Aluminium – Tin – Titanium

Anatoliy Bondar, Olga Fabrichnaya

Literature Data

The Ti rich corner of the system has been of great interest owing to the fact that Ti alloys with additions of Al and Sn are widely used in industry, in particular, the alloy Ti-5Al-2.5Sn (mass%, Ti to balance) [1954Fin, 1957Jaf, 1990Lam, 2003Mat]. Properties of the Ti-5Al-2.5Sn alloy have been the subject of many articles in the literature. The known phase equilibria of the Ti rich corner are due mainly to the work of [1960Kor, 1961Kor, 1962Kor] (isothermal sections at 600, 1000, and 1200°C for the region Ti-Ti₃Sn-Ti₄5Al₅5) and [1969Cro] (alloys annealed at 600-700°C containing (8-13)Al-(1-2)Sn (at.%)). The data have been assessed in [1966Gla] and [1993Kub]. [1993Pie, 1997Pie] have presented an isothermal section for the entire system at 900°C.

[1960Kor, 1961Kor, 1962Kor, 1963Kor] used both iodide and “magnesiumthermic” Ti, Al of 99.99 % purity and Sn of 99.9 % purity as their starting materials. The majority of their ingots were melted in a nonconsumable electrode arc furnace and the remaining using levitation induction melting. Alloys containing up to 22 mass% Al+Sn were forged and homogenized at 1200°C under vacuum for 100 h. The samples were then water quenched after heating at 1200°C for 75 h, or at 1000°C for 200 h. Also, samples were annealed at 1100°C for 50 h, at 1000°C for 200 h, at 800°C for 300 h and at 600°C for 500 h followed by furnace cooling. Other samples were annealed at 1000°C for 500 h, at 800°C for 1000 h and at 600°C for 1200 h followed by furnace cooling. The alloys were studied using light microscopy, XRD (in some cases) and thermal analysis using Nedumov's apparatus [1960Ned] (using the temperature dependence of sample conductance). In their studies, Kornilov & Nartova did not distinguish between the (αTi) phase and the Ti₃(Al,Sn) solid solution, the XRD patterns of which differ only by weak superstructure lines appearing in the pattern of the latter.

[1969Cro] prepared alloys from high purity electrolytically refined Ti and alloying additions of at least 99.9 % purity in a nonconsumable electrode arc furnace and the remaining using levitation induction melting. Alloys containing up to 22 mass% Al+Sn were forged and homogenized at 1200°C under vacuum for 100 h. The samples were then water quenched after heating at 1200°C for 75 h, or at 1000°C for 200 h. Also, samples were annealed at 1100°C for 50 h, at 1000°C for 200 h, at 800°C for 300 h and at 600°C for 500 h followed by furnace cooling. Other samples were annealed at 1000°C for 500 h, at 800°C for 1000 h and at 600°C for 1200 h followed by furnace cooling. The samples were studied using light microscopy, XRD (in some cases) and thermal analysis using Nedumov's apparatus [1960Ned] (using the temperature dependence of sample conductance). In their studies, Kornilov & Nartova did not distinguish between the (αTi) phase and the Ti₃(Al,Sn) solid solution, the XRD patterns of which differ only by weak superstructure lines appearing in the pattern of the latter.

[1984Li] prepared alloys from Ti of 99.9 mass% purity, Al of 99.999 % and Sn of 99.9 %. The samples were annealed at 600°C for 400 h and studied by optical microscopy.

[1993Pie] prepared alloys by arc melting powdered elements (Ti of 99 % purity, Al of 99.8 % and Sn of 99.5 %). The samples were annealed at 900°C for 140 h and water quenched before examination by powder XRD using Guinier-Huber cameras and Cu Kα₁ radiation. [1994Kus] studied alloys of Ti-(50-52)Al-(0-5)Sn (at.%) in the as cast and annealed (at 1000°C for 168 h) conditions by optical and electron transmission microscopy, XRD and Vickers hardness measurement. The alloys contained 0.3-0.4 % O, 0.1-0.2 % N, 0.04-0.05 % C, 0.04-0.07 H, and 0.04-0.06 % Fe (at.%).

