Aluminium – Cobalt – Titanium

Kazuhiro Ishikawa, Ryosuke Kainuma and Kiyohito Ishida

Literature Data

This evaluation updates and modifies in parts the thoroughly made critical evaluation by [1991Sch] in the same MSIT Ternary Evaluation Program. The Al-Co-Ti system was first investigated by [1966Mar], who prepared 110 alloys, melted from iodide titanium (99.97%), cobalt (99.9%) and aluminum (99.997%) under helium in an arc furnace with W-electrode, using a water cooled copper mould. The whole ternary system was determined by thermal, X-ray, and dilatometric analysis together with hardness and specific electrical resistivity measurements (only for Ti-rich alloys). The samples were annealed at 800°C and 600°C for 1 month in evacuated silica ampoules containing Ti-chips. The authors found two ternary phases: $TiCo_2Al$ and another one called Ti_2CoAl_2, reported with a small range of homogeneity. The samples annealed at 600°C had compositions identical to those annealed at 800°C. The phase $TiCo_2Al$ is a Heusler phase [1962Mar, 1963Gla, 1967Hof], the phase Ti_2CoAl_2 is of the Th_6Mn_{23} type [1969Mar], the latter paper gives an approximate composition $TiCoAl_2$. A Japanese group [1967Tsu, 1968Tsu] studied the equilibria in the Ti-rich corner (more than 80 mass% Ti) between 1100 and 600°C. Commercially pure Ti-sponge (99.8%), Co (99.54%) and Al (99.99%) were melted in an argon arc furnace. Alloys with more than 85 mass% Ti were hot rolled between 1000 and 800°C to eliminate the as-cast structure. The specimens for microscopic examination were heat treated in argon filled silica capsules and subsequently quenched in water. Annealing times: 8 h at 1100°C, 1 day at 1050°C or 1 week at 1000°C. The specimens quenched from below 950°C were cooled in stages from 1000°C to the annealing temperature, being held for 1 week at 1000°C and then 1 week at 950°C, then 2 weeks at 900°C and 950°C and 1 month at 800, 750, 700, 650 and 600°C. For X-ray diffraction the specimens were heated in vacuum for 1 h to the required temperature and quenched [1967Tsu]. Eleven isothermal sections and nine isopleths of the Ti-rich corner with more than 80 mass% Ti were constructed [1968Tsu]. The paper [1967Tsu] is a short version of [1968Tsu] with five isothermal and four vertical sections. In two further papers [1969Tsu1, 1969Tsu2] the investigations were extended to 70 mass% Al+Co. In [1972Tsu] these two papers are combined in an English translation containing the same diagram and micrographs. From 111 alloys, most of them chemically analyzed, the liquidus surface as well as 6 isothermal sections were constructed, covering the partial system with less than 50 mass% Al and more than 30 mass% Ti. The authors reported a continuous solid solution (Ti,Al)Co between TiCo and AlCo although the reported alloys cover only part of this range. The three phase fields L+(Ti,Al)Co+τ_2 and L+τ_2+TiAl have maxima with the reactions L+(Ti,Al)Co$\rightleftharpoons\tau_2$ and L$\rightleftharpoons\tau_2$+TiAl respectively. Phase equilibria in the Al-Ti portion were determined by [2000Kai]. The alloys prepared by arc melting were equilibrated at 1300°C for 1 day, 1200°C for 7 days and 1000°C 7 days in a evacuated quartz tube back-filled with Ar with Ti filings as getters. The equilibrium compositions were determined by EPMA with standard calibration method. The phase equilibria in the Co-Ti portion were investigated by [2001Ish]. Twenty six alloys were prepared with pure elements by arc melting under an Ar atmosphere. The alloys were sealed in a quartz tube with a titanium getter and equilibrated at 1100°C for 7 days, 1000°C for 14 days and 900°C for 21 days. The equilibrium compositions were determined by energy dispersive spectroscopy (EDS) using standard calibration method. The phase τ_2, contrary to [1966Mar], is assumed to have a large range of homogeneity by Ti to Al exchange. Six invariant four-phase reactions were found. By X-ray diffraction it is not possible to distinguish between the hexagonal (αTi) phase and Ti_3Al which is ordered. Therefore no ordering reflections were observed by [1972Tsu]. By thermal analysis, X-ray diffraction reflections and metallography of 16 as-cast alloys [1979Sei] constructed the whole liquidus surface. It was stated that the results of [1967Tsu] and [1972Tsu] were used to construct the phase diagram, but the lines of double saturation in this diagram differ significantly from those of [1972Tsu], although the alloys reported are not at all sufficient to prove these differences. The Al-rich part was not assessed but estimated to be similar to the Al-Fe-Ti system, assessed in the same paper and to match the known binary systems. Three ternary phases τ_1-$TiCo_2Al$, τ_2-$Ti_{1-x}CoAl_{2-x}$ and τ_3-$Ti_8Al_{22}Co_3$ were found by [1979Sei].

She indicated a field of primary crystallization of the Heusler-*cF*16 type phase $TiCo_2Al$, which implies that there is no continuous solid solution between CoAl and TiCo in contradiction to [1969Tsu1, 1969Tsu2, 1972Tsu] and [1986Zas]. Several works [1962Mar, 1963Gla, 1967Mar, 1967Hof, 1973Web, 1984End, 1993Nak] contributed to the crystal structure and the lattice parameter of the Heusler phase $TiCo_2Al$. The phase equilibria in the TiCo-$TiCo_2Al$-CoAl pseudo-binary section (Co = 50 at.%) were determined by [2002Ish1] using the diffusion couple method. The TiCo/$TiCo_2Al$ and $TiCo_2Al$/CoAl couples were equilibrated for 2 days at 1300°C, 14 days for 1200°C and 21 days at 1100°C. From the concentration-penetration profiles obtained by EDS analysis, it was confirmed in the TiCo-CoAl pseudo-binary section that a continuous ordering from the CsCl (B2) type to Heusler ($L2_1$) phase exist on both the TiCo and CoAl sides. The phase equilibria in the TiCo-$TiCo_2Al$ section (Co = 52 at.%) were also investigated by [2003Kaw] correlating microstructures and mechanical properties. Their alloys were prepared by arc melting and homogenized in a vacuum at 1200°C for 2 days, then annealed at 700 - ~900°C. Transmission electron microscopic observation was carried out to detect the anti-phase domain structure introduced during the ordering reaction in the as-quenched alloys. These studies also confirmed the continuous ordering reaction in the TiCo-$TiCo_2Al$ section.
A detailed refinement of the crystal structure of the τ_2 phase has been performed by [2003Gry] employing X-ray single crystal- and neutron powder diffraction as well as electron diffraction.

