The Al-Sc (Aluminum-Scandium) System

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Equilibrium Diagram

The assessed Sc-Al (Fig. 1) is based on investigations by [65Nau] and [73Dri], who made refinements to the high-Al region of the diagram proposed by [65Nau]. The melting point temperature for Sc and the $\beta \rightarrow \alpha$ transformation temperature for Sc are the accepted values [86Gsc]. The Al-rich region including the inset shows the solubility and eutectic data supplied by [79Fuj] in satisfactory agreement with the data reported by [73Dri].

[65Nau] prepared the test alloys for phase determination using 99.99 wt.% pure Al and distilled Sc of 99.5 wt.% purity (oxygen 0.2; copper 0.15; titanium, 0.1; iron 0.06; nitrogen 0.03; hydrogen and calcium each 0.01; aluminum < 0.01; carbon 0.0079; beryllium and silicon each < 0.001; zirconium, molybdenum, and tantalum not detected). The alloys were melted in an arc furnace with a nonconsumable tungsten electrode on a water-cooled copper hearth. An atmosphere of purified helium was maintained at a residual pressure of 200 to 300 mm Hg during the alloy preparation. The alloys

Table 1 Sc-Al Crystal Structure Data

<table>
<thead>
<tr>
<th>Phase</th>
<th>Composition, at.% Al</th>
<th>Pearson symbol</th>
<th>Space group</th>
<th>Strukturbericht designation</th>
<th>Prototype</th>
</tr>
</thead>
<tbody>
<tr>
<td>($\alpha$Sc)</td>
<td>0 to 4</td>
<td>hP2</td>
<td>P63/mmc</td>
<td>A3</td>
<td>Mg</td>
</tr>
<tr>
<td>($\beta$Sc)</td>
<td>0 to 8</td>
<td>cF2</td>
<td>Im3m</td>
<td>A2</td>
<td>W</td>
</tr>
<tr>
<td>Sc$_2$Al</td>
<td>33.3</td>
<td>hP6</td>
<td>P63/mmc</td>
<td>B8$_2$</td>
<td>Ni$_2$In</td>
</tr>
<tr>
<td>ScAl</td>
<td>50</td>
<td>cF2</td>
<td>P63/mmc</td>
<td>B2</td>
<td>CsCl</td>
</tr>
<tr>
<td>ScAl$_2$</td>
<td>66.7</td>
<td>cF24</td>
<td>Fm$\bar{3}$m</td>
<td>C15</td>
<td>Cu$_5$Mg</td>
</tr>
<tr>
<td>ScAl$_3$</td>
<td>75</td>
<td>cP4</td>
<td>Pm$\bar{3}$m</td>
<td>L1$_2$</td>
<td>Au$_5$Cu</td>
</tr>
<tr>
<td>Al</td>
<td>~ 99.8 to 100</td>
<td>cF4</td>
<td>Fm$\bar{3}$m</td>
<td>A1</td>
<td>Cu</td>
</tr>
</tbody>
</table>

Fig. 1 Assessed Sc-Al Diagram

Table 2  Sc-Al Lattice Parameter Data

<table>
<thead>
<tr>
<th>Phase</th>
<th>Composition, at.% Al</th>
<th>Lattice parameters, nm</th>
<th>Density, g/cm³</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>(αSc)</td>
<td>0 to 4</td>
<td>0.33088 0.52880</td>
<td>2.9890</td>
<td>[86Gsc]</td>
</tr>
<tr>
<td>(βSc)</td>
<td>0 to 8</td>
<td>0.373(est)</td>
<td>2.880(est)</td>
<td>[86Gsc]</td>
</tr>
<tr>
<td>Sc₂Al</td>
<td>33.3</td>
<td>0.4888(1) 0.6166(1)</td>
<td>3.043</td>
<td>[66Eym]</td>
</tr>
<tr>
<td>ScAl</td>
<td>50</td>
<td>0.3450(5)</td>
<td>2.909</td>
<td>[65Sch]</td>
</tr>
<tr>
<td>ScAl₂</td>
<td>66.7</td>
<td>0.7582(2)</td>
<td>3.015</td>
<td>(b)</td>
</tr>
<tr>
<td>ScAl₃</td>
<td>75</td>
<td>0.4103(1)</td>
<td>3.026</td>
<td>(a)</td>
</tr>
<tr>
<td>(Al)</td>
<td>~99.8 to 100</td>
<td>0.40486</td>
<td>2.699</td>
<td>[Pearson2]</td>
</tr>
</tbody>
</table>

(a) [64Rec, 65Mor, 67Zal, 69Can, 76Ock].  (b) [60Dwi, 63Mat, 64Kri, 64Rec, 74Mac].

were wrapped in Ta or Mo foil and placed in evacuated quartz ampules during the homogenization anneal, which varied in time and temperature with alloy composition.

