

Silver – Aluminium – Titanium

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Literature Data

Köster and Sampaio [1957Koe] investigated ternary isothermal sections at 800°C, 1000°C and 1100°C by X-ray and metallographic analyses ($x_{\text{Ti}} > 25$ at.% and $x_{\text{Ag}} < 42$ at.%). At these temperatures they found the binary Al-Ti phases in equilibrium with an Ag-rich melt or with the silver solid solution, (Ag).

Hashimoto et al. [1983Has] determined the 800°C isothermal section ($x_{\text{Al}} < 75$ at.%) and a vertical section from Ti+51 at.% Al to Ag+7.5 at.% Al by electron microprobe, X-ray diffraction, scanning electron microscopy and DTA. These authors analyzed also the ternary solubilities of the (Ag) solid solution at 800°C.

Mabuchi et al. [1990Mab] detected a ternary phase $\text{Ti}(\text{Al}_{1-x}\text{Ag}_x)_3$ of the AuCu_3 type (L_{12}) with $0.1 < x < 0.25$. This phase has also a considerable homogeneity range with respect to the ratio $\text{Ti}:(\text{Al}+\text{Ag})$, 25-30 at.% Ti at 1000°C. [1957Koe] did not investigate the area of this phase and [1986Has] investigated one alloy in this area (65 at.% Al+10 at.% Ag), reported it as single phase at 800°C, but interpreted it as a solid solution of the TiAl_3 phase.

Several papers [1991Dur, 1992Dur, 1993Nak, 1999Yam] compare L_{12} phases $\text{Ti}(\text{Al}_{1-x}\text{X}_x)_3$ with different elements X (Ag, Co, Cr, Cu, Fe, Mn, Ni, Pd, Zn) but similar compositions of X. Yamamoto et al. [1999Yam] reported the homogeneity range of the L_{12} phase at 1177°C. Tian and Nemeto [2002Tia] studied the precipitation of TiAl and TiAl_2 from the L_{12} phase, homogenized at 1000°C, as well as that of L_{12} from TiAl during annealing at lower temperatures (700-900°C). The present evaluation updates that of [1990Luk].

Binary Systems

The three binary systems are accepted from the SGTE assessments in Landolt-Börnstein [2002LB]. For Ag-Ti [2002Li] and Al-Ti [2003Sch] the MSIT Workplace provides assessments with nearly equivalent contents. For Al-Ti the [2003Sch] evaluation states, that there is still some uncertainty, especially on the area between TiAl and TiAl_3 .

The Ag-Ti system used by [1957Koe] assumed a much higher temperature of peritectic formation of the Ti_2Ag phase (1280°C) than [2002LB] (940°C).

All three [2002LB] diagrams are based on thermodynamic calculations, two of them published before: Ag-Al [1995Lim], Al-Ti [1998Sau].

Solid Phases

A single ternary phase, τ , of the AuCu_3 (L_{12}) type was found near TiAl_3 . Like TiAl_3 , TiAl_2 , $\text{Ti}_5\text{Al}_{11}$, TiAl and Ti_3Al it is an ordered form of a close packed crystal structure [1991Dur, 1992Dur]. Some more binary Al-Ti phases between TiAl and TiAl_3 were not considered as stable phases in the accepted binary Al-Ti system. All solid phases regarded to be stable in the Landolt-Börnstein evaluations are summarized in Table 1.

Invariant Equilibria

A tentative reaction scheme was given by [1957Koe]. Due to the discrepancies between the binary systems used by [1957Koe] and those accepted here, it needs modification. Using the approximate thermodynamic description given below in section “Thermodynamics” a tentative reaction scheme above 800°C can be calculated. Figure 1 shows the result. The temperatures and phase compositions of the ternary invariant reactions must be taken as tentative only, therefore no table of invariant reactions is given. Below 800°C the system is nearly degenerate and the reaction scheme is equal to the binary Ag-Al system with either the τ phase or TiAl_3 being in equilibrium with the Ag-Al phases, but not taking part in the reactions.

After the calculation the Ag solubility in the (Ti)(r) phase decreases very rapidly above 1000°C and thus there appears twice a four phase reaction between liquid, (Ti)(r), (Ti)(h) and Ti₃Al (at 1280 and 1033°C). This may be an artefact, although the three phase field liquid+(Ti)(h)+Ti₃Al between these two temperatures is supported by the 1100°C isothermal section reported by [1957Koe].