Binary Systems

The binary systems Al-Co and Co-Ti compiled by [Mas] are used as boundary systems. The Al-Ti system [1989Pri] is based on the critical assessment of Murray [1987Mur], but corrected with the results [1989McC] for the range of 40 to 55 at.% Al and [1989Kal] for the range of 65 to 75 at.% Al. This phase diagram is shown in Fig. 1.

Pseudobinary Systems

The TiCo-CoAl section is reported by [2002Ish1] and [2003Kaw] to be a pseudobinary one and shown in Figs. 12 and 13 by dashed lines.

Solid Phases

The reported binary phases and the ternary phases are represented in Table 1. The solid solubility of Co in (Ti) and Ti_3Al is less than 5 at.% Co at 800°C [1966Mar]. There are conflicting assumptions on the solid solution between TiCo and CoAl and the observation of the ternary Heusler phase $TiCo_2Al$, which is an ordered form of the CsCl-solid solution “Co(Ti,Al)”. Complete solid solubility is claimed by [1972Tsu], although the experimental points cover only the Co-rich part. An enthalpy vs concentration curve of the CoAl-TiCo section which shows no interruption by a two phase field was reported by [1986Zas]. Since the Heusler phase is a superstructure of the CsCl type, the distinction between both phases was possibly not well established. The ternary phase τ_3 [1979Sei] was not found by [1966Mar] and is outside the ranges investigated by other authors. But since similar phases exist in Al-Ni-Ti and Al-Cu-Ti [1965Ram], its existence is very probable. The solvus of the (βTi) phase was determined by [1967Tsu], it is shown in Fig. 2. The refinement of the crystal strucure of the τ_2 phase gives as formula: $Ti_{27.5}Co_{23.4}Al_{49.1}$, its structure type has been determined as $Mg_6Cu_{16}Si_7$, a filled variant of the Th_6Mn_{23} type.

Invariant Equilibria

The partial reaction scheme after [1972Tsu], corrected to the accepted binaries, is given in Fig. 3. A reaction scheme given by [1979Sei] is partially in contradiction to that of [1972Tsu] and to the accepted Al-Ti binary system. In the reaction scheme in Fig. 3 a continuous solid solution (Ti,Al)Co is assumed, from which the Heusler phase $TiCo_2Al$ may form at lower temperatures.

Liquidus Surface

The liquidus surfaces given by [1972Tsu] and [1979Sei] disagree in many details. That of [1972Tsu] is based on many more alloys and therefore is preferred in the construction of the liquidus surface in Fig. 4. The remaining parts given by [1979Sei] are based on so few alloys that they can be taken only as very tentative. Furthermore the phases $TiCo_3$ and the two different modifications of $TiCo_2$ are neglected in [1979Sei].

Isothermal Sections

The isothermal sections of 1300, 1200, 1100, 1000, 900, 800 and 600°C in the Ti-rich part by [1972Tsu], the Al-Ti corner by [2000Kai] and the Co-Ti by [2001Ish] are integrated in Figs. 5, 6, 7, 8, 9, 10 and 11, respectively. Because of the discrepancy between [1967Tsu, 1972Tsu, 1979Sei] and [1966Mar], the isothermal section of [1966Mar] at 800°C is not shown. For the same reason, the isothermal section at 1000°C by [1972Tsu] was replaced by one constructed on the basis of recent data [2000Kai, 2001Ish].

Temperature – Composition Sections

Nine vertical sections were constructed by [1968Tsu] in the Ti-corner.

Thermodynamics

Enthalpies of formation by solution calorimetry in liquid Al for five alloys of the section $Ti_{1-x}CoAl_x$ were determined by [1986Zas]. The entropies of alloys of the $Ti_{1-x}CoAl_x$ section were determined by [1987Kra] using low temperature (78 to 273 K) heat capacity measurements.

Notes on Materials Properties and Applications

Magnetic measurements on the Heusler phase $TiCo_2Al$ were made by [1973Web, 1983Bus, 1984End]. For alloy concentrations of $Ti_{1-x}CoAl_x$ with $x > 0.6$ the ferromagnetic behavior changes to paramagnetic. The Curie temperature for the $TiCo_2Al$ compound is determined as 134 K in [1983Bus] on a sample annealed at 527°C for 14 days.
The characteristic of the electrical resistivity of the $Ti_{32}Co_{22}Al_{46}$ compound is typical metalic and the temperature dependence follows the Bloch-Grüneisen relation with a Debye temperature of ~300 K [2003Gry]. The residual resistivity for the $Ti_{32}Co_{22}Al_{46}$ compound is 0.97 mΩ·cm [2003Gry].
The $Ti_{47}Co_{28}Al_{25}$ compound can absorb up to 0.8 wt.% hydrogen (8.57 mg) [2003Gry].

Miscellaneous

The stability of the Heusler phase $TiCo_2Al$ up to the liquidus surface (1750°C) is described by [1979Sei]. The phase stability of the $L2_1$ phase in the TiCo-$TiCo_2Al$-CoAl quasibinary section was reported by [2002Ish2]. There, the (metastable) critical temperature of $B2/L2_1$ order-disorder transition of stoichiometric $TiCo_2Al$ was given as 1827°C and the two tri-critical temperatures of the $B2+L2_1$ decompositions were estimated as about 1127°C. The critical compositions of the continuous ordering evaluated by [2002Ish2] are shown in Fig. 12 superimposed on the stable melting equilibria (dashed lines). Also shown are the assumed limits of both $B2+L2_1$ two-phase fields [2002Ish2]. [2003Kaw] describes the ordering temperature vs composition for continuous ordering on the TiCo rich side of the section at 52 at.% Co from ~1300 down to 600°C but does not recognize the separation into two phases $B2+L2_1$, see Fig. 13.

Note added in press

Phase equilibria at 950°C has been reported by [2000Din] based on EPMA, quantitative X-ray diffraction and optical microscopy data for arc-melted samples annealed at 950°C for 240 hours. Note: In this work the existence of the τ_3 phase has been confirmed in as-cast and annealed samples.