Binary Systems

The Sn-Ti and Al-Sn binary systems are accepted from [Mas2] (where the Sn-Ti phase diagram was taken from [1987Mur]). For the Al-Ti system, critical assessments of [2003Sch] and [2003Gry] are available, which are based on the latest thermodynamic optimizations of [1992Kat, 1997Zha] and [2000Ohn] and taking into account experimental studies. The Al-Ti phase diagram was accepted from [2003Gry] which combined the liquidus and the Ti rich part (up to 50 at.% Al) of the diagram presented by [1997Zha], the work of [2000Ohn] (the CsCl type ordered region within the (βTi) field) and also solid phase equilibria in the range 50 to 75 at.% Al as presented by [2001Bra].
Solid Phases

The binary phases, relevant to the phase equilibria under consideration and the ternary Ti₅Al₂Sn phase are listed in Table 1. The only ternary phase reported is given by [1993Pie] and has a narrow homogeneity range, based on the observed variation in the lattice parameters. The isostructural α₂,Ti₃Al and Ti₅Sn phases have been shown by [1961Kor, 1962Kor] to form a complete series of solid solutions Ti₃(Al,Sn). As found in [1993Pie], Ti₅Sn₃ dissolves up to 18 at.% Al and Ti₆Sn₅ dissolves up to 3 at.% Al. There are conflicting opinions on the Sn solubility in γ,TiAl; up to 18 mass% Sn at 22 mass% Al(Ti₅₆Al₃₇Sn₇) in [1960Kor, 1961Kor, 1962Kor] at 600, 1000 and 1200°C, up to the composition Ti₄₈Al₁₅₁Sn₄ at 1000°C in [1994Kus] and no solubility at all given by [1993Pie]. The site occupancies of Sn in Ti₃Al in an alloy of Ti-26Al-(1-2)Sn, and in γ,TiAl in an alloy of Ti-51Al-3Sn (at.%) were measured by the atom location channeling enhanced microanalysis (ALCHEMI) method by [1999Hao]. In the both phases, Sn atoms were found to occupy Al sites. However, [1994Kus] reported a more complicated influence of Sn alloying on site occupation in the γ phase. Tin atoms occupy both Ti (predominantly) and Al sites, and with increasing Sn content, the mutual exchanges of Ti and Al atoms increase in the lattice sites. The solubility lobes of Sn in γ,TiAl, as seen in the isothermal sections given by Kornilov & Nartova [1960Kor, 1962Kor] (Figs. 2, 4, 5), showing some extension of the homogeneity range towards increasing Ti content, are in agreement with the data of [1994Kus].

Liquidus and Solidus Surfaces

The liquidus and solidus surfaces of the Al-Sn-Ti system in the Ti-rich corner have been estimated by [2000Bul] on the basis of experimental data [1961Kor, 1962Kor, 1969Cro] and the associated binary systems. They are shown in Fig. 1. The (βTi)+α₂ eutectic was observed microstructurally by [1962Kor] to lie at 45 mass% Ti₃Sn (Ti₃Al to balance, i.e. at Ti₇₅Al₁₆Sn₉), the melting point being a little lower than the binary eutectic (1605°C after [1987Mur]).

Isothermal Sections

Isothermal sections at 600, 1000 and 1200°C were constructed in [1960Kor, 1962Kor] for the Ti-rich portion of the system. In the 600°C isothermal section the narrow two phase field of (αTi)+α₂ was found to adjoin Sn-Ti side. This result of [1960Kor, 1962Kor] contradicts later data of [1969Cro] and [1984Li], as well as the Sn-Ti and Al-Ti binary phase diagrams. The isothermal section at 600°C was modified by [1993Kub] taking into account data of [1969Cro] and [1984Li] for the (αTi)/(αTi)+α₂ phase boundary and phase diagrams of the binary systems. The isothermal section at 600°C is presented in Fig. 2. The 900°C isothermal section presented by [1993Pie, 1997Pie] is shown in Fig. 3 with some modifications taking into account the solubility of Sn in γ,TiAl according to the work of [1962Kor, 1994Kus] and the binary systems. The authors of [1993Pie] noted an absence of Sn solubility in the γ,TiAl phase but they did not give any composition. The alloys near the Al-Sn side are in the liquid state at 900°C and the liquid is in equilibrium with the βTi₅Sn₃ and Ti₅Al₃ solid phases. The ternary phase Ti₅Sn₂Al has been found by [1993Pie] at 900°C, but the temperature range of its stability is not reported. If its stability range is wide enough, the appearance of the ternary phase could influence phase equilibria in the isothermal sections presented in Figs. 2, 4, 5.

