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Al-Cu-Fe-Mg-Ni-Si (Aluminum-Copper-Iron-Magnesium-Nickel-Silicon)

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Cast Al alloys for piston applications contain about 12-13 mass % Si and smaller quantities of Cu, Fe, Mg, and Ni. The concentration of Mn is usually low enough to be neglected for the purpose of understanding the phase distribution in such alloys. As a first step in the study of this senary (six-component) system, [2005Bel] determined the constitution of three quinary subsystems, using alloys in the commercial composition range.

Ternary and Quaternary Systems

Recent updates on the relevant ternary systems that contain both Al and Si are: Al-Cu-Si (this issue), Al-Fe-Si [2002Rag], Al-Mg-Si (this issue) and Al-Ni-Si [2005Rag]. Binary and ternary compounds that appear in the quinary equilibria discussed by [2005Bel] are: $CuAl_2$ (θ), Mg_2Si(M), $NiAl_3$ (ε), $(Ni,Cu)_2Al_3$ (δ), Al_7Cu_4Ni (γ), Al_9FeNi (T), and Al_5FeSi (β). The symbols given in brackets for the above compounds are those used by [2005Bel].

The relevant quaternary systems that contain both Al and Si are: Al-Cu-Fe-Si (updated in this issue), Al-Cu-Mg-Si (this issue), Al-Cu-Ni-Si, Al-Fe-Mg-Si (this issue), Al-Fe-Ni-Si, and Al-Mg-Ni-Si. The quaternary phases that appear in the quinary systems discussed by [2005Bel] are: $Fe_2Mg_7Si_{10}Al_{18}$ (π) and $Cu_2Mg_8Si_6Al_5$ (Q). [2005Bel] listed the invariant reactions during solidification in these quaternary systems, giving the reaction temperatures.

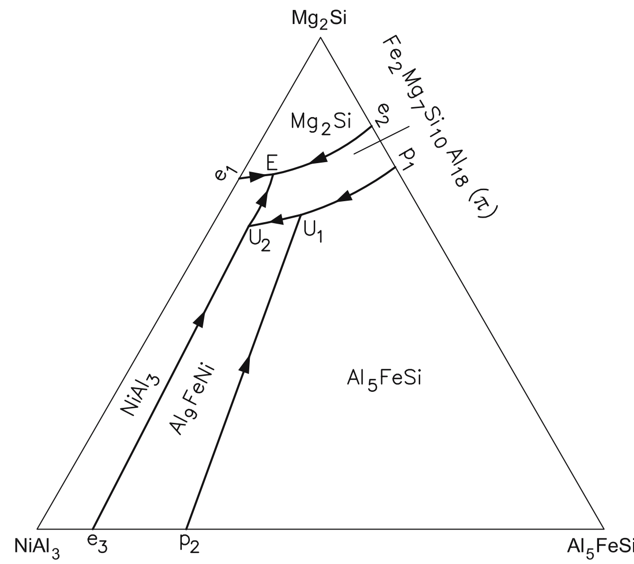

Fig. 2 Al-Fe-Mg-Ni-Si projection of liquidus for Al-rich alloys with ~12 mass % Si. All fields contain additionally (Al) and (Si) [2005Bel]

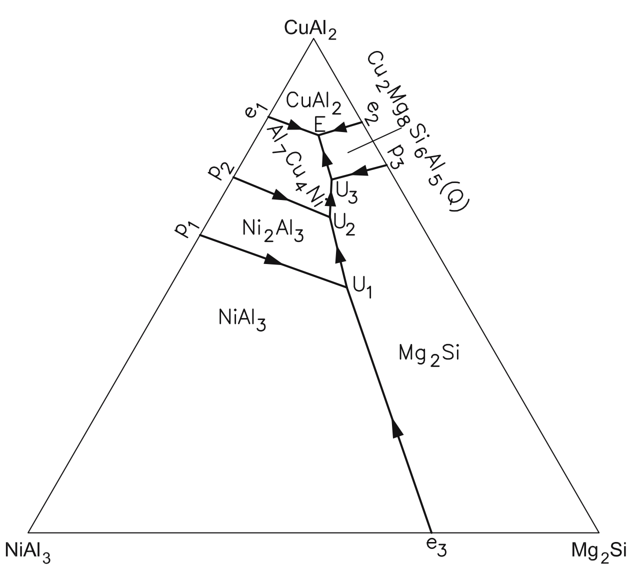

Fig. 1 Al-Cu-Mg-Ni-Si projection of liquidus for Al-rich alloys with ~12 mass % Si. All fields contain additionally (Al) and (Si) [2005Bel]