References

[1962Mar] Markiv, V.Ya., Teslyuk, M.Y., "Crystal Structure of Ternary Compounds $TiCo_2Al$, $MgNi_2Zn$, $TlNi_2Zn$ and $TiCu_2Zn$" (in Russian), *Dop. Akad. Nauk Ukr. RSR*, (12), 1607-1609 (1962) (Crys. Structure, 7)

[1963Gla] Gladyshevskij, E.I., Markiv, V.Ya., Kuz'ma, Yu.B., Cherkashin, E.E., "Crystal Structure of Some Ternary Intermetallic Compounds of Titanium" (in Russian*), Titan. Splavy. Izv. Akad. Nauk SSSR*, Moskva, **10**, 71-73 (1963) (Crys. Structure, 10)

[1965Ram] Raman, A, Schubert, K., "On the Structure of Some Alloy Phases Related to $TiAl_3$. III. Investigations in Several T-Ni-Al and T-Cu-Al Alloy Systems (T = Transition Element)" (in German), *Z. Metallkd*., **56**, 99-104 (1965) (Experimental, Crys. Structure, 14)

[1966Mar] Markiv, V.Ya., "Phase Equilibrium in the Ti-Co-Al System", *Izv. Akad. Nauk SSSR, Met*., (1), 156-158 (1966) (Experimental, Crys. Structure, Equi. Diagram, #, 10)

[1967Hof] Hofer, G., Stadelmaier, H.H., "Cobalt-, Nickel- and Copper-Phases of the Ternary $MnCu_2Al$ Type" (in German), *Monatsh. Chem.*, **98**, 408-411 (1967) (Experimental, Crys. Structure, 9)

[1967Mar] Markiv V.Ya., Kripyakevich, P.I., "Compounds of the Type $R(X',X'')_2$ in Systems with R=Ti, Zr, Hf, X'=Fe, Co, Ni, Cu and X''=Al, Ga and their Crystal Structures", *Sov. Phys. - Crystallogr*., **11**, 733-738 (1967), translated from *Kristallografiya*, **11**, 859-865 (1966) (Crys. Structure, 25)

[1967Tsu] Tsujimoto, T., Adachi, M., "The Titanium-Rich Corner of the Ternary Ti-Al-Co System", *J. Inst. Met.*, **95**, 146-151 (1967) (Experimental, Equi. Diagram, 8)

[1968Tsu] Tsujimoto, T., Adachi, M. "The Titanium-Rich Corner of the Ternary Ti-Al-Co System", *Trans. Nat. Res. Inst. Met. (Jpn.)*, **10**, 325-343 (1968) (Experimental, Equi. Diagram, 8)

[1969Mar] Markiv, V.Ya., Burnashova, V.V., "New Ternary Compounds in the (Sc, Ti, Zr, Hf)-(V, Cr, Mn, Fe, Co, Ni, Cu)-(Al, Ga) Systems" (in Ukrainian), *Dop. Akad. Nauk Ukr. RSR, A*, (5), 463-464 (1969) (Crys. Structure, 12)

[1969Tsu1] Tsujimoto, T., Adachi, M., "Reactions with the Melt in the Titanium-Rich Region of the Ternary Titanium-Aluminium-Cobalt System" (in Japanese), *Nippon Kinzoku Gakkaishi*, **33**, 606-611 (1969) (Experimental, Equi. Diagram, Crys. Structure, #, 19)

[1969Tsu2] Tsujimoto, T., Adachi, M., "Reactions in the Solid State in the Titanium-Rich Region of the Ternary Titanium-Aluminium-Cobalt System" (in Japanese), *Nippon Kinzoku Gakkaishi*, **33**, 612-617 (1969) (Experimental, Equi. Diagram, 6)

[1972Tsu] Tsujimoto, T., Adachi, M., "The Titanium-Rich Region of the Ternary Ti-Al-Co System", *Trans. Nat. Res. Inst. Met. (Jpn.)*, **14**, 178-188 (1972) (Experimental, Equi. Diagram, Crys. Structure, #, *)

[1973Web] Webster, P.J., Ziebeck, K.R.A., "Magnetic and Chemical Order in Heusler Alloys Containing Cobalt and Titanium", *J. Phys. Chem. Solids*, **34**, 1647-1654 (1973) (Crys. Structure, 26)

[1979Sei] Seibold, A., "Determination of Ternary and Quaternary Systems of Titanium for the Development of Technical Appliable Casting Alloys" (in German), *Thesis*, Univ. Erlangen-Nürnberg, (1979) (Experimental, Equi. Diagram, #, 70)

[1983Bus] Buschow, K.H.J., van Engen, P.G., Jongebreur, R., "Magneto-Optical Properties of Metallic Ferromagnetic Materials", *J. Magn. Magn. Mater.*, **38**, 1-22 (1983) (Magn. Prop., Optical Prop., 23)

[1984End] Endo, K., Shinogi, A., Ooiwa, K., Date, M., Hiramoto, K., "The Transitions from Nonmagnetic State to Ferromagnetic State of Co is a Pseudobinary Alloy $CoTi_{1-x}Al_x$", *J. Phys. Soc. Jpn.*, **53**, 1487-1494 (1984) (Experimental, 12)

[1986Zas] Zasypalov, Yu.V., Kiselev, O.A., Mogutnov, B.M., "The Enthalpies of Formation of Intermetallic Compounds $CoTi_{1-x}Al_x$ and $TiNi_{1-x}Co_x$ ($0 \le x \le 1$)" (in Russian*), Dokl. Akad. Nauk SSSR*, **287**, 158-161 (1986) (Thermodyn., 9)

[1987Kra] Krasheninnikova, N.G., Mogutnov, B.M., Tomilin, I.A., Shaposhnikov, N.G., "Thermodynamic Properties of the Intermetallic Compounds $(Ni_{0.5}Ti_{0.5})_x(Co_{0.5}Ti_{0.5})_{1-x}$ and $(Co_{0.5}Ti_{0.5})_x(Co_{0.5}Al_{0.5})_{1-x}$ at Low Temperatures", *Russ. J. Phys. Chem*., **61**, 1627-1630 (1987), translated from *Zh. Fiz. Khim*., **61**, 3089-3093 (1987) (Experimental, Thermodyn., 10)

[1987Mur] Murray, J.L., "Phase Diagrams of Binary Titanium Alloys" in "*Series on Alloy Phase Diagrams*", ASM Metals Park Ohio, (1987) (Equi. Diagram, Crys. Structure, Review, #, 93)

[1989Kal] Kaltenbach, K., Gama, S., Pinatti, D.G., Schulze, K., "A Contribution to the Al-Ti Phase Diagram", *Z. Metallkd*., **80**, 511-514 (1989) (Experimental, Equi. Diagram, Crys. Structure, #, 14)

[1989McC] McCullough, C., Valencia, J.J., Levi, C.G., Mehrabian, R., "Phase Equilibria and Solidification in Ti-Al Alloys", *Acta Metall*., **37**, 1321-1336 (1989) (Experimental, Equi. Diagram, Crys. Structure, #, 25)

[1989Pri] Prince, A., "The Al-Ti Binary Phases Diagram", private communication (1989) (Equi. Diagram, Review)

[1991Sch] Schmid, E.E., "Aluminium-Cobalt-Titanium", MSIT Ternary Evaluation Program, in *MSIT Workplace*, Effenberg, G. (Ed.), MSI, Materials Science International Services GmbH, Stuttgart; Document ID: 10.10909.1.20, (1991) (Equi. Diagram, Crys. Structure, Assessment, 21)

[1993Nak] Nakayama, Y., Mabuchi, H., "Formation of Ternary L1(2) Compounds in Al_3Ti-Base Alloys", *Intermetallics*, **1**, 41-48 (1993) (Crys. Structure, Experimental, Equi. Diagram, 40)