Isothermal Sections

The sections at 1100, 1000 and 800°C, (Fig. 2, Fig. 3 and Fig. 4), are drawn from thermodynamic calculations using the description given in the next section. The homogeneity range of the τ phase as well as the (Ti)(r)+(Ti)(h)+liquid equilibrium at 1000°C are modified to fit to the reported measured points of [1957Koe, 1986Has, 1990Mab]. The sections differ from those of [1957Koe] due to the differences in the accepted binary systems and due to the consideration of the τ phase. In Köster's diagrams Ti₂Ag appears as stable above 1100°C and all phases between Ti₃Al and TiAl were not yet known. The 800°C section of [1983Has] differs from that given by [1957Koe] for the same temperature mainly by the equilibria containing the Ag-Ti phases TiAg and Ti₂Ag. The calculation strongly supports the equilibria given by [1983Has]. The Ti solubility measurements in liquid and solid Ag reported by [1983Has] gave significantly lower values than compatible with the Ag-Ti system of [2002LB]. Also [1983Has] did not consider the TiAl₂ phase between TiAl and TiAl₃ and they did not distinguish τ from TiAl₃. The Ag solubilities in Ti₃Al, TiAl and TiAl₃ are accepted from [1957Koe].

Thermodynamics

The thermodynamic data sets as used in [2002LB] allow approximate calculation of the ternary system. Without the introduction of ternary parameters, however, the homogeneity ranges of the (Ti)(h) and (Ti)(r) solid solutions in this calculation disagree significantly with [1957Koe] and [1986Has]. For phases with only small ternary solubilities the calculated equilibria agree fairly well with those reported by [1957Koe] and [1986Has].

Using the thermodynamic descriptions of the binary systems [2002LB] with additional ternary terms of $+120000 x_{\text{Ag}} x_{\text{Al}} x_{\text{Ti}}$ J·mol⁻¹ for G^{bcc} and $(+80000 - 12T)x_{\text{Ag}} x_{\text{Al}} x_{\text{Ti}}$ J·mol⁻¹ for G^{hcp} the ternary system can be approximately calculated. The ternary phase τ can be roughly approximated by a stoichiometric phase Ti_{0.27}Ag_{0.12}Al_{0.61} with the Gibbs energy of formation $G^{\tau} - 0.27G_{\text{Ti}}^{\text{hcp}} - 0.12G_{\text{Ag}}^{\text{fcc}} - 0.61G_{\text{Al}}^{\text{fcc}} = -36500 + 7T$ J·mol⁻¹.

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Table 1: Crystallographic Data of Solid Phases

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(Ti)(h) 1715-882	<i>cI2</i> <i>Im$\bar{3}m$</i> W	$a = 330.65$	pure element, 900°C [Mas2]
(Ti)(r) < 1500	<i>hP2</i> <i>P6$_3$/mmc</i> Mg	$a = 295.06$ $c = 468.35$	pure element, 25°C [Mas2]
(Ag) < 962	<i>cF4</i> <i>Fm$\bar{3}m$</i> Cu	$a = 408.57$	pure element, 25°C [Mas2]
(Al) < 661	<i>cF4</i> <i>Fm$\bar{3}m$</i> Cu	$a = 404.96$	pure element, 25°C [Mas2]
Ti ₂ Ag < 940	<i>tI6</i> <i>I4/mmm</i> MoSi ₂	$a = 295$ $c = 1180$	[1965Sch]
TiAg < 1020	<i>tP4</i> <i>P4/nmm</i> TiCu	$a = 290$ $c = 814$	[1965Sch]
Ti ₃ Al < 1190	<i>hP8</i> <i>P6$_3$/mmc</i> Ni ₃ Sn	$a = 577.5$ $c = 463.8$	[2001Bra]
TiAl < 1444	<i>tP4</i> <i>P4/mmm</i> CuAu	$a = 399.8$ $c = 407.6$	[2001Bra]
TiAl ₂ < 1181	<i>tI24</i> <i>I4$_1$/amd</i> HfGa ₂	$a = 397.6$ $c = 2497$	[1962Poe, 1990Sch]
Ti ₅ Al ₁₁ 1379-996	<i>tI16</i> <i>I4/mmm</i> ZrAl ₃	$a = 391.7$ $c = 1652.4$	[1965Ram, 1990Sch]
TiAl ₃ < 1373	<i>tI8</i> <i>I4/mmm</i> TiAl ₃	$a = 384$ $c = 857.9$	[1965Ram, 1990Sch]
Ag ₃ Al(h) 780-610	<i>cI2</i> <i>Im$\bar{3}m$</i> W	$a = 330.2$	700°C [V-C2]
Ag ₃ Al(r) < 448	<i>cP20</i> <i>P4$_1$32</i> β Mn	$a = 693.4$	[V-C2]
Ag ₂ Al < 727	<i>hP2</i> <i>P6$_3$/mmc</i> Mg	$a = 288.5$ $c = 458.2$	[V-C2]
* τ , Ti(Al _{1-x} Ag _x) ₃	<i>cP4</i> <i>Pm$\bar{3}m$</i> AuCu ₃	$a = 399.0$ to 400.4	[1990Mab]

