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Al-Mg-Sr (Aluminum-Magnesium-Strontium)

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The somewhat-contradictory experimental results reported in the early 80s on the phase equilibria of this ternary system were reviewed recently by [2007Jan]. [1994Cha] presented a thermodynamic assessment of the constituent binary systems and computed a liquidus projection based on binary extrapolations, without using any of the

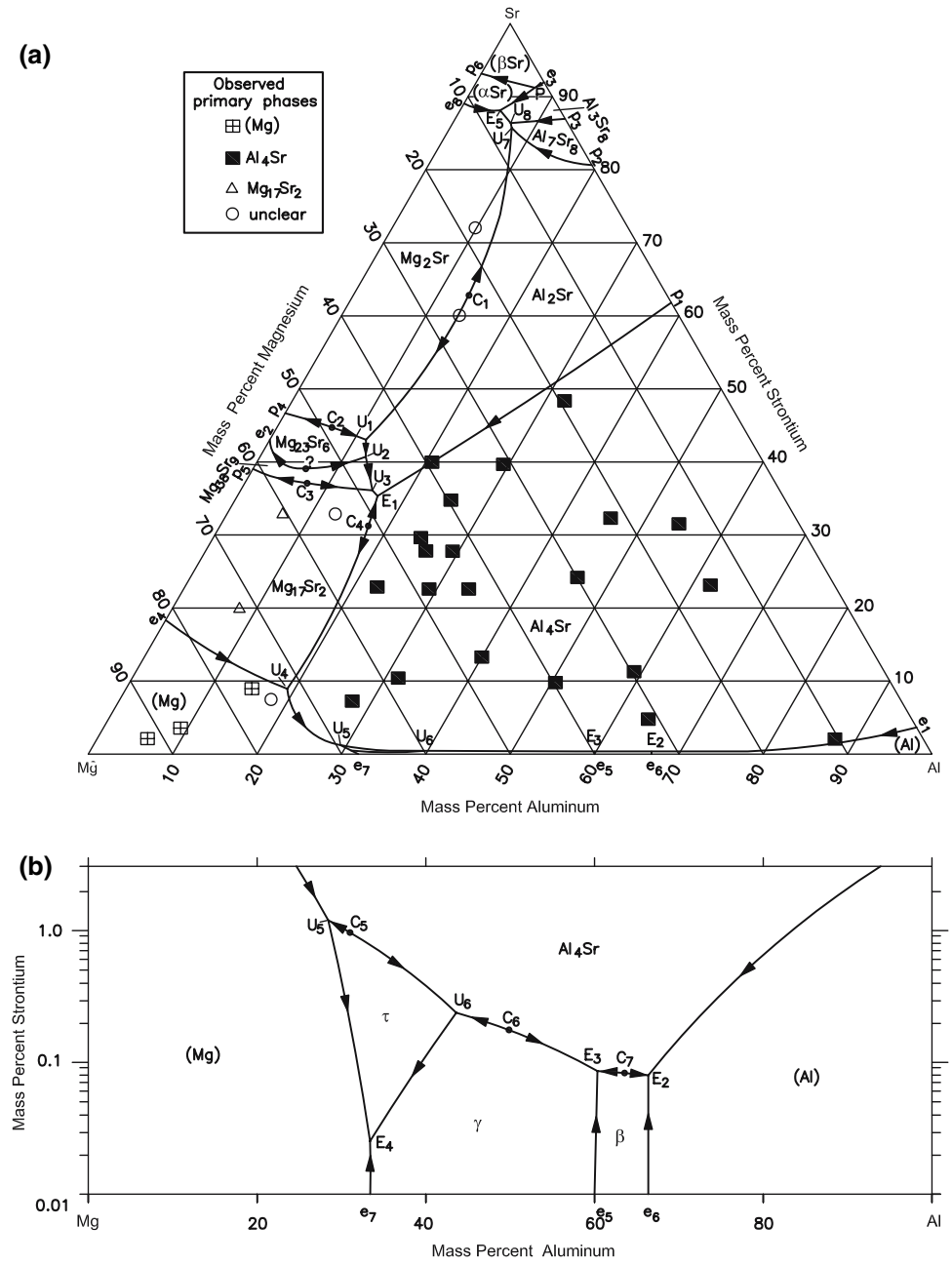

Fig. 1 Al-Mg-Sr computed liquidus projection [2007Jan]. Details along the Al-Mg side are shown in (b)

