic Assessments

[2007Du] accepted the binary descriptions of Al-Mg and Mg-Mn systems from [1998Lia] and [2005Gro], respectively, and used their version of the Al-Mn phase diagram. In the ternary optimization, only one ternary interaction parameter was found necessary for the liquid phase. The CALPHAD-optimized parameters for the ternary compound $Mn_2Mg_3Al_{18}(\tau)$ were in reasonable agreement with those derived from first-principles methodology [2007Du].

[2009Shu] carried out another thermodynamic assessment of this ternary system, using their assessed Al-Mn phase diagram with the binary descriptions of Al-Mg and Mg-Mn systems from the literature. Selected phase diagram and thermodynamic data were used in the optimization. The ternary

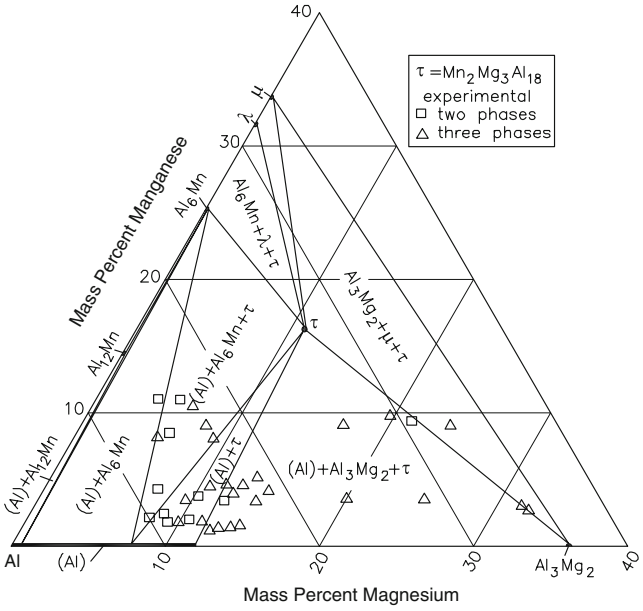

Fig. 7 Al-Mg-Mn computed isothermal section at 400 °C for Al-rich alloys [2007Du]. Narrow two-phase regions are omitted

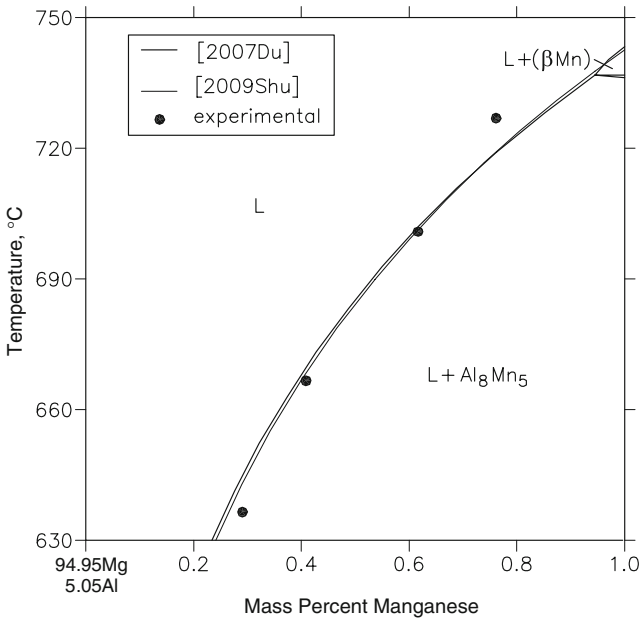

Fig. 8 Al-Mg-Mn computed vertical section at 5.05 mass% Al [2007Du, 2009Shu]

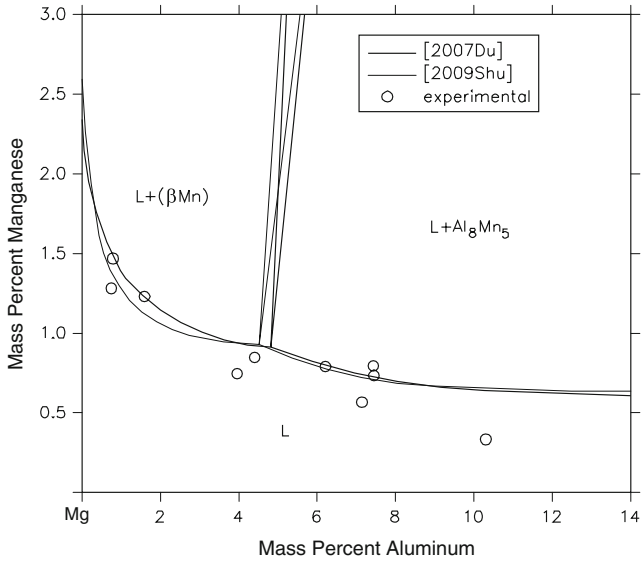

Fig. 9 Al-Mg-Mn computed solubility of Mn and Al in Mg-rich liquid at 730 °C [2007Du, 2009Shu]

