JPEDAV (2007) 28:215–217
DOI: 10.1007/s11669-007-9034-9
1547-7037 ©ASM International

Al-Fe-Mn-Si (Aluminum-Iron-Manganese-Silicon)

V. Raghavan

Early literature on this quaternary system includes the results of [1943Phi] and [1950Phr]. More recently, [1975Bar] reviewed the experimental data on the liquidus projection and the phase distribution in the solid state. In a series of papers, Zakharov et al. [1988Zak, 1989Zak1, 1989Zak2] prepared two series of alloys with a constant Si content of either 10 or 14 mass% and reported several isothermal and polythermal sections. [1996Dav] investigated Al-rich alloys at 550 °C. [2003Bal] presented a thermodynamic assessment of the system and compared computed vertical sections and isothermal sections with the results of [1943Phi], [1988Zak] and [1989Zak1]. The most recent thermodynamic description of the system is by [2005Du]. They listed the optimized interaction parameters for the ternary phases αAlMnSi and β AlFeSi, and the quaternary phase $FeMnSi_2Al_8$. The computed temperatures and compositions of the invariant reactions in Al-rich alloys were listed and a typical computed isopleth was given.

Ternary Systems

Recent studies/reviews of the four ternaries are: [2006Umi] (Al-Fe-Mn), [2004Du] (Al-Mn-Si), [2002Rag] (Al-Fe-Si) and [1988Ray] (Fe-Mn-Si).

Quaternary Phase Equilibria

One quaternary phase is stable in this system. Occurring at the nominal composition $FeMnSi_2Al_8$ (or $Fe_2MnSi_2Al_{15}$ or $(Fe,Mn)_4Si_3Al_{16}$), it is cubic (space group $Im\bar{3}$) with a = 1.252 nm.

During the course of their investigation of the Al-Fe-Mg-Mn-Si quinary system, [1975Bar] reviewed the experimental data on the liquidus projection for this quaternary system, in which the Al apex of the tetrahedron was used to project on the basal plane the features nearest to the apex. The fields marked in Fig. 1 from [1975Bar] have additionally (Al) in equilibrium with the liquid. Figure 2 shows the phase distribution in the solid state. The fields contain (Al) as an additional phase [1975Bar].

In a series of investigations, [1988Zak], [1989Zak1] and [1989Zak2] examined quaternary alloys in the composition range of 10-14 mass% Si, 0-3 mass% Fe and 0-4 mass% Mn. They prepared the alloys with the starting metals of minimum purity of 99.995% Al, 99.98% Fe, 99.85% Mn and 99.9999% Si. The phase equilibria were studied with differential thermal analysis (DTA), metallography and x-ray diffraction. The results were presented as six polythermal sections at 10Si-1Fe and 14Si-1Fe (in mass%) [1988Zak], at 10Si-2Fe and 14Si-2Fe (in mass%) [1989Zak1] and at 10Si-3Fe and 14Si-3Fe (in mass%) [1988Zak]. [1989Zak2] presented four isothermal sections at constant 10Si and 14Si (in mass%) and at 660 and

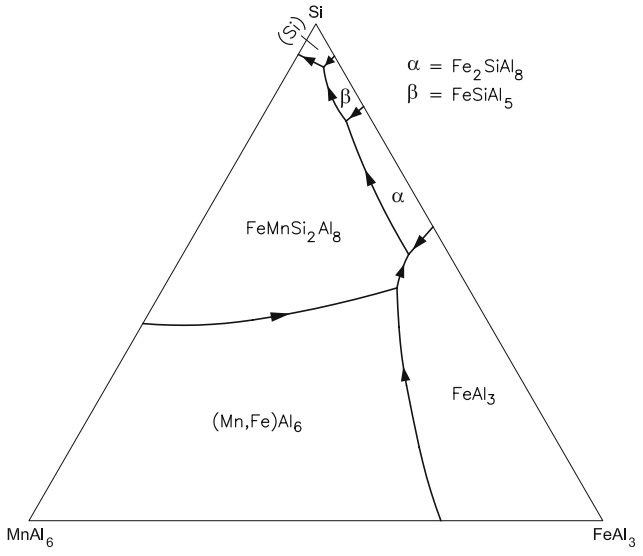

Fig. 1 Al-Fe-Mn-Si liquidus projection from the Al apex on to the basal plane showing the phases nearest to the apex. All fields have (Al) additionally [1975Bar]