[2000Din] Ding, J.J., Rogl, P., Schmidt, H., Podloucky, R., "Structure Chemistry and Constitution in TiAl-Based Intermetallics", *Visn. L'viv. Univ., Ser. Khim*, (39), 136-141 (2000) (Crys. Structure, 12)

[2000Kai] Kainuma, R., Fujita, Y., Mitsui, H., Ohnuma, I., Ishida, K., "Phase Equilibria Among α (hcp), β (bcc) and γ ($L1_0$) Phases in Ti-Al Base Ternary Alloys", *Intermetallics*, **8**, 855-867 (2000) (Experimental, Equi. Diagram, 29)

[2001Ish] Ishikawa, K., Himuro, Y., Ohnuma, I., Kainuma, R., Aoki, K., Ishida, K., "Phase Equilibria in the Co-Ti Portion of the Co-Al-Ti Ternary System", *J. Phase Equilib*., **22**, 219-226 (2001) (Experimental, Equi. Diagram, #, 10)

[2002Ish1] Ishikawa, K., Mitsui, H., Ohnuma, I., Kainuma, R., Aoki, K., Ishida, K., "Ordering and Phase Separation of BCC Aluminides in (Ni, Co)-Al-Ti System", *Mat. Sci. Eng. A*, **329-331**, 276-281 (2002) (Experimental, Equi. Diagram, 11)

[2002Ish2] Ishikawa, K., Kainuma, R., Ohnuma, I., Aoki, K., Ishida, K., "Phase Stability of the X_2AlTi (X: Fe, Co, Ni and Cu) Heusler and B2-Type Intermetallic Compounds", *Acta Mater*., **50**, 2233-2243 (2002) (Experimental, Equi. Diagram, 12)

[2003Gry] Grytsiv, A., Ding, J.J., Rogl, P., Weill, F., Chevalier, B., Etourneau, J., Andre, G., Bouree, F., Noel, H., Hundegger, P., Wiesinger, G., "Crystal Chemistry of the G-Phases in the Systems Ti-{Fe, Co, Ni}-Al with a Novel Filled Variant of the Th_6Mn_{23}-Type", *Intermetallics*, **11**, 351-359 (2003) (Experimental, Crys. Structure, 26)

[2003Kaw] Kawai, H., Kaneko, Y., Yoshida, M., Takasugi, T., "Microstructures and Mechanical Properties of CoTi(B2)-Co_2AlTi ($L2_1$) Pseudo-Binary Intermetallic Compounds", *Intermetallics*, **11**, 467-473 (2003) (Experimental, Equi. Diagram, Mechan. Prop., 17)

Table 1: Crystallographic Data of Solid Phases

Phase / Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(Al) < 660	*cF*4 *Fm*$\bar{3}$*m* Cu	*a* = 404.88	24°C [V-C]
(γCo)(h) 1495-422	*cF*4 *Fm*$\bar{3}$*m* Cu	*a* = 354.46	[V-C]
(εCo)(r) < 422	*hP*2 *P*6$_3$/*mmc* Mg	*a* = 250.71 *c* = 406.95	[V-C]
(βTi)(h) 1670-882	*cI*2 *Im*$\bar{3}$*m* W	*a* = 330.65	[V-C]
(αTi)(r) < 882	*hP*2 *P*6$_3$/*mmc* Mg	*a* = 295.08 *c* = 468.55	[V-C]
Ti_2Co < 1058	*cF*96 *Fd*$\bar{3}$*m* Ti_2Ni	*a* = 1130	[V-C]
$TiCo_2$(c) < 1235	*cF*24 [a] *Fd*$\bar{3}$*m* $MgCu_2$	*a* = 669.2	[V-C], homogeneity range 66.5 to 67 at.% Co [Mas]
$TiCo_2$(h)	*hP*24 [a] *P*6$_3$/*mmc* $MgNi_2$	*a* = 473 *c* = 1541	[V-C], homogeneity range 68.75 to 72 at.% Co [Mas]
$TiCo_3$ ≲ 1190	*cP*4 *Pm*$\bar{3}$*m* $CuAu_3$	*a* = 361.4	[V-C]
Co_2Al_5 < 1172	*hP*28 *P*6$_3$/*mmc* Co_2Al_5	*a* = 767.15 *c* = 760.85	[V-C]
Co_4Al_{13} ≲ 1100	*mC*100 *Cm* Co_4Al_{13}	*a* = 1518.3 *b* = 812.2 *c* = 1234.0 β =107.9°	[V-C]
Co_2Al_9 < 944	*mP*22 *P*2$_1$/*a* Co_2Al_9	*a* = 855.6 *b* = 629.0 *c* = 621.3 β = 94.76°	[V-C]
$TiAl_3$ < 1395	*tI*8 *I*4/*mmm* $TiAl_3$	*a* = 384.9 *c* = 861	[1989Kal]

Phase / Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
Ti_9Al_{23} ≲ 780		a = 384.3 c = 3346.4	superstructure of $TiAl_3$ [1989Kal]
ξ, $TiAl_{2.4}$(h) 1415-990	*tI*16 *I4/mmm* $ZrAl_3$	a = 391.7 c = 1652.4	[1989Kal]
$TiAl_2$ < 1175	*tI*24 *I41/amd* $HfGa_2$	a = 397.6 c = 2436	[1989Kal]
TiAl < 1447	*tP*4 *P4/mmm* CuAu	a = 401.1 c = 406.9 a = 398.8 c = 408.1	at 46 at.% Al [1989Kal] at 62 at.% Al
Ti_3Al ≲ 1180	*hP*8 *P6$_3$/mmc* Ni_3Sn	a = 578.2 c = 462.9	[V-C]
$(Ti_{1-x}Al_x)Co$ TiCo < 1325 CoAl < 1648	*cP*2 *Pm$\bar{3}$m* CsCl	 a = 299.5 a = 286.11	$0 \le x \le 1$ [V-C] [V-C]
*τ_1, $TiCo_2Al$	*cF*16 *Fm$\bar{3}$m* BiF_3	a = 584.7 a = 584.8	[1962Mar], [1979Sei] [V-C]
*τ_2, $Ti_{1+x}CoAl_{2-x}$	*cF*116 *Fm$\bar{3}$m* Th_6Mn_{23} $Mg_6Cu_{16}Si_7$	 a = 1193 a = 1193.56 ± 0.03	$0 \le x \le 1$ [1972Tsu] $TiCoAl_2$ [1969Mar] $Ti_{27.5}Co_{23.4}Al_{49.1}$ [2003Gry]; a filled variant of the Th_6Mn_{23}-type
*τ_3, ≈$Ti_8Co_3Al_{22}$	*cF*4	a = 395	Cu_3Au-like [1979Sei]

