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Al-Nb-Si-Ti (Aluminum-Niobium-Silicon-Titanium)

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The information on this quaternary system is limited to the experimental results of [2004Ant] in Ti-rich quaternary alloys with low Nb contents (up to 5 at.%). The experimental data were used to derive the binary and ternary interaction parameters. The vertical sections and an isothermal section at 800 °C computed by [2004Ant] are not quite in agreement with their own experimental data.

Binary Systems

For brief descriptions of the Al-Nb, Al-Ti, and Nb-Ti systems, see the Al-Nb-Ti update by [2005Rag]. For Al-Si and Si-Ti descriptions, see the Al-Si-Ti update in this issue. The Nb-Si phase diagram [Massalski2] has the following intermediate phases: Nb_3Si (Ti_3P-type tetragonal) stable between 1980 and 1770 °C, βNb_5Si_3 ($D8_m$, W_5Si_3-type tetragonal), αNb_5Si_3 ($D8_l$, Cr_5B_3-type tetragonal), and $NbSi_2$ ($C40$, $CrSi_2$-type hexagonal).

Ternary Systems

For an update of the Al-Nb-Ti system, see [2005Rag]. An update of the Al-Si-Ti system appears in this issue. A thermodynamic assessment of the Al-Nb-Si system was reported by [2004Sha]. Two isothermal sections at 1400 and 1000 °C were computed by [2004Sha] and were found to be in good agreement with the published experimental data. At both these temperatures, a ternary phase with the $C54$, $\alpha TiSi_2$-type orthorhombic structure is stable and has a small homogeneity range along the isoconcentrate line of 33.3 at.% Nb. A computed liquidus projection was also given by [2004Sha]. Recent investigations of the Nb-Si-Ti system have reported isothermal sections at 1200, 1150, and 1000 °C [2004Zha] and at 1200 and 1100 °C [2002Wan].

Quaternary Phase Equilibria

With starting metals of 99.995% Al, 99.86% Nb, 99.999% Si, and 99.98% Ti, [2004Ant] arc-melted under Ar atm eight quaternary alloys with 2.5, 3.5, or 5 at.% Nb, with Al and Si contents up to 30 and 6.5 at.%, respectively. Low Nb contents were chosen, so that no Ti_2NbAl (O phase) forms in the "in-situ" composite microstructure of (βTi) + Ti_5Si_3 of the as-cast alloys. The phase equilibria were studied with scanning and transmission electron microscopy, x-ray diffraction, and electron probe microanalysis. Differential thermal analysis was carried out at a heating/cooling rate of 10 °C per min. In alloys annealed at 800 °C, the following phases were identified: (βTi), (αTi), α_2 (Ti_3Al), Ti_5Si_3 (denoted z by [2004Ant]), and Ti_3Si (denoted η by [2004Ant]). Ti_3Si (η) was found to have a composition range of $(Ti_{1-x}Nb_x)_3(Si_{1-y}Al_y)$ ($0.05 \le x \le 0.07$ and $0.001 \le y \le 0.02$). It was confirmed to have the Ti_3P-type tetragonal structure [2004Ant]. The solubility of Nb in Ti_3Si is significant, but that of Al is more limited. The morphology observed in the microstructure suggested its formation through a peritectoid reaction as in the Ti-Si system: (βTi) + $Ti_5Si_3 \rightarrow Ti_3Si$. Ti_5Si_3 (z) found to have a composition range of $(Ti_{1-x}Nb_x)_5(Si_{1-y}Al_y)_3$ ($0.01 \le x \le 0.05$ and $0.07 \le y \le 0.788$) [2004Ant].

Using a subregular solution model, [2004Ant] computed the quaternary phase equilibria and presented two vertical sections at a constant content (at.%) of 5Si-3.5Nb and 5Al-6.5Si, respectively. An isothermal section at 800 °C was also computed at a constant content of 3.5Nb. Further, a vertical section between 10-30 at.% Al at a constant content of 5Si-3.5Nb was presented, that "combines the experimental data (at 800 °C) and calculated points" [2004Ant]. The agreement between the computed and experimental phase fields is only partial in the diagrams presented by [2004Ant]. Clearly, there is a need to examine the problem further. The qualitative conclusions of [2004Ant] are as follows: Nb stabilizes Ti_3Si at zero or low concentrations of Al. Beyond 10 at.% Al, the stabilizing effect of Nb on Ti_3Si appears to be neutralized by Al, and this phase is not stable at 800 °C. See also the discussion in [Massalski2] on the stability of Ti_3Si in the Si-Ti binary system.

[1991Che] made three quaternary alloys with Nb additions of 5, 10, and 15 at.%, respectively (substituted by Ti) to a hypoeutectic Ti-Al-Si alloy with the composition Ti-23.5Al-6.5Si (at.%). The microstructure of the as-cast hypoeutectic alloy consisted of primary α_2 in a eutectic mixture of (α_2 + Ti_5Si_3). With the addition of 10 and 15 at.% Nb, the microstructure consisted of the primary α_2, the eutectic mixture, (βTi), and the O phase (Ti_2NbAl). Heat treatment at temperatures between 1100 and 850 °C resulted in changes such as the ordering of the body-centered cubic (bcc) phase and precipitation of Ti_5Si_3. No phase relationships were determined.

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