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 ($x_{Ti} > 25$ at.% and $x_{Ag} < 42$ 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 ($x_{Al} < 75$ 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 $Ti(Al_{1-x}Ag_x)_3$ of the $AuCu_3$ type ($L1_2$) with $0.1<x<0.25$. This phase has also a considerable homogeneity range with respect to the ratio Ti:(Al+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 $L1_2$ phases $Ti(Al_{1-x}X_x)_3$ 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 $L1_2$ phase at 1177°C. Tian and Nemeto [2002Tia] studied the precipitation of TiAl and $TiAl_2$ from the $L1_2$ phase, homogenized at 1000°C, as well as that of $L1_2$ 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 $AuCu_3$ ($L1_2$) type was found near $TiAl_3$. Like $TiAl_3$, $TiAl_2$, Ti_5Al_{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 Ti_3Al (at 1280 and 1033°C). This may be an artefact, although the three phase field liquid+(Ti)(h)+Ti_3Al 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 Ti_2Ag appears as stable above 1100°C and all phases between Ti_3Al 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 Ti_2Ag. 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 $TiAl_2$ phase between TiAl and $TiAl_3$ and they did not distinguish τ from $TiAl_3$. The Ag solubilities in Ti_3Al, TiAl and $TiAl_3$ 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 $+120000\, x_{Ag}x_{Al}x_{Ti}$ J·mol^{-1} for G^{bcc} and $(+80000-12T)x_{Ag}x_{Al}x_{Ti}$ 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^{τ}-0.27-$G^{hcp}{}_{Ti}$-0.12$G^{fcc}{}_{Ag}$-0.61 $G^{fcc}{}_{Al}$=−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	*cI*2 *Im*$\bar{3}$*m* W	*a* = 330.65	pure element, 900°C [Mas2]
(Ti)(r) < 1500	*hP*2 *P*6$_3$*/mmc* Mg	*a* = 295.06 *c* = 468.35	pure element, 25°C [Mas2]
(Ag) < 962	cF4 *Fm*$\bar{3}$*m* Cu	*a* = 408.57	pure element, 25°C [Mas2]
(Al) < 661	*cF*4 *Fm*$\bar{3}$*m* Cu	*a* = 404.96	pure element, 25°C [Mas2]
Ti_2Ag < 940	*tI*6 *I4/mmm* $MoSi_2$	*a* = 295 *c* = 1180	[1965Sch]
TiAg < 1020	*tP*4 *P4/nmm* TiCu	*a* = 290 *c* = 814	[1965Sch]
Ti_3Al < 1190	*hP*8 *P*6$_3$*/mmc* Ni_3Sn	*a* = 577.5 *c* = 463.8	[2001Bra]
TiAl < 1444	*tP*4 *P4/mmm* CuAu	*a* = 399.8 *c* = 407.6	[2001Bra]
$TiAl_2$ < 1181	*tI*24 *I*4$_1$*/amd* $HfGa_2$	*a* = 397.6 *c* = 2497	[1962Poe, 1990Sch]
Ti_5Al_{11} 1379-996	*tI*16 *I4/mmm* $ZrAl_3$	*a* = 391.7 *c* = 1652.4	[1965Ram, 1990Sch]
$TiAl_3$ < 1373	*tI*8 *I4/mmm* $TiAl_3$	*a* = 384 *c* = 857.9	[1965Ram, 1990Sch]
Ag_3Al(h) 780-610	*cI*2 *Im*$\bar{3}$*m* W	*a* = 330.2	700°C [V-C2]
Ag_3Al(r) < 448	*cP*20 *P*4$_1$*32* βMn	*a* = 693.4	[V-C2]
Ag_2Al < 727	*hP*2 *P*6$_3$*/mmc* Mg	*a* = 288.5 *c* = 458.2	[V-C2]
* τ, $Ti(Al_{1-x}Ag_x)_3$	*cP*4 *Pm*$\bar{3}$*m* $AuCu_3$	*a* = 399.0 to 400.4	[1990Mab]