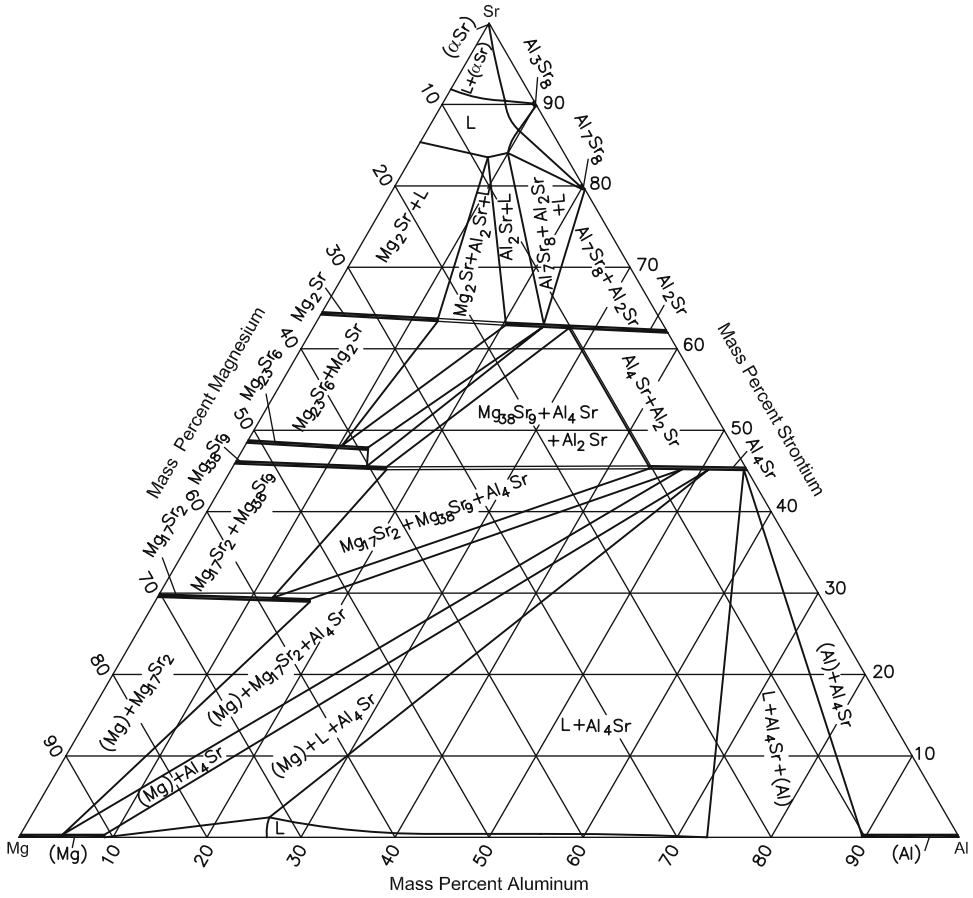

Fig. 2 Al-Mg-Sr computed isothermal section at 500 °C [2007Jan]

ternary experimental data from the literature. Recently, [2005Par] investigated 22 ternary alloys and compared the data with the calculations based on the thermodynamic model of [1994Cha]. [2006Cao] used improved binary descriptions and modeled the solubility of the third component in the binary compounds in the Sr-lean region. [2007Jan] supplemented the results of [2006Cao] with new results from six ternary alloys with Sr content up to 72 mass% and presented a revised thermodynamic assessment.