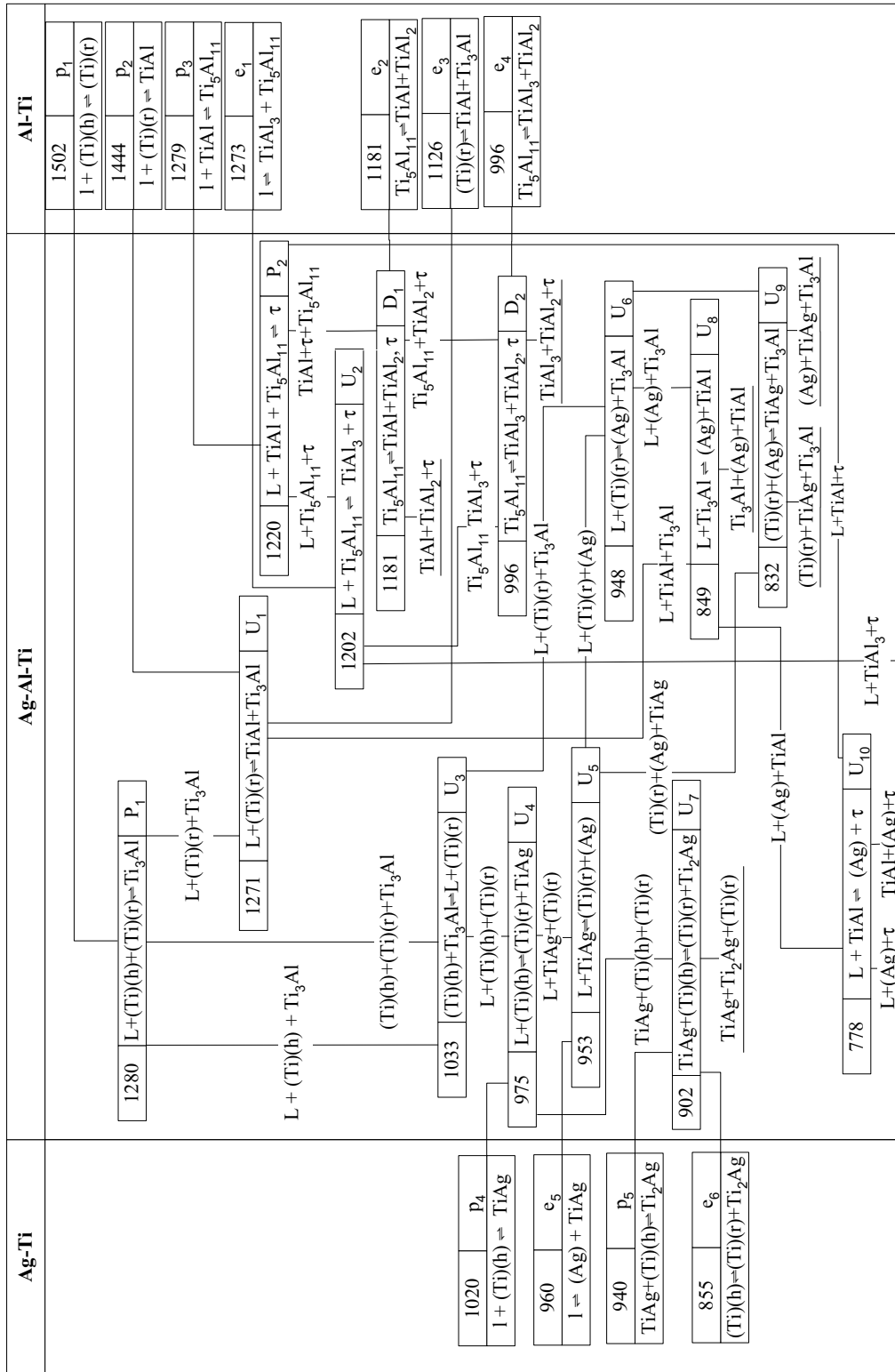


Fig. 1: Ag-Al-Ti. Tentative reaction scheme

Fig. 2: Ag-Al-Ti.
Isothermal section at
1100°C

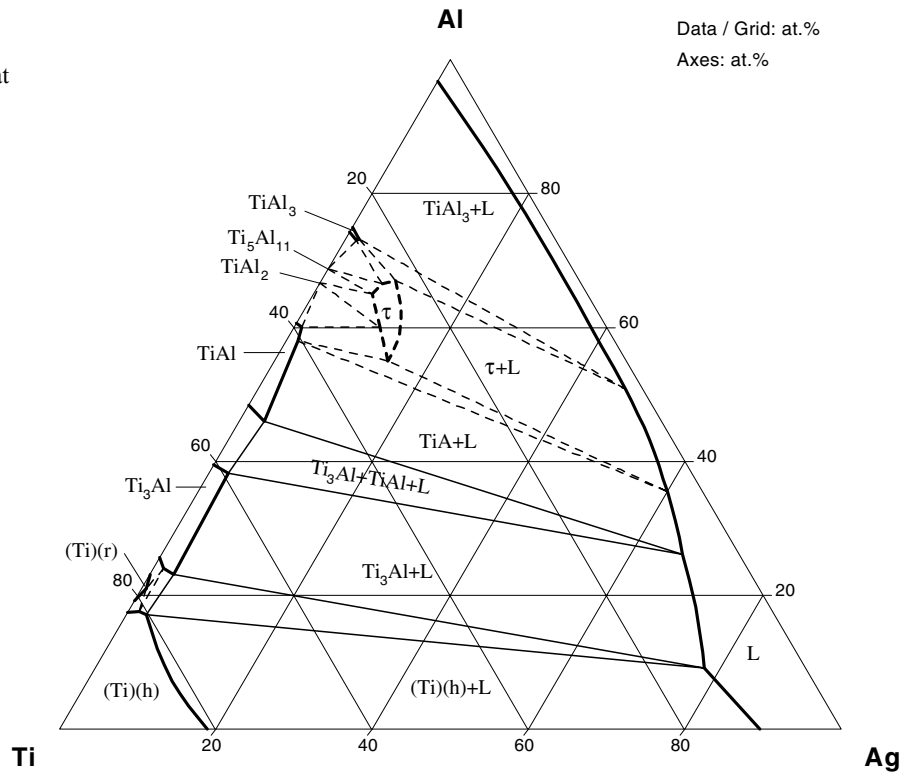


