JPEDAV (2007) 28:456–458
DOI: 10.1007/s11669-007-9138-2
1547-7037 ©ASM International

Al-Ce-Si (Aluminum-Cerium-Silicon)

V. Raghavan

Rare-earth mischmetal additions are made to Al-Si hypereutectic alloys for grain refinement. Cerium being a primary constituent of commercial mischmetal alloys, the study of the Al-Ce-Si system is of practical interest. The early data on this ternary system compiled by [1995Vil] depict a partial isothermal section in the Ce-poor region at 400 °C and list several ternary compounds. Recently, [2004Gro] reinvestigated this system experimentally and provided a thermodynamic description. Two vertical sections, an isothermal section at 500 °C and a liquidus projection were calculated by [2004Gro].

Binary Systems

The Al-Ce system [2005Gao] depicts the following intermediate phases: αCe_3Al_{11}(αLa_3Al_{11}-type orthorhombic), $CeAl_4$ or βCe_3Al_{11} (Al-deficient Al_4Ba-type tetragonal), $CeAl_3$ ($D0_{19}$, Ni_3Sn-type hexagonal), $CeAl_2$ ($C15$, $MgCu_2$-type cubic), CeAl (orthorhombic), αCe_3Al ($D0_{19}$, Ni_3Sn-type hexagonal), and βCe_3Al ($L1_2$, $AuCu_3$-type cubic). The Al-Si phase diagram is a simple eutectic system with the eutectic reaction at 577 °C and 12.2 at.% Si. The Ce-Si phase diagram [2004Gro] depicts the following intermediate phases: Ce_5Si_3 ($D8_m$, W_5Si_3-type tetragonal), Ce_3Si_2 ($D5_a$, U_3Si_2-type tetragonal), Ce_5Si_4 (Zr_5Si_4-type tetragonal), CeSi ($B27$, FeB-type orthorhombic), Ce_3Si_5 ($GdSi_2$-type orthorhombic), and $CeSi_2$ (C_c,$ThSi_2$-type tetragonal). Among these, only $CeSi_2$ has a homogeneity range (from 64 to 66.7 at.% Si).

Ternary Phases

[2004Gro] listed the known ternary phases in this system. Ce $(Si_{1-x}Al_x)_2$ (denoted τ_1) is an extension of the binary phase $CeSi_2$ into the ternary region, with $x = 0$ to ~ 1 at high temperatures and $x = 0.1$-0.9 at 500 °C. $AlCeSi_2$ (τ_2) is hexagonal. Al_xCeSi_{2-x} ($1.55<x<1.64$) (denoted τ_3) is AlB_2-type hexagonal. Al_2CeSi_2 (τ_4) is La_2O_3-type hexagonal and is a metastable phase. $Al_4Ce_3Si_6$ (τ_5) is hexagonal. It disappears after prolonged annealing at 500 °C [2004Gro].

Computed Ternary Equilibria

With starting metals of 99.997% Al, 99.9% Ce, and 99.9998% Si, [2004Gro] arc-melted nine ternary alloys with Ce content up to 25 at.% and Si up to 45 at.%. The samples were annealed at 500 °C for 870 h and quenched in water. The phase equilibria were studied by means of x-ray diffraction, scanning electron microscope with energy dispersive spectroscopic attachment. Differential thermal analysis and differential scanning calorimetry were carried out at heating/cooling rates of 2 and 5 °C per min. Two computed vertical sections at 90 at.% Al