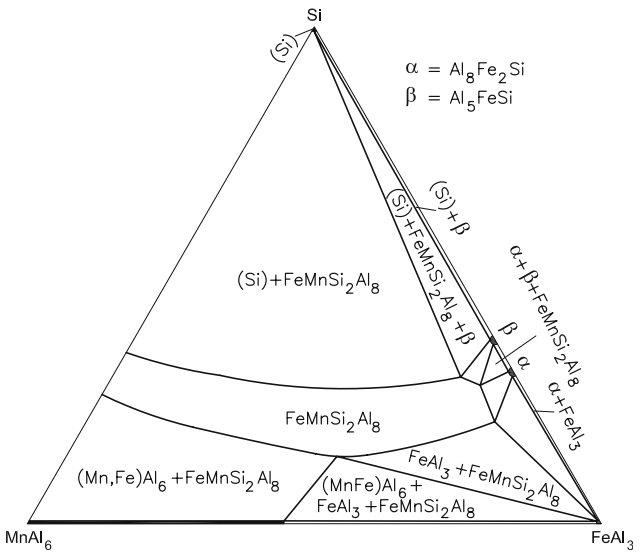

Fig. 2 Al-Fe-Mn-Si phase distribution in the solid state with (Al) as an additional phase [1975Bar]

580 °C. [2003Bal] accepted the results of Zakharov et al. in their CALPHAD modeling. In addition, they used other selected data and the thermodynamic description of the ternary subsystems from COST 507 database. Two polythermal sections at 10Si-1Fe and 10Si-3Fe (mass%) were computed by [2003Bal]. The section at 10Si-3Fe is compared with the DTA data of [1988Zak] in Fig. 3 and the agreement is satisfactory. Two isothermal sections at 660 °C and at 10 and 14 mass% Si, respectively computed by [2003Bal] are compared with the experimental data of [1988Zak] in Fig. 4 and 5. The comparison shows satisfactory agreement. [2003Bal] computed two more polythermal sections at 1Fe-1Mn and at 1Fe-1Si (mass%), respectively and compared the same with data of [1943Phi]. Here, there is no agreement between the computed and experimental invariant horizontals. [2005Du] have pointed out that the melting characteristics of $FeMnSi_2Al_8$ reported by [1994Flo] and the large solubility of Fe in αAlMnSi (determined by [1996Dav] and confirmed by [2005Du]) were not considered in the thermodynamic evaluation of [2003Bal].

In the course of their investigation of the Al-Fe-Mg-Mn-Si quinary system, [2005Du] assessed the Al-Fe-Mn-Si system. For the ternary subsystems, the COST 507 database was used. The additional input for the quaternary optimization were the invariant reactions data from [1943Phi], [1988Zak] and [1989Zak1], the melting point and the thermochemical data of $FeMnSi_2Al_8$ from [1994Flo] and the phase equilibrium data of [1996Dav]. The optimized interaction parameters for $FeMnSi_2Al_8$, αAlMnSi and βAlFeSi were listed. The computed invariant reactions in Al-rich alloys were compared with those determined by [1943Phi], [1975Bar] and [1988Zak]. The agreement is satisfactory. A typical isopleth at 1Mn-3Si (in mass%) computed by [2005Du] is shown in Fig. 6. Five invariant reaction horizontals (labeled p, q, r, s and t) are seen in Fig. 6 at 616, 576, 576, 575 and ~562 °C, respectively. The last reaction (labeled t in Fig. 6) is a eutectoid reaction, through which the quaternary phase decomposes: $FeMnSi_2Al_8 \leftrightarrow$ (Al) + (Si) + αAlMnSi + βAlMnSi.

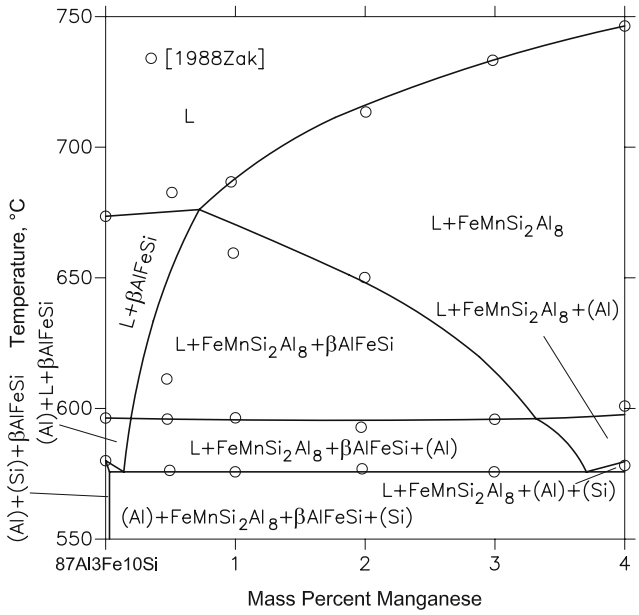

Fig. 3 Al-Fe-Mn-Si computed polythermal section at 3Fe-10Si (in mass%) [2003Bal]