[a] Possibly only one of the two $TiCo_2$ based Laves phases is a stable phase [Mas]

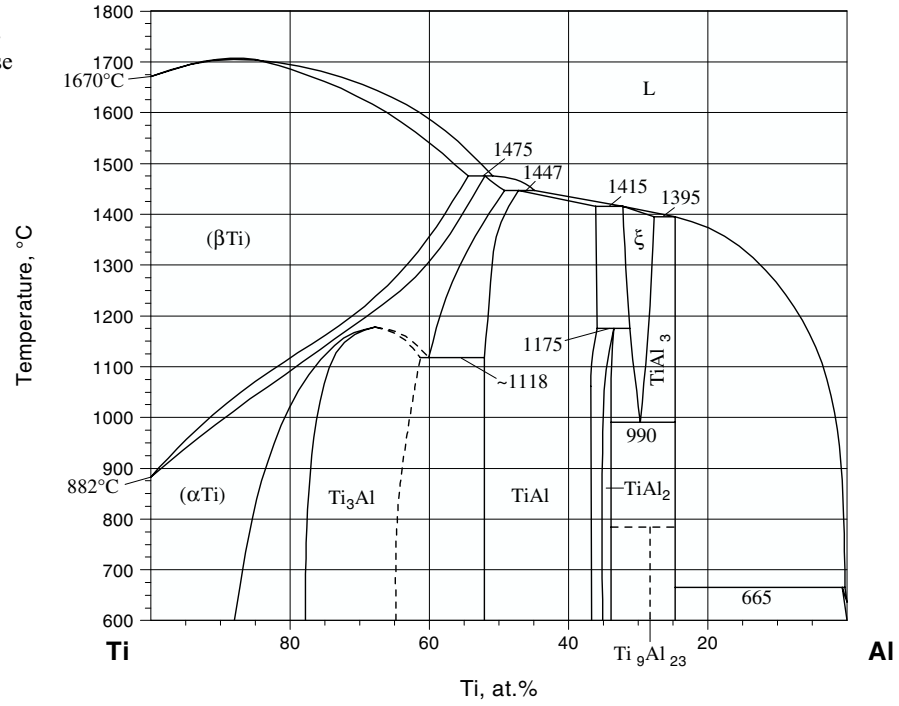


Fig. 1: Al-Co-Ti. Acceped Al-Ti phase diagram

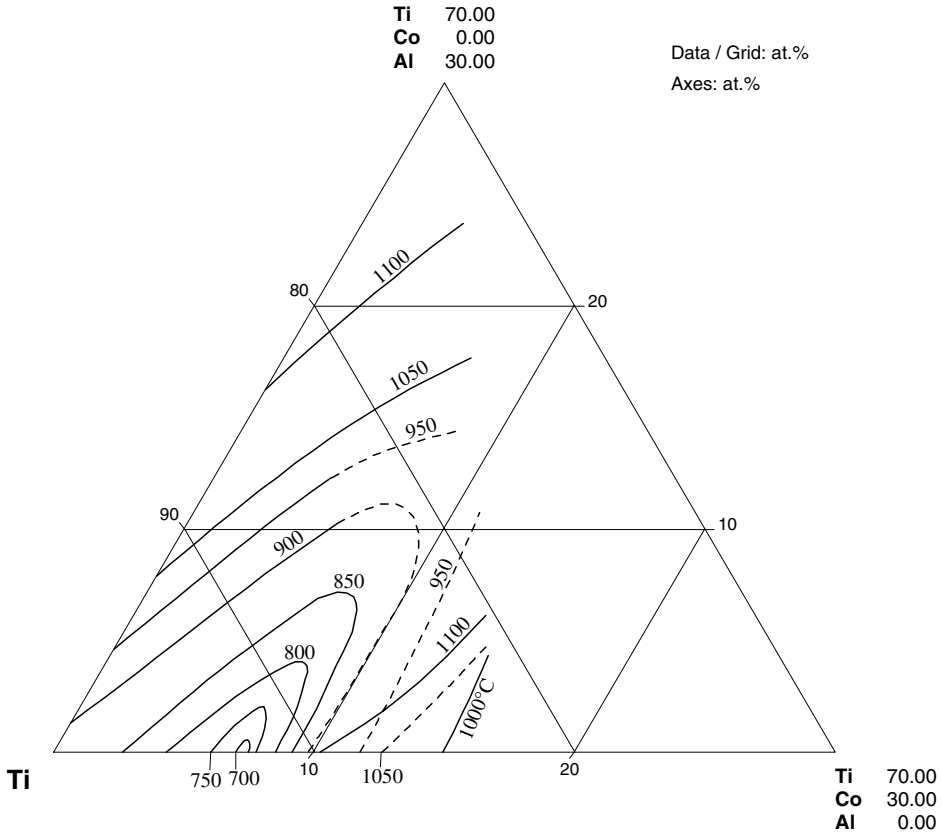


Fig. 2: Al-Co-Ti. Solvus lines of the (βTi) phase field [1967Tsu]