Binary Systems

The Al-Mg phase diagram [1998Lia] has the following intermediate phases: Mg_2Al_3 (cubic, labeled β), R or ε (rhombohedral), and $Mg_{17}Al_{12}$ (*A*12, α-Mn-type cubic, denoted γ). The Al-Sr phase diagram [1994Cha, Massalski2] depicts the following compounds: Al_4Sr($D1_3$,Al_4Ba-type tetragonal), Al_2Sr ($CeCu_2$-type orthorhombic), and Al_7Sr_8 (space group $P2_13$, cubic). The Al-Sr diagram adopted by [2007Jan] shows an additional phase Al_3Sr_8 (Ca_8In_3-type triclinic). The Mg-Sr phase diagram [Massalski2, 1994Cha] shows the following four compounds: $Mg_{17}Sr_2$ ($Ni_{17}Th_2$-type hexagonal), $Mg_{38}Sr_9$ (hexagonal), $Mg_{23}Sr_6$ ($D8_a$, $Mn_{23}Th_6$-type cubic), and Mg_2Sr (*C*14, $MgZn_2$-type hexagonal).

Ternary Phase Equilibria

[1994Cha] reviewed the experimental data on the three constituent binaries, optimized the interaction parameters, and calculated the binary phase diagrams. In the ternary system, the liquid, (Al), (Mg), and Al-Mg γ phases were treated as solution phases, with no ternary solubility in the solid phases. All other binary phases were treated as stoichiometric compounds with no third component solubility. Due to lack of reliable information, all reported ternary phases were ignored. A liquidus projection was computed for the entire composition range. The regions of primary crystallization of Al_4Sr, Al_2Sr and Mg_2Sr dominate the liquidus surface. [1994Cha] listed the temperatures and the compositions of the participating phases in four-phase invariant reactions that occur on the liquidus surface. The neglect of the solubility of the third component in the binary phases is a limitation of this thermodynamic assessment.

With starting metals of 99.9% Al, 99.8% Mg, and 99% Sr, [2005Par] induction-melted 22 ternary alloys under Ar