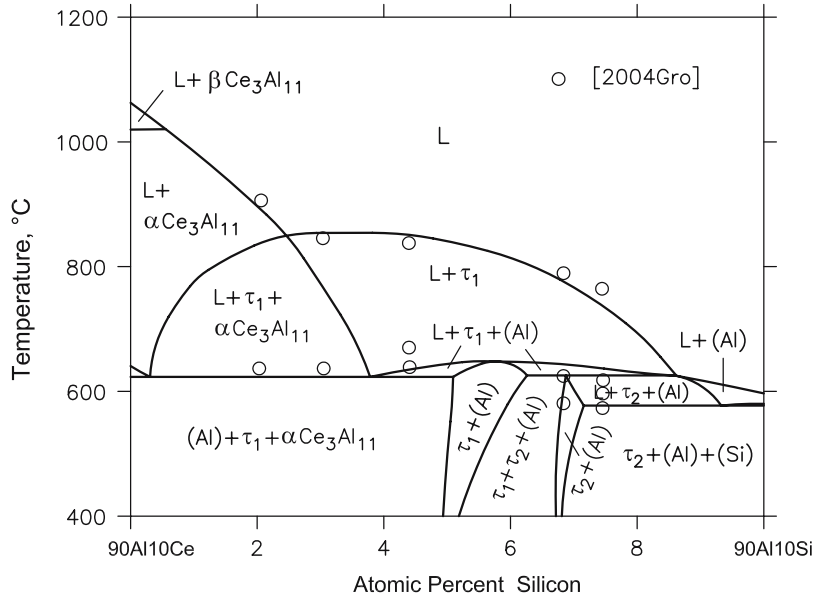

Fig. 1 Al-Ce-Si computed vertical section at 90 at.% Al [2004Gro]

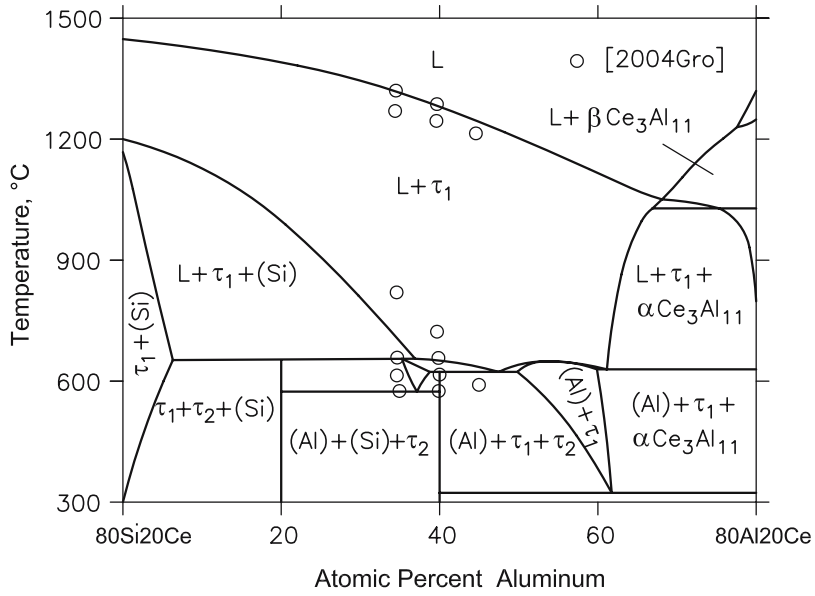

Fig. 2 Al-Ce-Si computed vertical section at 20 at.% Ce [2004Gro]