Fig. 3: Al-Co-Ti. Reaction scheme

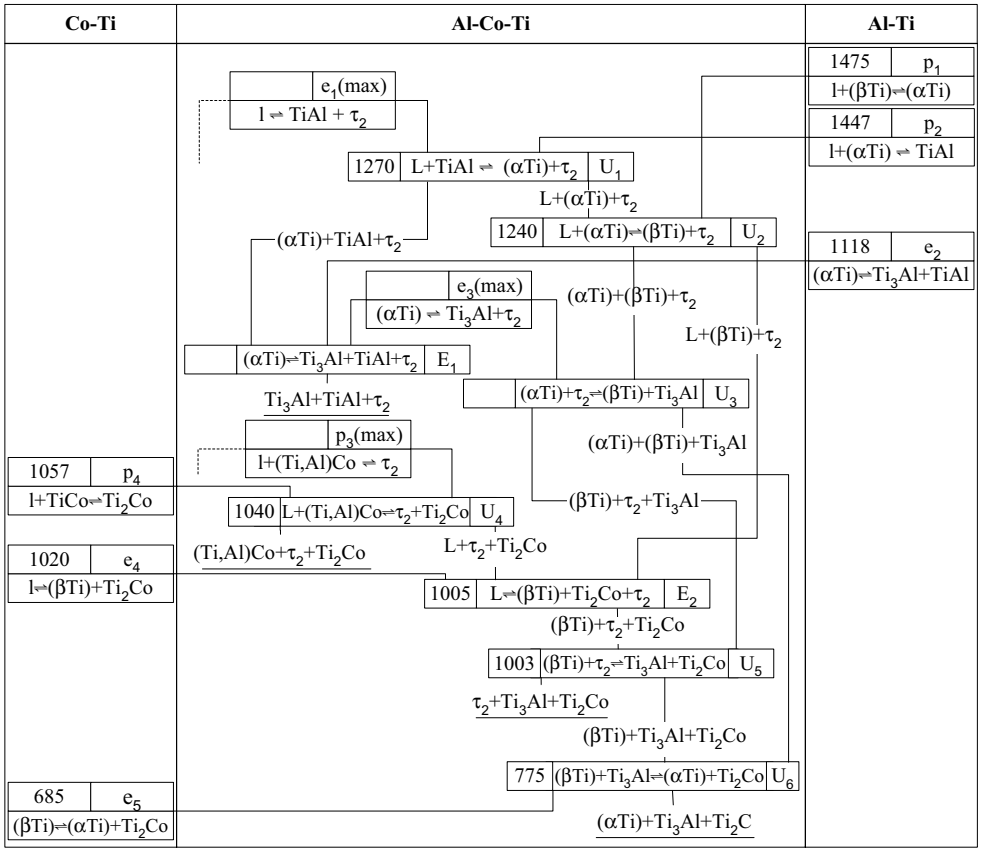
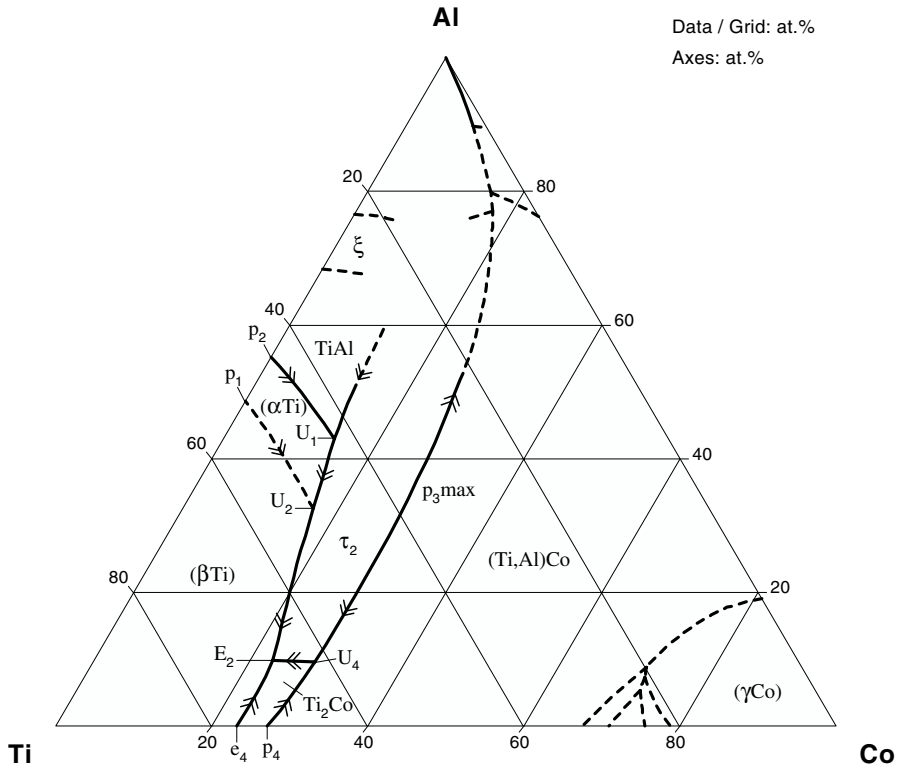