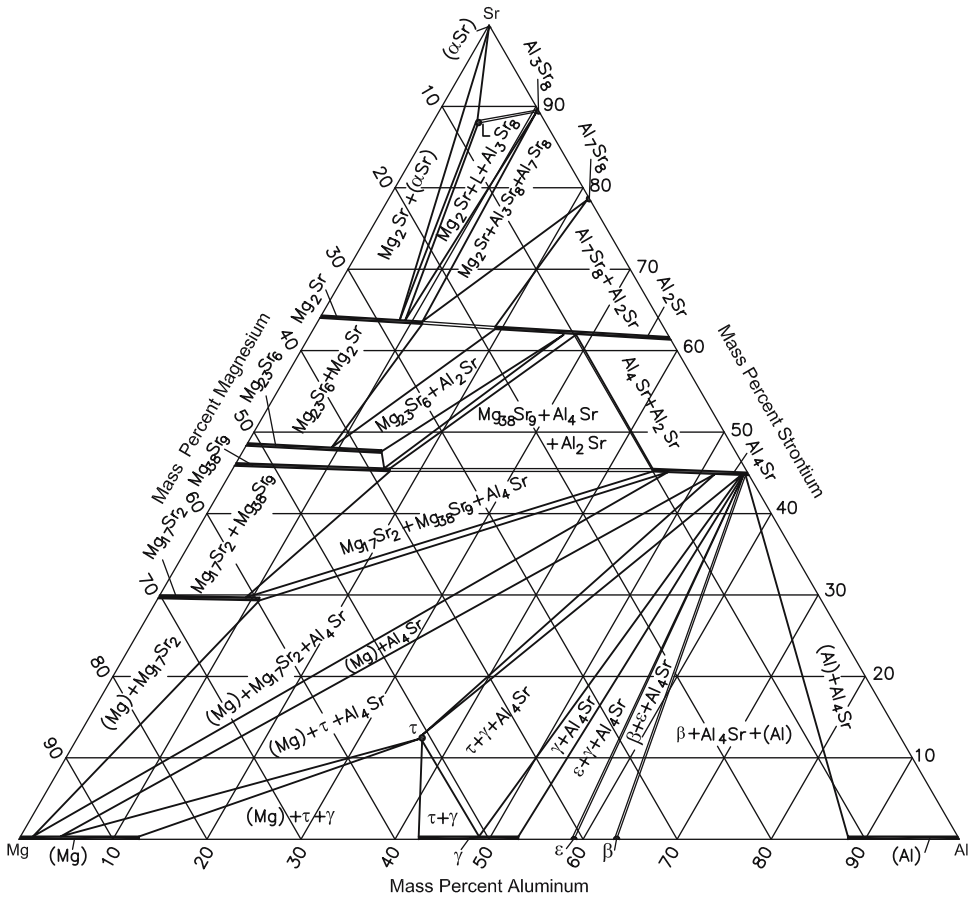

Fig. 3 Al-Mg-Sr computed isothermal section at 400 °C [2007Jan]

atm with the addition of 1% SF_6 to protect against oxidation. Differential scanning calorimetry (DSC) measurements were done at a heating/cooling rate of 5 °C per min. Phase identification was done with x-ray powder diffraction and the microstructures were examined with the optical microscope. Vertical sections and phase fractions as a function of temperature were calculated using the thermodynamic parameters derived by [1994Cha]. The phase transition temperatures from the computed vertical sections were compared with the DSC signals. Considerable disagreement between the thermodynamic model and the experimental results was found in many cases. [2005Par] suggested that the system should be remodeled on the basis of the new experimental findings. Furthermore, [2005Par] indicated several ternary solid solutions (or compounds), in the as-cast condition as well as in the post-DSC samples. No further details about their nature and structure were given.

[2006Cao] used improved thermodynamic descriptions of the binary systems and calculated initially an isothermal section at 400 °C, in order to identify compositions for key experiments. Using the results from the new experiments, a revised thermodynamic description of the ternary system was obtained. With starting metals of 99.5% Al, 99.9% Mg, and 99% Sr, [2006Cao] induction-melted five ternary alloys in the composition range up to 20 at.% Sr. The alloys were annealed at 400 °C for 835-770 h. The phase equilibria were studied with scanning electron microscope, x-ray powder diffraction and electron probe microanalysis. The liquid phase, (Al), (Mg) and (Sr) were modeled as substitutional solutions. In view of the extensive solubility of Mg found in Al_4Sr, this phase was modeled as $(Al,Mg)_4Sr$. Similarly, the solubility of Al in $Mg_{17}Sr_2$ and $Mg_{38}Sr_9$ was considered. Due to lack of information, the third component solubility in binary compounds richer in Sr was ignored. The optimized parameters were listed. A liquidus projection and an isothermal section at 400 °C were computed by [2006Cao].

Most recently, [2007Jan] extended the studies on this ternary system, by performing experiments on six more alloys with Sr content up to 70 mass%. With starting metals of 99.998 mass% Al, 99.98 mass% Mg and 99.99 mass% Sr, alloy pellets were prepared and sealed in tantalum capsules. The DSC experiments were carried out at heating/cooling rates of 5 and 1°C per min. Microstructures were examined with the scanning electron microscope. The local compositions were obtained with the electron microprobe analyzer. Only one ternary compound τ with an unknown crystal structure was found at the composition $Al_{38}Mg_{58}Sr_4$ (atomic percent). Substantial third component solubility in Al-Sr and Mg-Sr compounds