The isothermal sections at 1000 and 1200°C are shown according to [1962Kor] taking into account data for the binary systems (Figs. 4, 5). The homogeneity range of the (αTi) phase at 1000 and 1200°C is delineated by dashed lines. It should be noted that the data of [1994Kus] for the solubility of Sn in γ,TiAl as Ti₅₆Al₃₇Sn₇ agrees with the 1000°C isothermal section (Fig. 4). The Sn influence on the (αTi)/(αTi)+α₂ phase boundary was studied by Crossley [1969Cro], also at 700°C and Sn contents up to 2 at.%., where the phase boundary was found to be at ~13 at.% Al.

Temperature – Composition Sections

[1961Kor, 1962Kor] presented the section through the Ti corner at an equal ratio of Al to Sn in mass% (Al:Sn=1:1) and the section Ti₃Al-Ti₅Sn (Figs. 6, 7, respectively). There is a remarkable difference in the
composition for the $\alpha/\alpha+\alpha_2$ boundary presented in the isothermal sections and the isopleth. The Ti corner at Al:Sn=1:1 is corrected to be in agreement with the isothermal sections. The portion of the Ti$_3$Al-Ti$_3$Sn section at temperatures below 1200°C is shown by dashed lines because the equilibria involving ($\alpha$Ti) were omitted by [1961Kor, 1962Kor] as already discussed above.

**Thermodynamics**

The heat capacity of the Ti-5Al-2.5Sn alloy is reported for temperatures between 4 and 290 K [1978Ili] and between 273 and 973 K [1986Ric].

**Notes on Materials Properties and Applications**

The commercial alloy Ti-5Al-2.5Sn is widely used and there are many references to its properties in the literature [1988Fuj, 1990Lam, 2003Mat], including low temperature properties [1980Kaw, 1993Gri, 1993Gri2, 2001Sun] and cyclic loading behavior [2001Sun].

[1954Fin] showed that Sn additions of up to 5 mass% to the (0-5)Al-Ti (in mass%) alloys led to an increase in bend and tensile strength properties without suffering any loss in hot fabricability or substantial loss of ductility.

[1963Kor] reported results of bending creep tests for alloys in the section of equal Al to Sn ratio (in mass% Al:Sn=1:1) and sections Ti$_3$Al-Ti$_3$Sn and TiAl-Ti$_3$Sn. Other properties were also studied. The creep behavior was studied at 700°C using a technique presented in [1957Pro]. The maximum creep resistance was found in the alloy of composition Ti$_3$Al:Ti$_3$Sn=1:1 (in mass%) and alloys based on the $\gamma$ phase.

**Miscellaneous**

In the literature, there is information concerning the hydrogen solubility of the alloy Ti-5Al-2.5Sn [1958Alb] and the influence of hydrogen on its properties [1972Wil, 1984Ham].