Fig. 4: Al-Co-Ti. Liquidus surface



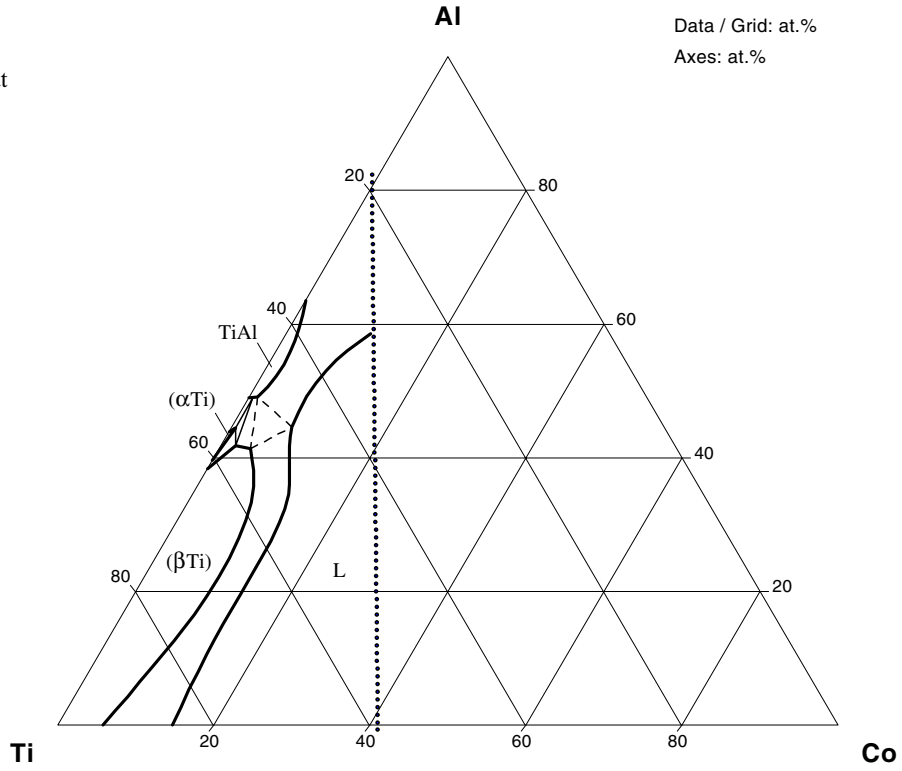


Fig. 5: Al-Co-Ti.
Isothermal section at 1300°C

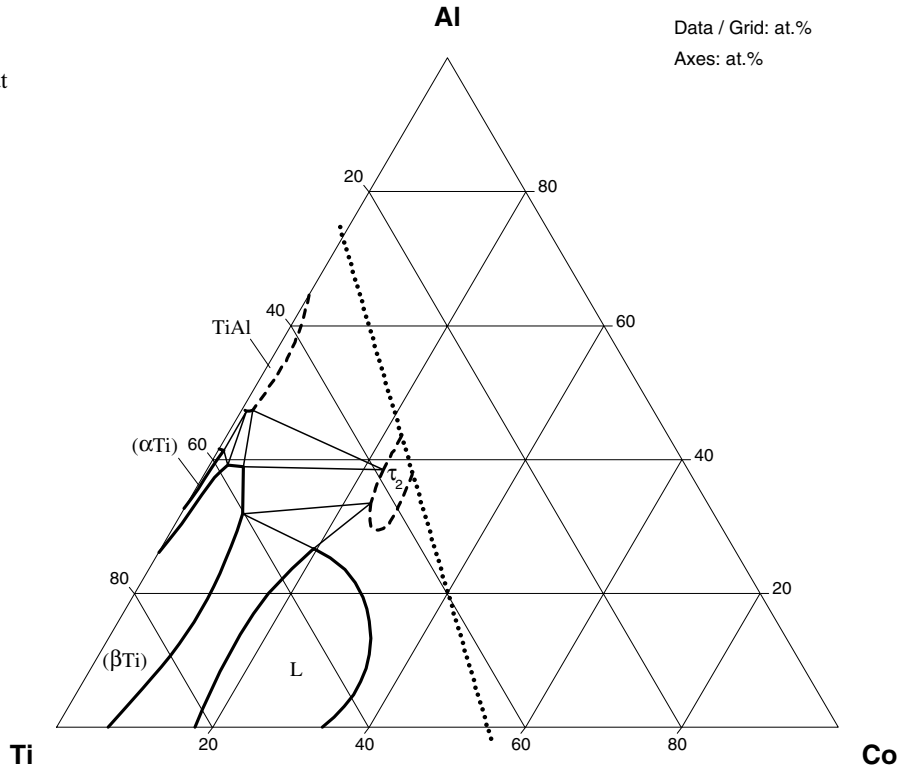


Fig. 6: Al-Co-Ti.
Isothermal section at 1200°C

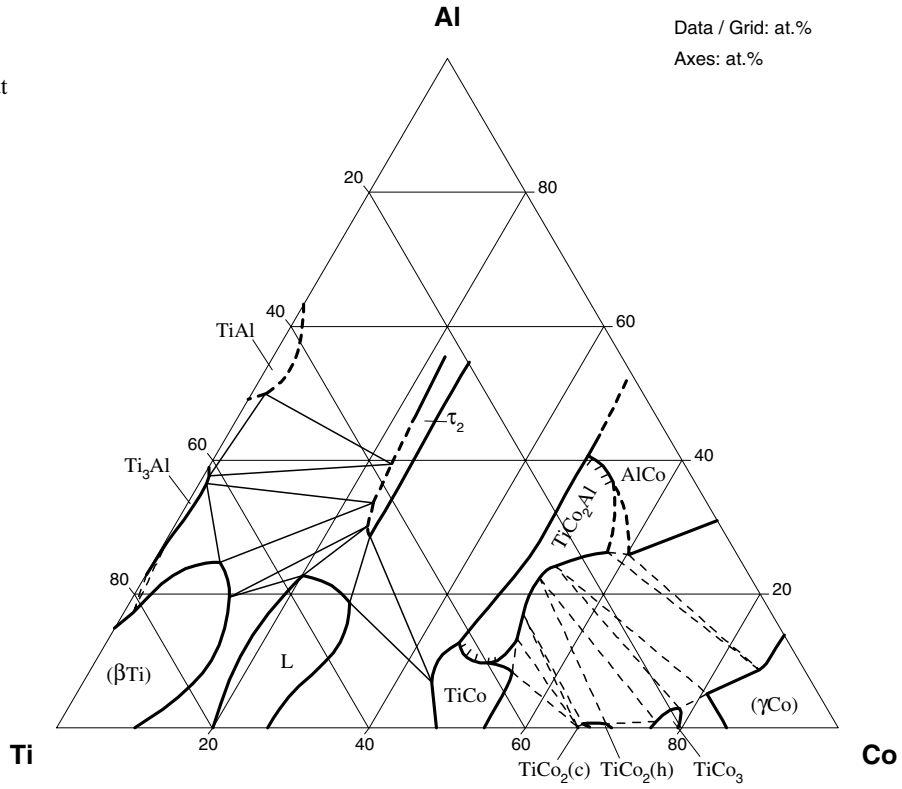


Fig. 7: Al-Co-Ti. Isothermal section at 1100°C

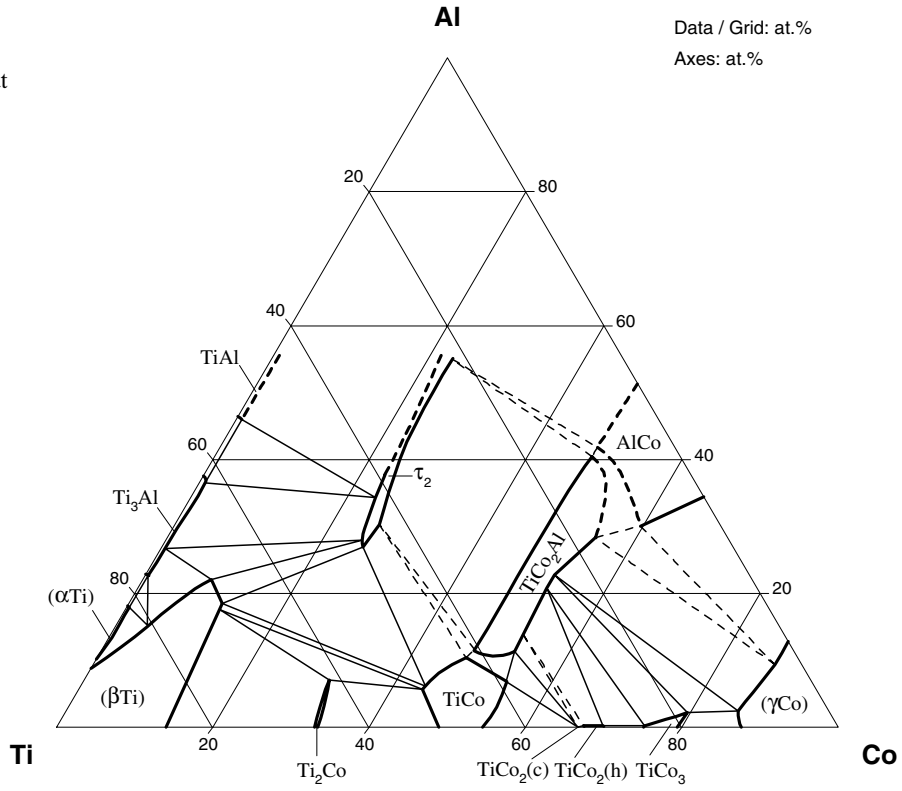