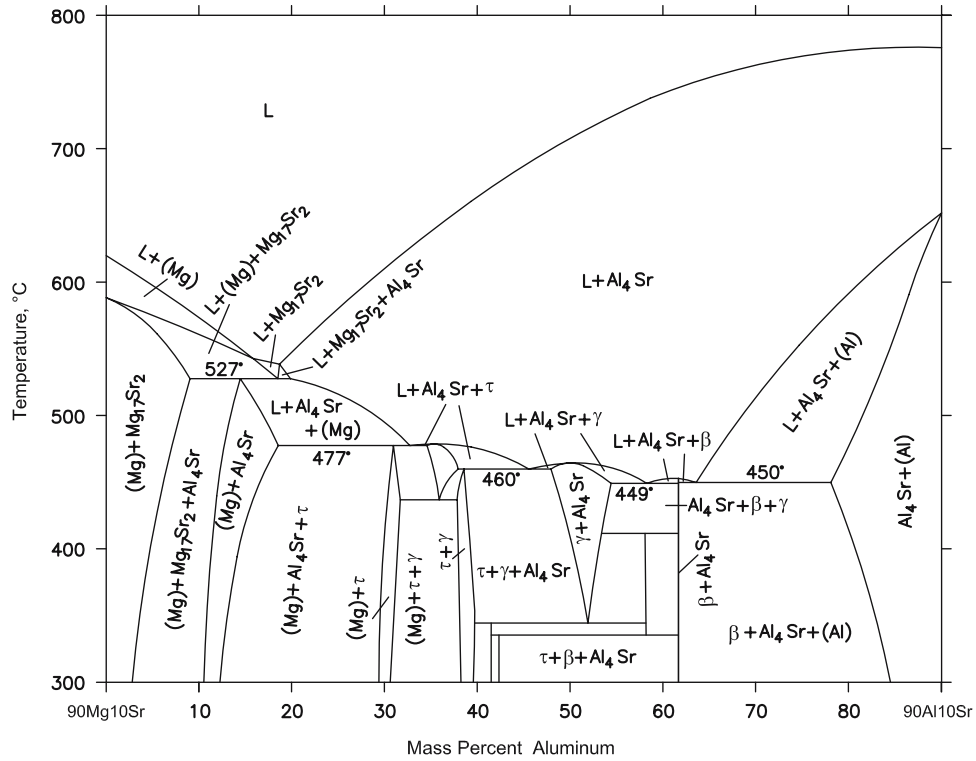

Fig. 4 Al-Mg-Sr computed vertical section at constant 10 mass% Sr [2007Jan]

was measured. The Sr solubility in $Mg_{17}Al_{12}$ (γ) was found to be negligible.

In the thermodynamic modeling, [2007Jan] described the liquid, fcc, bcc and cph solution phases with a single lattice. The binary compounds Al_4Sr, Al_2Sr, $Mg_{17}Sr_2$, $Mg_{38}Sr_9$, $Mg_{23}Sr_6$, and Mg_2Sr were modeled with two sublattices, with only Sr residing in the second sublattice, as substitution occurs at constant atomic percent of Sr. The binary Al-Mg phases β and ε , Al_7Sr_8, Al_3Sr_8 and τ were taken to be stoichiometric compounds. The homogeneity range of Al-Mg γ was taken into account in the adopted binary description of [1998Lia]. In addition to the new experimental results [2007Jan], raw experimental information from the studies of [2005Par] was re-evaluated and included in the thermodynamic optimization.

The liquidus projection computed by [2007Jan] is shown in Fig. 1. The phases of primary crystallization are shown, along with the experimental information. Al_4Sr is the dominant phase of primary crystallization. The temperature maxima on the liquidus lines are indicated by C_1, C_2, etc. Figure 1b shows the reactions near the Al-Mg side in greater detail. The ternary phase τ forms peritectically at 477 °C. Two computed isothermal sections at 500 and 400 °C are shown in Fig. 2 and 3. At 500 °C (Fig. 2), the ternary phase τ is not present. Two residual liquid fields are present, one near the Sr corner and the other along the Al-Mg side. At 400 °C (Fig. 3), the τ phase is present and the liquid fields have disappeared. At both temperatures, considerable third component solubilities in the binary compounds are seen. The computed phase equilibria above 70 mass% Sr are not supported by experiments. Two vertical sections were computed by [2007Jan] along the $Mg_{65}Al_{35}$ (mass%)—Sr join and at constant 10 mass% Sr respectively. Figure 4 shows the vertical section at constant 10 mass% Sr [2007Jan].

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