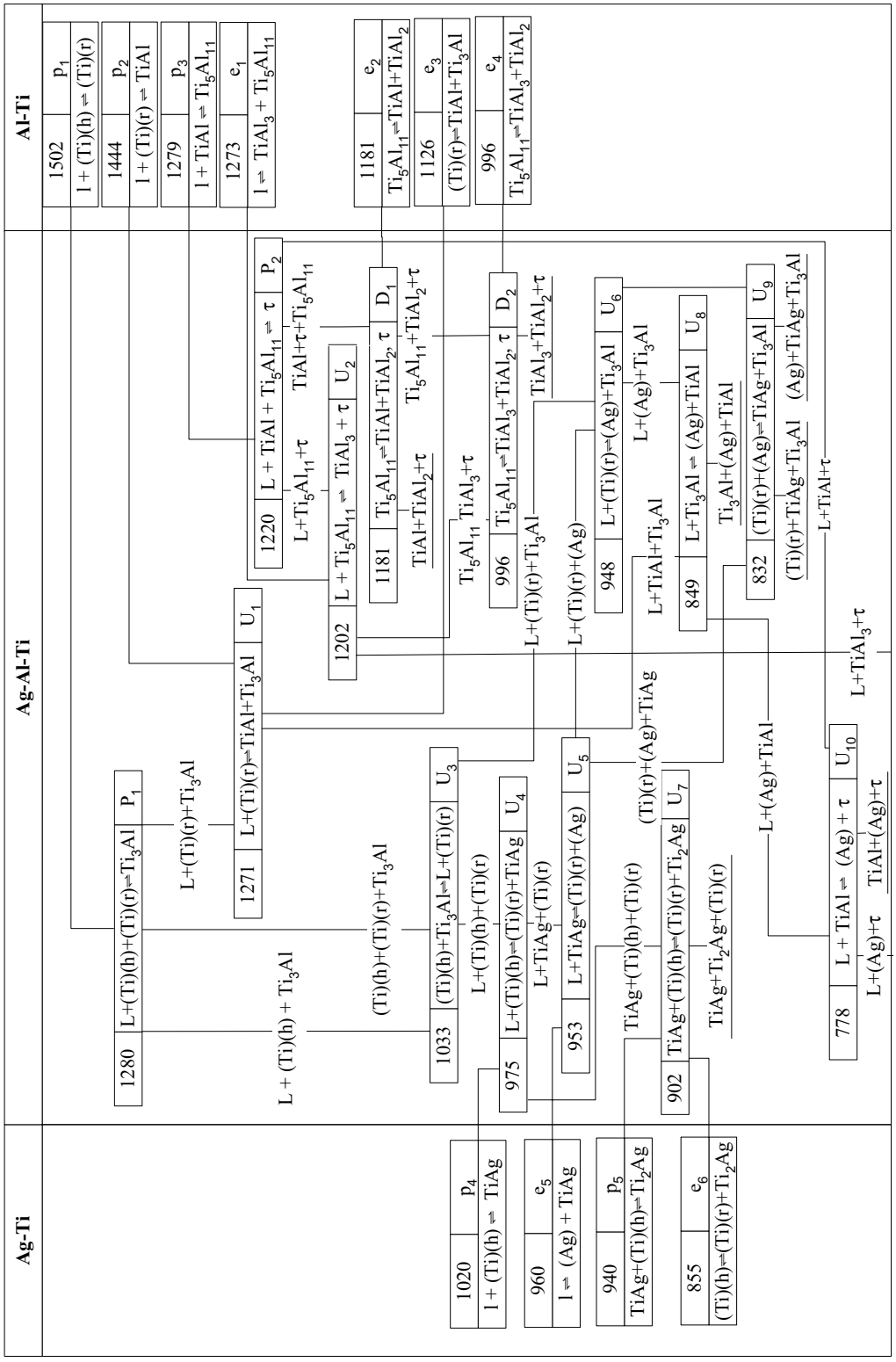

Fig. 1: Ag-Al-Ti. Tentative reaction scheme

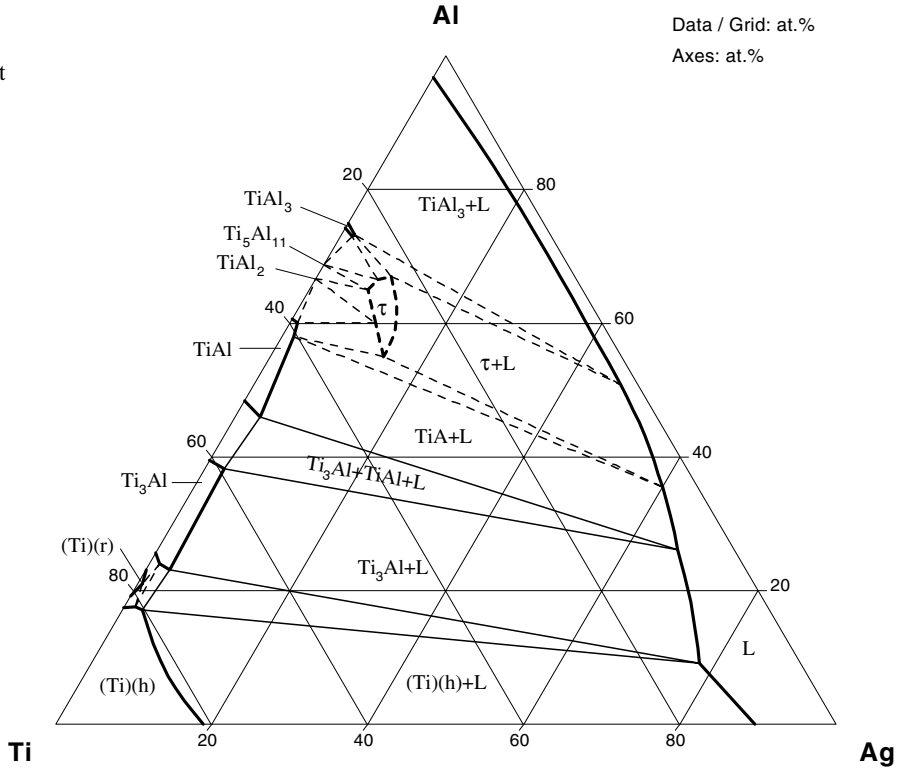

Fig. 2: Ag-Al-Ti. Isothermal section at 1100°C