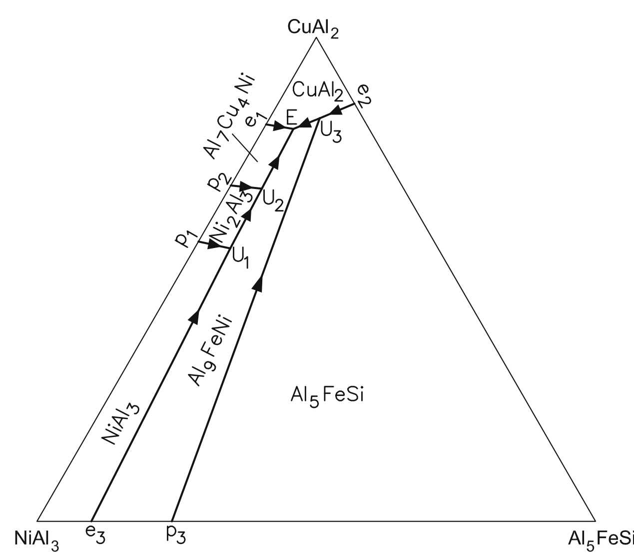

Fig. 3 Al-Cu-Fe-Ni-Si projection of liquidus for Al-rich alloys with ~12 mass % Si. All fields contain additionally (Al) and (Si) [2005Bel]

Phase Equilibria in the Quinary Systems

The relevant quinary systems that contain both Al and Si are: Al-Cu-Fe-Mg-Si, Al-Cu-Fe-Ni-Si, Al-Cu-Mg-Ni-Si, and Al-Fe-Mg-Ni-Si. An update on the Al-Cu-Fe-Mg-Si system appears in this issue. [2005Bel] investigated the other three quinary systems.

With starting metals of 99.95% Al, 99.9% Cu, 99.9% Mg, and 99.9% Si (in mass %) and other master alloys, [2005Bel] melted four alloys in the composition range relevant to piston applications and used two other commercial alloys. The alloys were examined in the following conditions: as-cast; annealed at 300 °C for 10 h; and solution treated at 495 °C for 10 h and water quenched.

Table 1 Invariant reactions in the quinary subsystems [2005Bel]

Reaction	Liquid composition in mass %					Temperature, °C
	Cu	Fe	Mg	Ni	Si	
Al-Cu-Mg-Ni-Si						
U_1 : L + ε↔(Al) + (Si) + δ + M	~12	0	~3	<1	~10	535-540
U_2 : L + δ↔(Al) + (Si) + γ + M	~10	0	~3	<2	~11	530-535
U_3 : L + M + (Si)↔(Al) + Q + γ	~8	0	~3	<2	~12	525-530
E: L↔(Al) + (Si) + θ + Q + γ	~28	0	~2	<1	~6	503-506
Al-Fe-Mg-Ni-Si						
U_1 : L + β ↔ (Al) + (Si) + π + T	0	<0.5	~3	~1	~12	560-565
U_2 : L + T ↔ (Al) + (Si) + π + ε	0	<0.5	~3	~1	~12	550-560
E: L ↔ (Al) + (Si) + M + π + ε	0	<0.15	~3.5	~2	~13	~548
Al-Cu-Fe-Ni-Si						
U_1 : L + ε ↔ (Al) + (Si) + δ + T	~16	<0.5	0	~4	~3	540-550
U_2 : L + δ ↔ (Al) + (Si) + γ + T	~22	<0.5	0	~2	~4	530-540
U_3 : L + β ↔ (Al) + (Si) + θ + T	~28	<0.5	0	<1	~5	520-525
E: L ↔ (Al) + (Si) + θ + T + γ	~30	<0.5	0	~1	~5	515-520

β = Al_5FeSi; γ = Al_7Cu_4Ni; δ = $(Ni,Cu)_2Al_3$; ε = $NiAl_3$; π = $Fe_2Mg_7Si_{10}Al_{18}$; θ = $CuAl_2$; M = Mg_2Si; Q = $Cu_2Mg_8Si_6Al_5$; and T = Al_9FeNi