Fig. 3: Ag-Al-Ti.
Isothermal section at
1000°C

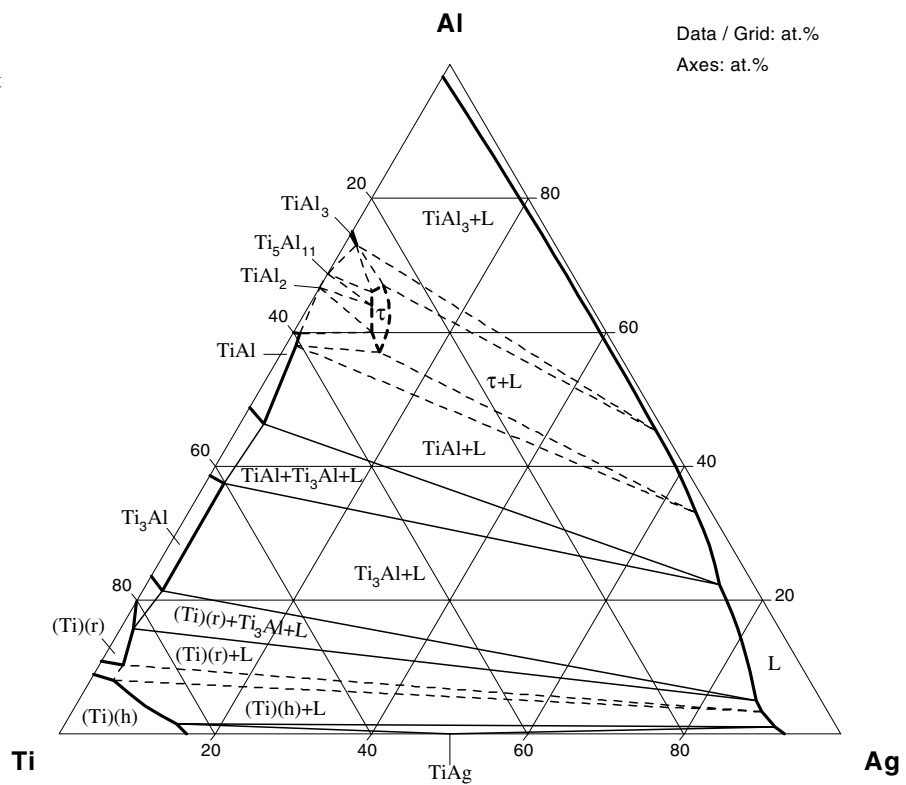


Fig. 4: Ag-Al-Ti.
Isothermal section at
800°C