**References**


Table 1: Crystallographic Data of Solid Phases

<table>
<thead>
<tr>
<th>Phase/ Temperature Range</th>
<th>Pearson Symbol/ Space Group/ Prototype</th>
<th>Lattice Parameters [pm]</th>
<th>Comments/References</th>
</tr>
</thead>
<tbody>
<tr>
<td>(αAl) &lt; 660.452</td>
<td>cF4/ Fm5m/ Cu</td>
<td>a = 404.96</td>
<td>at 25°C [Mas2]</td>
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<td>(Sn) &lt; 231.9681</td>
<td>tI4/ I4/amd/ βSn</td>
<td>a = 583.15</td>
<td>[Mas2]</td>
</tr>
<tr>
<td>Phase/ Temperature Range</td>
<td>Pearson Symbol/ Space Group/ Prototype</td>
<td>Lattice Parameters [pm]</td>
<td>Comments/References</td>
</tr>
<tr>
<td>--------------------------</td>
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<tr>
<td>(αTi) &lt; 1490</td>
<td>hP2 P6/mmc Mg</td>
<td>a = 295.06 c = 468.35</td>
<td>[Mas2]</td>
</tr>
<tr>
<td>(βTi) 1670 - 882</td>
<td>cI2 Im3m W</td>
<td>a = 330.65</td>
<td>[Mas2]</td>
</tr>
<tr>
<td>α₂Ti₃SnₓAl₁₋ₓ &lt; 1670</td>
<td>hP8 P6/mmc Ni₃Sn</td>
<td>a = 591.6 c = 476.4 a = 577.5 c = 465.5</td>
<td>0 &lt; x &lt; 1 Ti₃Al is stable at T &lt; 1166 x = 1 [1987Mur] x = 0 [V-C2]</td>
</tr>
<tr>
<td>Ti₂Sn &lt; 1550</td>
<td>hP6 P6/mmc InNi₂₃</td>
<td>a = 465.3 c = 570</td>
<td>[1987Mur]</td>
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<tr>
<td>Ti₅Sn₃ ≤ 1510</td>
<td>hP16 P6/mcm Mn₅Si₃</td>
<td>a = 804.9 c = 545.4</td>
<td>[1987Mur]</td>
</tr>
<tr>
<td>βTi₆Sn₅ ~1490 - 790</td>
<td>hP22 P6/mmc αTi₅Sn₅ hP22 P31c</td>
<td>a = 922 c = 569 a = 924.8 c = 589</td>
<td>[1987Mur]</td>
</tr>
<tr>
<td>αTi₆Sn₅ &lt; 790</td>
<td>oI44 Immm Nb₆Sn₅</td>
<td>a = 1693 b = 914.4 c = 573.5</td>
<td>[1987Mur]</td>
</tr>
<tr>
<td>γ, TiAl &lt; 1463</td>
<td>tP4 P4/mmm AuCu</td>
<td>a = 400.0 c = 407.5 a = 398.4 c = 406.0 a = 399.6 c = 407 a = 399.5 c = 408 a = 400 c = 408.6 a = 399.8 c = 408.9</td>
<td>at 50.0 at.% Al [2001Bra] at 62.0 at.% Al [2001Bra] at 50.55 at.% Al [1994Kus] at 51.89 at.% Al [1994Kus] at 50.56Al-2.25Sn (at.%) [1994Kus] at 51.12Al-3.92Sn (at.%) [1994Kus]</td>
</tr>
<tr>
<td>TiAl₂ &lt; 1215</td>
<td>tI24 I4/amd HfGa₂</td>
<td>a = 0.3970 c = 2.4970</td>
<td>[2001Bra]</td>
</tr>
<tr>
<td>TiAl₃ (h) 1387 - 735</td>
<td>tI8 I4/mmm TiAl₃ (h)</td>
<td>a = 384.9 c = 860.9</td>
<td>[2001Bra]</td>
</tr>
</tbody>
</table>
### Al–Sn–Ti

#### Phase/ Temperature Range [°C] | Pearson Symbol/ Space Group/ Prototype | Lattice Parameters [pm] | Comments/References
---|---|---|---
TiAl₃ (l) < 950 (Ti rich) | $\alpha\bar{3}$ | $a = 387.7$ | [2001Bra]
| $I4/mmm$ | $c = 3382.8$
| TiAl₃ (l) | $cP4_1$ | $a = 397.2 \pm 0.1$ | [1994Bra]
| \textit{Pm}3\textit{m} | | |
| AuCu₃ | | |

* $\tau_1$, Ti₅Sn₂Al (obtained at 900°C) | $\alpha\bar{3}$ | $a = 1054.9 \pm 0.2$ | [1993Pie, 1995Pie]
| $I4/mcm$ | $c = 524.2 \pm 0.2$ | Al rich composition;
| W₅Si₃ | $a = 1056.4$ | Al lean
| | $c = 526.4$

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**Fig. 1: Al-Sn-Ti.**
Partial liquidus and solidus surfaces in Ti corner

![Al-Sn-Ti Phase Diagram](image-url)
Fig. 2: Al–Sn–Ti.
Partial isothermal section at 600°C

Fig. 3: Al–Sn–Ti.
Partial isothermal section at 900°C
Fig. 4: Al–Sn–Ti.
Partial isothermal section at 1000°C

Fig. 5: Al–Sn–Ti.
Partial isothermal section at 1200°C
**Fig. 6: Al-Sn-Ti.**
Vertical section at the equal Al to Sn ratio in mass%