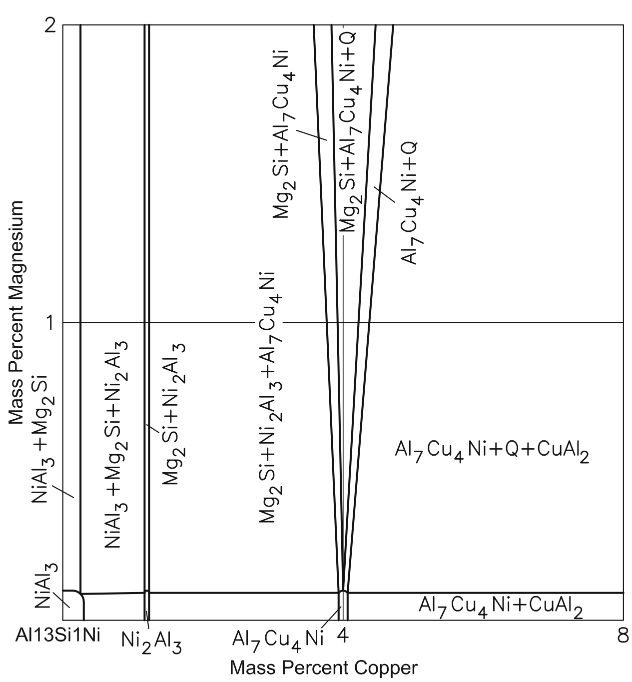

Fig. 4 Al-Cu-Mg-Ni-Si isothermal section at 13Si-1Ni (in mass %) and 300 °C. All fields contain additionally (Al) and (Si) [2005Bel]

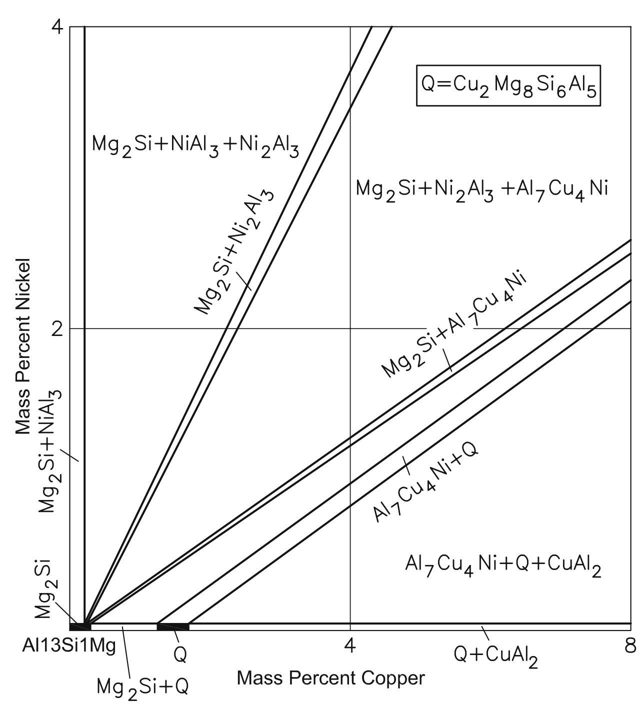

Fig. 5 Al-Cu-Mg-Ni-Si isothermal section at 13Si-1Mg (in mass %) and 300 °C. All fields contain additionally (Al) and (Si) [2005Bel]

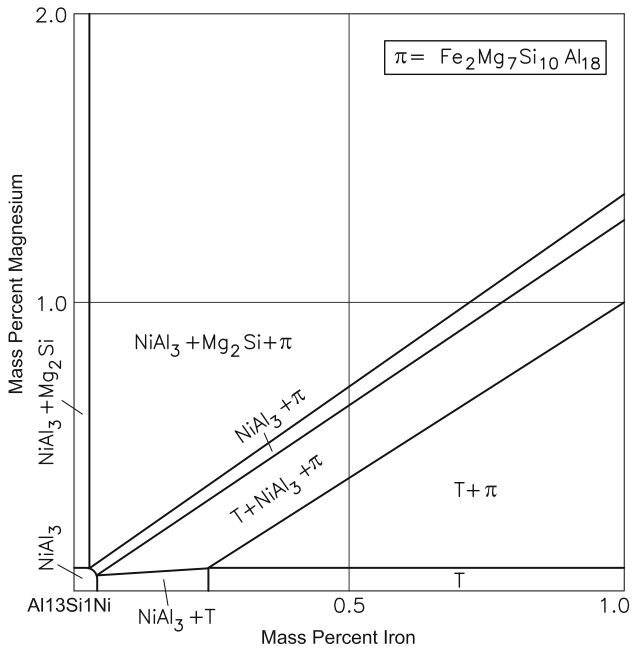

Fig. 6 Al-Fe-Mg-Ni-Si isothermal section at 13Si-1Ni (in mass %) and 300 °C [2005Bel]