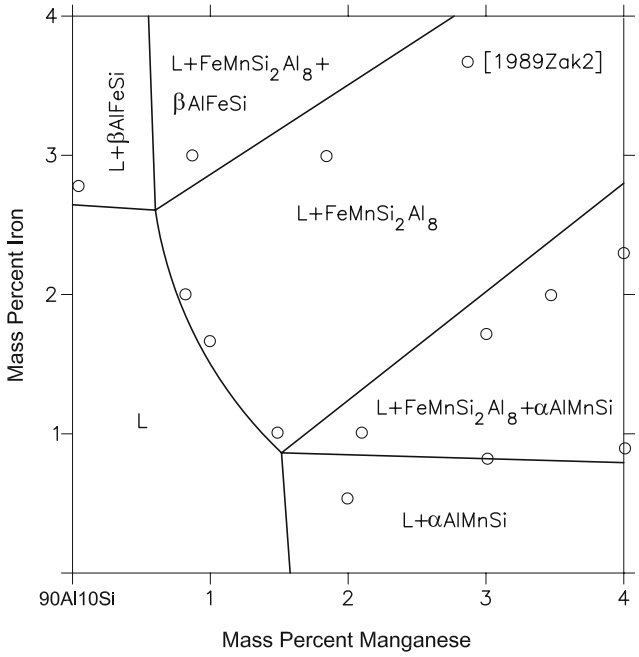

Fig. 4 Al-Fe-Mn-Si computed isothermal section at 10 mass% Si and 660 °C [2003Bal]

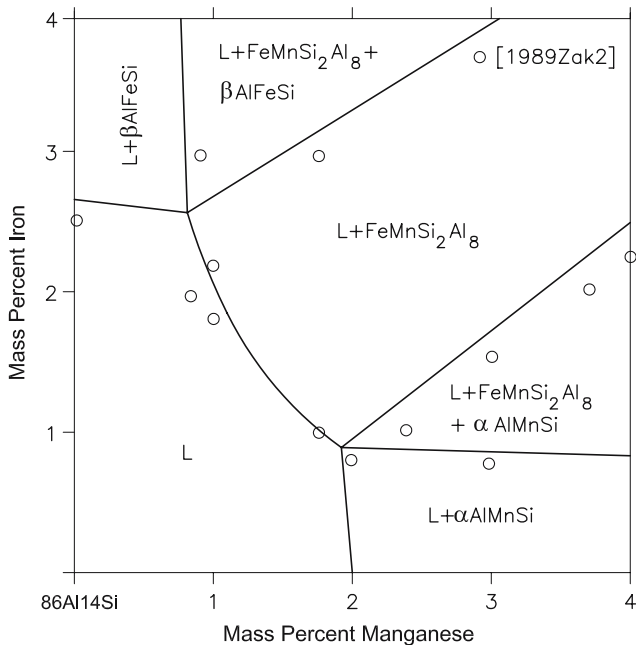

Fig. 5 Al-Fe-Mn-Si computed isothermal section at 14 mass% Si and 660 °C [2003Bal]

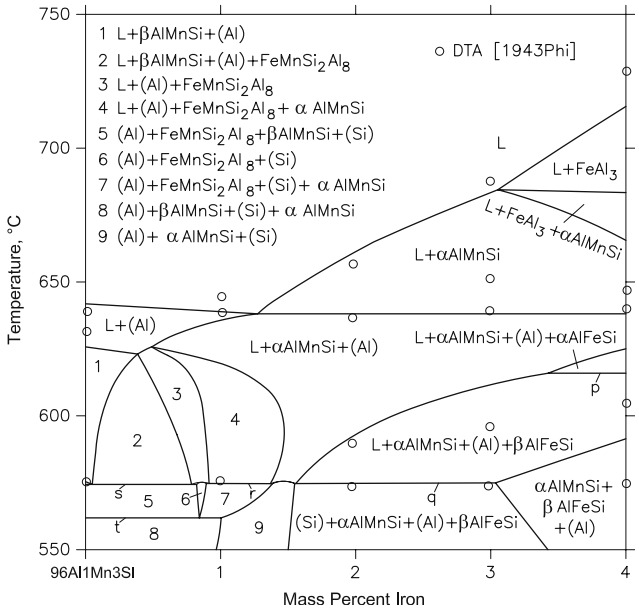

Fig. 6 Al-Fe-Mn-Si computed polythermal section at 1Mn-3Si (in mass%) [2005Du]

[2005Du] extended their equilibrium calculations to non-equilibrium conditions by incorporating the effects of diffusion kinetics, dendrite morphology, dendrite coarsening, etc. Calculated data were presented for multicomponent commercial Al alloys and compared with the experimental data.