Microstructural and thermal analysis studies were employed in determining the various features of the phase diagram. Al and Sc were found to be miscible in the liquid state at all concentrations. Four intermetallic compounds (Sc₃Al₃, ScAl₂, ScAl, and Sc₂Al) were observed. ScAl₂ and ScAl melt congruently at 1420 and ~1300 °C, respectively, whereas Sc₃Al₃ and Sc₂Al form peritectically at 1320 ± 7 and 1195 ± 5 °C, respectively. The investigators found a eutectic between ScAl₂ and ScAl (at 1150 °C and about 45 at.% Sc) and a eutectic between Sc₂Al and (Sc) (at 945 °C and about 87 at.% Sc). In addition, they reported the solubility of Sc in (Al) at room temperature to be 0.5 at.% and that of Al in (Sc) to be about 4 at.%.

They did not report a eutectic between Al and Sc₃Al₃, but claimed a peritectic at 665 °C, just above the melting point of pure Al. [73Dri] reinvestigated the Al-rich side of the diagram, using 99.99 wt.% pure Al and Sc with 0.1 wt.% Ca, 0.015% Cu, and 0.01% Fe. The Sc was introduced in the form of a master alloy with 5 or 10% Sc. No information was presented on the melting procedures, except that the alloys were cast in copper ingot molds. Differential thermal analysis, microstructural examination, resistivity, and microhardness measurements were used in this investigation. [73Dri] found that the solubility of Sc in (Al) ranges from 0.03 at.% at 500 °C to 0.13 at.% at 640 °C. In addition, they found that an (Al)-Sc₃Al₃ eutectic exists at 655 °C and about 99.64 at.% Al (99.4 wt.% Al), as scaled from their phase diagram. These authors attributed the differences between their findings and those of [65Nau] to their use of purer Sc (99.875 vs 99.5% purity) and possibly to more sensitive thermal analysis techniques.

[79Fuj] determined the solid solubility of Sc in (Al) by measuring the electrical resistivity at ~196 °C (77 K) of Sc-Al alloys that were air cooled after annealing at various temperatures for sufficient time to completely precipitate Sc₃Al₃. The Al metal used by [79Fuj] was taken from ingots of 99.999 wt.% purity that had been zone refined to reduce influence of impurity atoms on solid solubility of Sc in (Al). Purity of their Sc metal was 99.9 wt.%. The concentration of Sc in the alloys was determined by flame spectrochemical analyses and by photon activation analysis using bremsstrahlung irradiation. The solidus line of the Al-rich alloys was determined by thermal analysis. Solid solubility of Sc in (Al) was found to vary from 0.186 at.% at 640 °C to 0.033 at.% at 470 °C.

Sc₃Al₃ reacts eutectically with (Al) at 655 °C (as shown on their partial phase diagram), in good agreement with other reports, although their abstract and the text quoted a eutectic temperature of "823 ± 1 K" (550 °C). A maximum solid solubility of 99.79 at.% Al was observed at the eutectic temperature.

Crystal Structures and Lattice Parameters

None of the groups that reported on phase diagram data included structure information on the observed intermetallic compounds, but other investigators have...
reported this information. ScAl3 has cubic AlCu3 type structure, ScAl2 has cubic Cu21VIg type structure, and Sc2Al has hexagonal Ni2In type structure. The structure of ScAl was reported by [65Sch] to be cubic CsCl type, and although extra unidentified lines were observed in their X-ray pattern, this appears to be the equilibrium structure. There is strong evidence that this is not an equilibrium structure for any other AI-RE compound. Tables 1 and 2 list crystal structure and lattice parameter data for Sc-Al phases.

Thermodynamics

No experimental data were available. However, [76Mie] predicted the heat of formation for AlSc to be \(-84 \text{ kJ/mol}\).

Effects of Pressure

[75Can] studied the effects of high pressure on the crystal structures of several REAl3 compounds (see the "Effects of Pressure" section of "The AI-RE (Aluminum-Rare Earth) Systems," [88Gse], for sample preparation details). Synthesis at 62 Kbar for 64 min at 970 °C resulted in the formation of ScAl3 with AuCu3 type structure and lattice parameters similar to those found by [64Rec].

Cited References


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