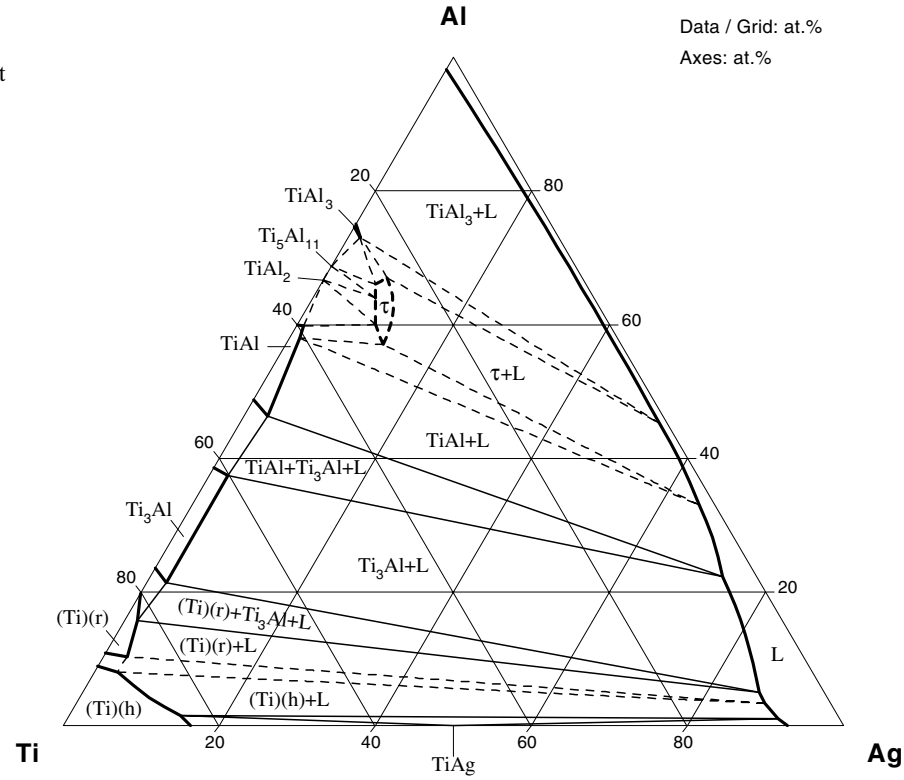

Fig. 3: Ag-Al-Ti. Isothermal section at 1000°C

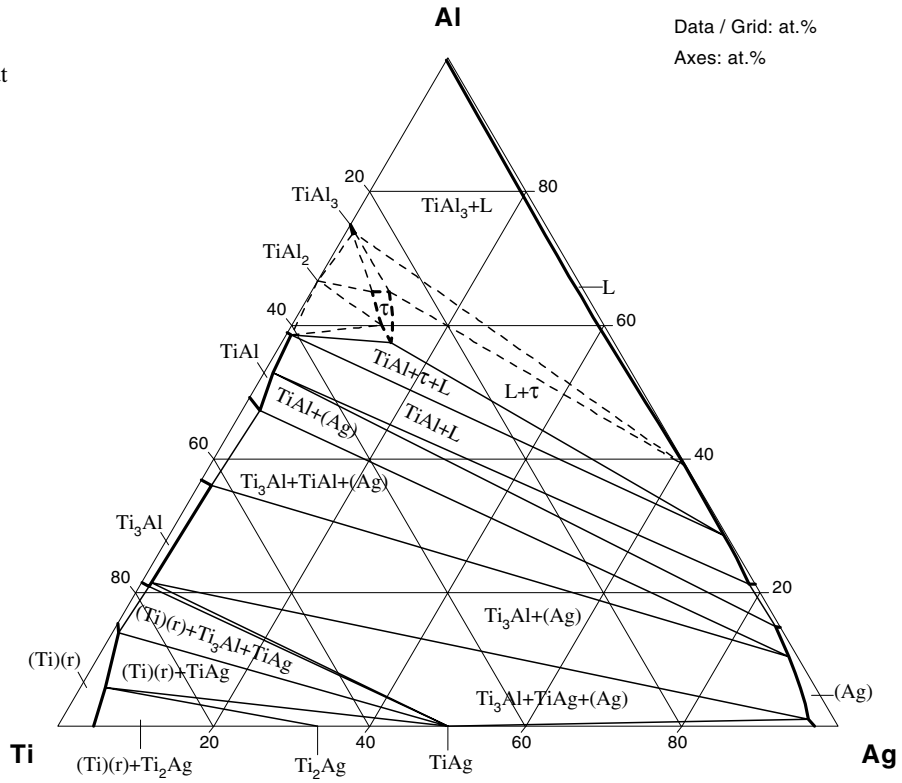

Fig. 4: Ag-Al-Ti.
Isothermal section at 800°C