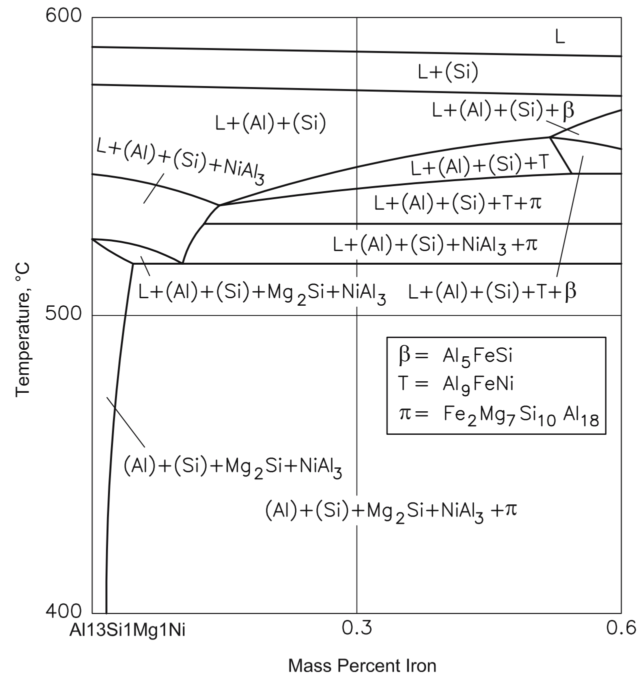

Fig. 8 Al-Fe-Mg-Ni-Si polythermal section at 13Si-1Mg-1Ni (in mass %) [2005Bel]

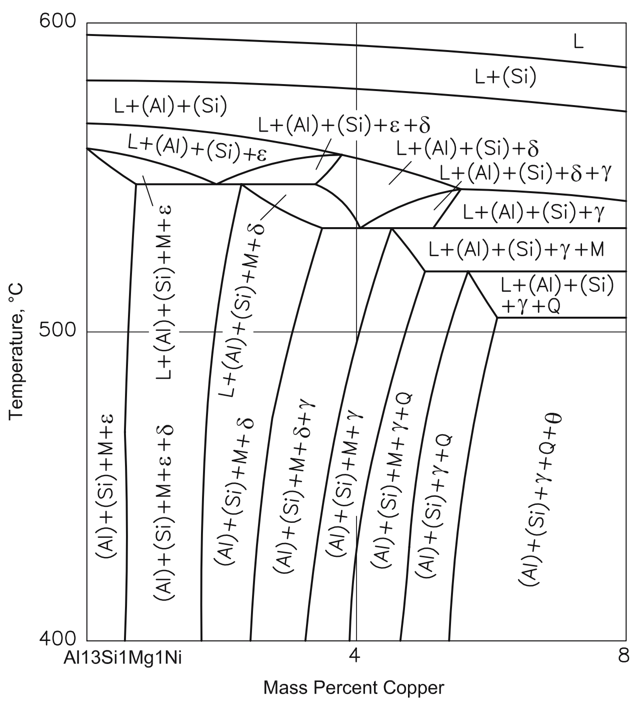

Fig. 7 Al-Cu-Mg-Ni-Si polythermal section at 13Si-1Mg-1Ni (in mass %) [2005Bel]

The phase equilibria were studied by optical and scanning electron metallography, x-ray diffraction, electron probe microanalysis and differential scanning calorimetry.

Since all alloys contain (Al) and (Si), the quinary phase relationships were shown on a concentration triangle. The liquidus projected on the triangle are shown in Fig. 1-3 for the Al-Cu-Mg-Ni-Si, Al-Fe-Mg-Ni-Si, and Al-Cu-Fe-Ni-Si systems respectively. All fields contain additionally (Al) and (Si) in equilibrium. The lines correspond to univariant equilibria and the points represent the invariant six-phase equilibria. The temperatures of the invariant reactions in the three systems are listed in Table 1 [2005Bel].

Two isothermal sections of the Al-Cu-Mg-Ni-Si system at 300 °C and at 13Si-1Ni (in mass %) and 13Si-1Mg (in mass %) respectively constructed by [2005Bel] are shown in Fig. 4 and 5. The isothermal section of Al-Fe-Mg-Ni-Si at 13Si-1Ni (in mass %) and 300 °C is redrawn in Fig. 6. Two vertical sections at 13Si-1Mg-1Ni as a function of Cu and Fe contents respectively are given in Fig. 7 and 8. The invariant horizontals in Fig. 8 do not match the temperatures listed in Table 1. Due to the relatively small number of alloys investigated by [2005Bel], these above sections may be considered semi-quantitative.

References

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