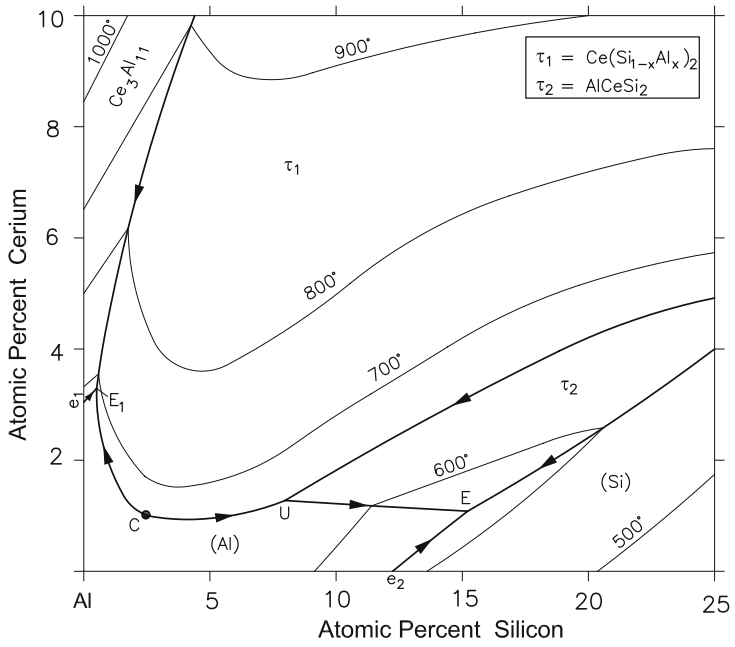

Fig. 3 Al-Ce-Si computed liquidus projection for Al-rich alloys [2004Gro]

and 20 at.% Ce respectively are compared with experimental data in Fig. 1 and 2 [2004Gro]. The agreement is satisfactory. The liquidus projection for Al-rich alloys computed by [2004Gro] is given in Fig. 3. Here, τ_1 and τ_2 appear as phases of primary crystallization, in addition to (Al), (Si) and Ce_3Al_{11}. The computed isothermal section at 500 °C shown in Fig. 4 agrees with the limited experimental results of [2004Gro]. The ternary phases τ_1, τ_2, and τ_3 are present at this temperature. The τ_1 phase was modeled as extending up to the binary Ce-Si side at 500 °C. The homogeneity range of the binary $CeSi_2$ was not considered.

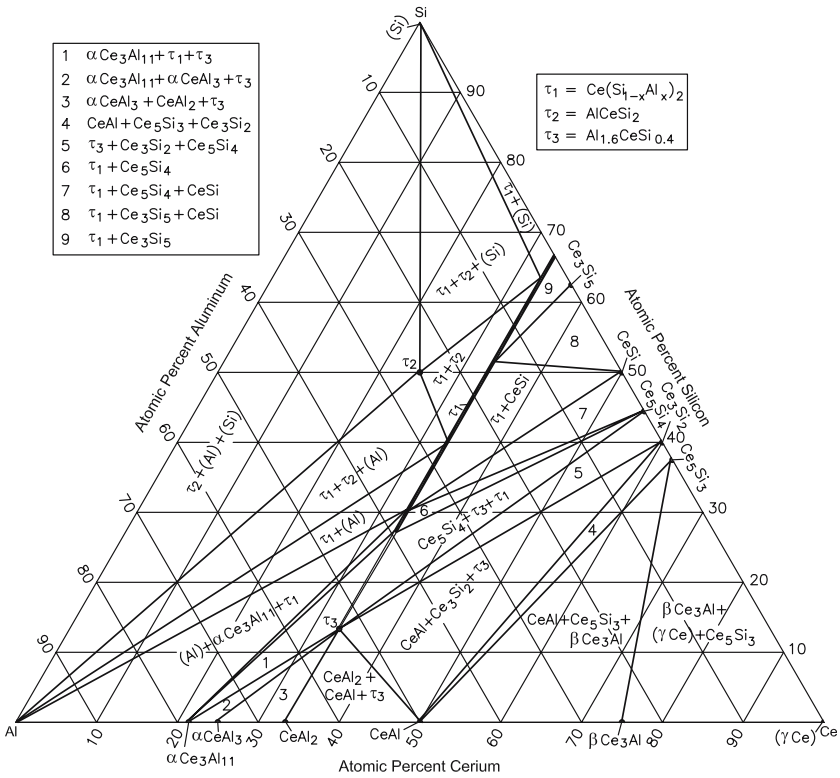

Fig. 4 Al-Ce-Si computed isothermal section at 500 °C [2004Gro]. Thin two-phase regions are omitted

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