References

1943Phi: H.W.L. Phillips and P.C. Varley, The Constitution of Alloys of Aluminum with Manganese, Silicon and Iron. III. The Ternary System Al-Si-Fe. IV. The Quaternary System: Al-Mn-Si-Fe, *J. Inst. Metals (London)*, 1943, **69**, p 317-350

1950Phr: G. Phragmen, On the Phases Occurring in Alloys of Aluminum with Copper, Magnesium, Manganese, Iron and Silicon, *J. Inst. Metals (London)*, 1950, **77**, p 489-552

1975Bar: J.G. Barlock and L.F. Mondolfo, Structure of Some Aluminum-Iron-Magnesium-Manganese-Silicon Alloys, *Z. Metallkd.,*, 1975, **66**(10), p 605-611

1988Ray: G.V. Raynor and V.G. Rivlin, Fe-Mn-Si, *Phase Equilibria in Iron Ternary Alloys, Inst. Metals, London*, 1988, p 363-377

1988Zak: A.M. Zakharov, I.T. Guldin, A.A. Arnold and Yu.A. Matsenko, Phase Equilibria in the Al-Si-Fe-Mn System in the Concentration Range of 10-14% Si, 0-3% Fe and 0-4% Mn, *Tsvetn. Metall*., 1988, (4), p 89-94, in Russian

1989Zak1: A.M. Zakharov, I.T. Guldin, A.A. Arnold and Yu.A. Matsenko, Phase Diagram of the Al-Si-Fe-Mn System in the 10–14% Si, 0–3% Fe, and 0–4% Mn Concentration Range, *Metally*, 1989, (4), p 214-218, in Russian; TR: *Russ. Metall*., 1989, (4), p 209-213

1989Zak2: A.M. Zakharov, I.T. Guldin, A.A. Arnold, and Yu.A. Matsenko, Sections of the Isothermal Tetrahedron of the Aluminum-Silicon-Iron-Manganese System with 10–14% Si, ≤3% Fe, and ≤4% Mn at 660-580°C, *Tsvetn. Metall*., 1989, (4), p 78–81, in Russian

1994Flo: A. Flores-Valdes, M.I. Pech-Canul, M. Mendez-Nonell, and M. Sukiennik, Differential Thermal Analysis of $Al_8FeMnSi_2$ Intermetallic Phase Particles, *Scripta Metall. Mater.*, 1994, **30**, p 435-439

1996Dav: G. Davignon, A. Serneels, B. Verlinden, and L. Delaey, An Isothermal Section at 550°C in the Al-rich Corner of the Al-Fe-Mn-Si System, *Metall. Mater. Trans. A*, 1996, **27A**, p 3357-3361

2002Rag: V. Raghavan, Al-Fe-Si (Aluminum-Iron-Silicon), *J. Phase Equilibria*, 2002, **23**(4), p 362-366

2003Bal: E. Balitchev, T. Jantzen, I. Hurtado, and D. Neuschutz, Thermodynamic Assessment of the Quaternary System Al-Fe-Mn-Si in the Al-Rich Corner, *CALPHAD*, 2003, **27**, p 275-278

2004Du: Y. Du, J.C. Schuster, F. Weitzer, N. Krendelsberger, B. Huang, Z. Jin, W. Gong, Z. Yuan, and H. Xu, A Thermodynamic Description of the Al-Mn-Si System over the Entire Composition and Temperature Ranges, *Metall. Mater. Trans, A*, 2004, **35**, p 1613-1628

2005Du: Y. Du, Y.A. Chang, S. Liu, B. Huang, F.Y. Xie, Y. Yang, and S.L. Chen, Thermodynamic Description of the Al-Fe-Mg-Mn-Si System and Investigation of Microstructure and Micro-segregation during Directional Solidification of an Al-Fe-Mg-Mn-Si Alloy, *Z. Metallkd.*, 2005, **96**(12), p 1351-1362

2006Umi: R. Umino, X.J. Liu, Y. Sutou, C.P. Wang, I. Ohnuma, R. Kainuma, and K. Ishida, Experimental Determination and Thermodynamic Calculation of Phase Equilibria in the Fe-Mn-Al System, *J. Phase Equilb. Diffus.*, 2006, **27**(1), p 54-62