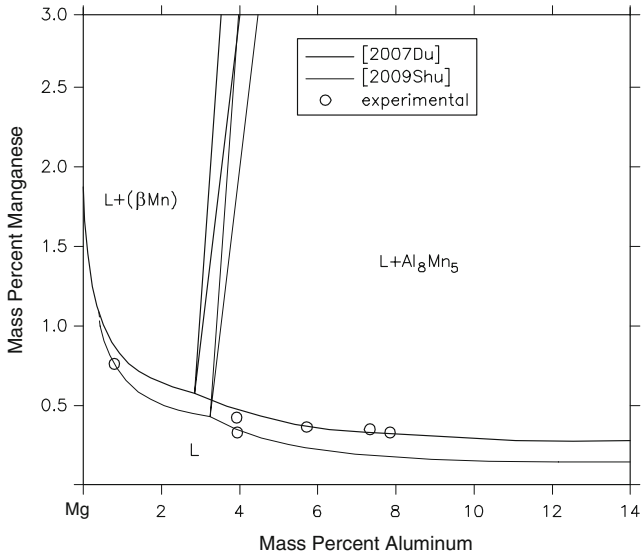

Fig. 10 Al-Mg-Mn computed solubility of Mn and Al in Mg-rich liquid at 670 °C [2007Du, 2009Shu]

phase relationships could be reproduced satisfactorily, with one small additional ternary parameter for the liquid phase.

Computed Phase Equilibria

The liquidus projection computed by [2007Du] is shown in Fig. 3. The details of the phase equilibria near the Mg corner are shown in an enlarged view in Fig. 3, as well as in Fig. 4. Invariant reactions marked M_1 and M_2 by [2007Du] are transition reactions and are relabeled as U_0 and U in Fig. 3. Reactions involving Al_3Mg_2 and $Al_{12}Mg_{17}$ are too close to the Al-Mg side and are not shown in Fig. 3. Phase equilibria close to the Al corner are omitted, as the mode of formation of the λ phase is not established.

Three isothermal sections at 710, 450 and 400 °C from the computed results of [2007Du] are shown in Fig. 5-7. The isothermal sections at 450 and 400 °C are for Al-rich

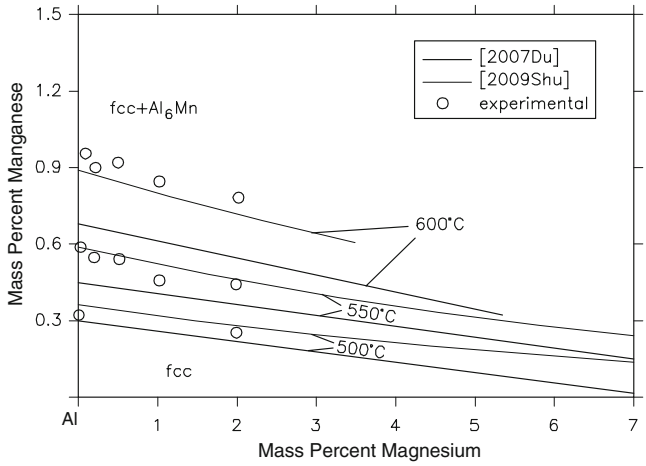

Fig. 11 Al-Mg-Mn computed solubility of Mg and Mn in solid Al [2007Du, 2009Shu]

alloys and are compared with the experimental data from the literature. [2009Shu] also computed a liquidus projection and isothermal sections at 1200, 850, 700, 450 and 400 °C.

The computed vertical sections at 5.05 mass% Al from the results of [2007Du] and [2009Shu] are compared in Fig. 8. The agreement between the two computed phase boundaries and with the experimental data is good. Figures 9 and 10 show the solubility of Mn and Al in (Mg)-rich liquid at 730 and 670 °C from the computed results of [2007Du] and [2009Shu]. The results of [2007Du] show better agreement with experimental data at 670 °C. Figure 11 shows the solubility of Mg and Mn in solid (Al) at 600, 550 and 500 °C as computed by [2007Du] and [2009Shu]. The results of [2009Shu] agree better with the experimental results.

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