Fig. 8: Al-Co-Ti. Isothermal section at 1000°C

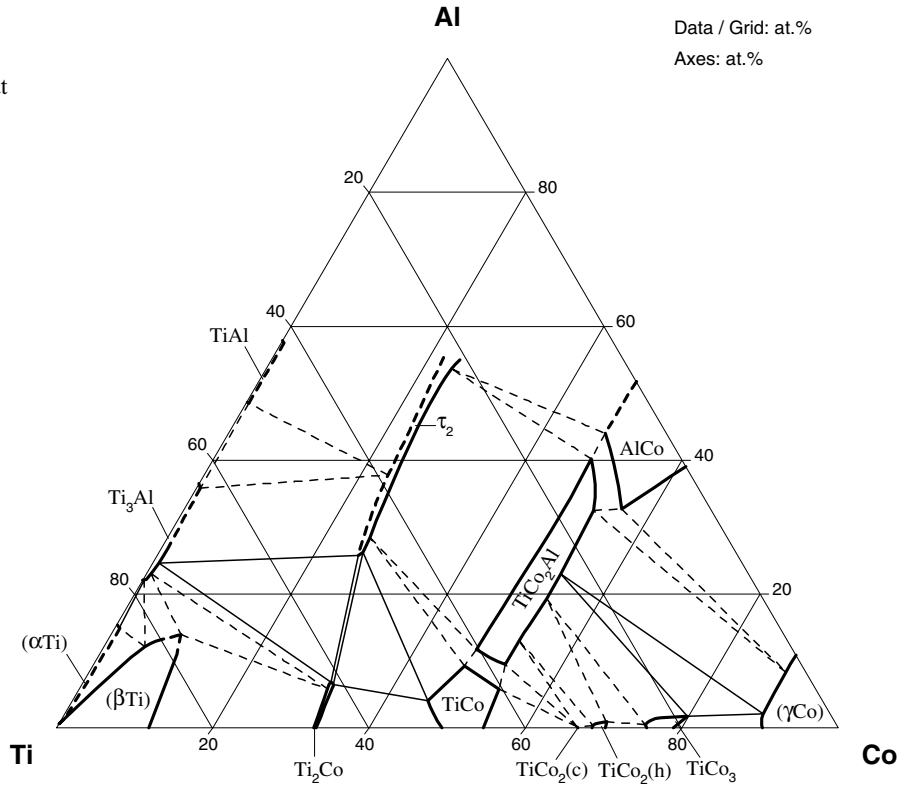


Fig. 9: Al-Co-Ti. Isothermal section at 900°C

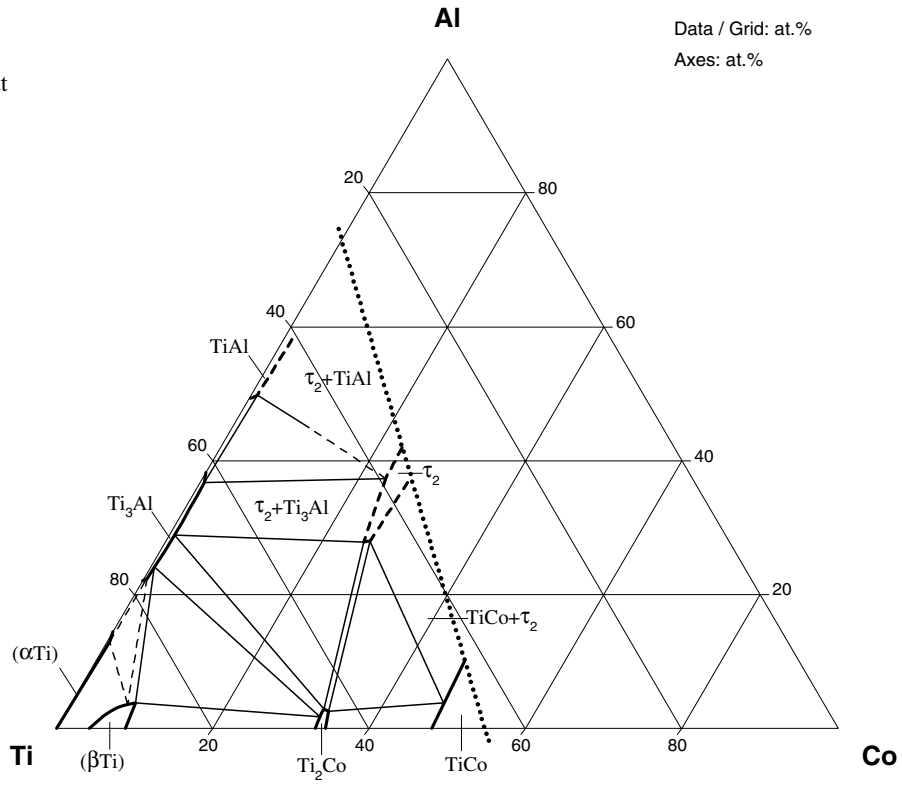


Fig. 10: Al-Co-Ti. Isothermal section at 800°C [1972Tsu]

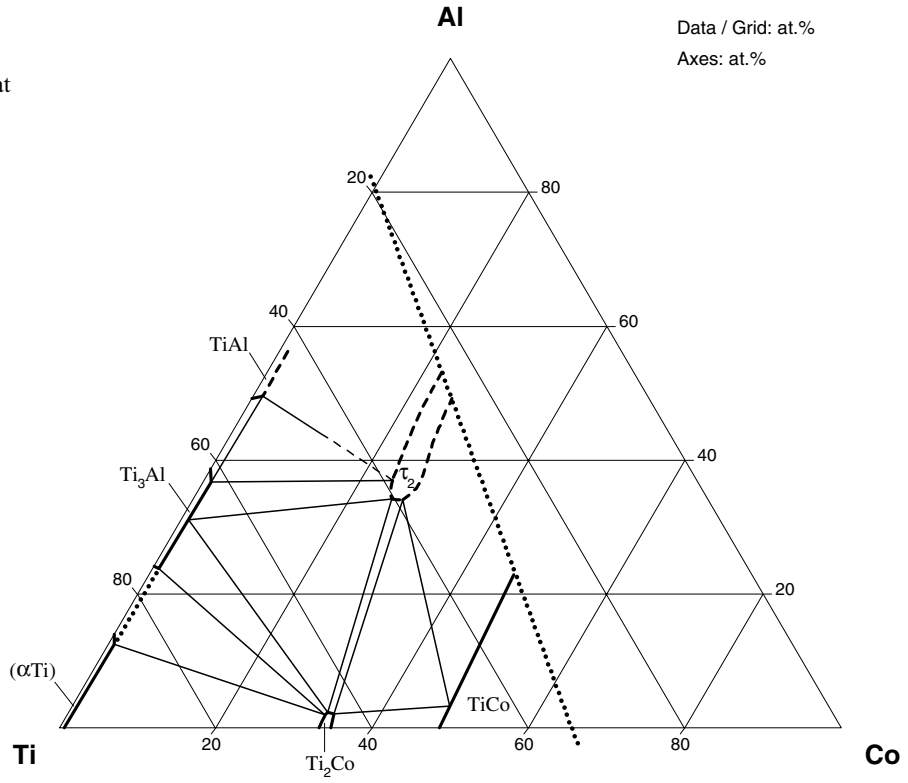


Fig. 11: Al-Co-Ti. Isothermal section at 600°C [1972Tsu]

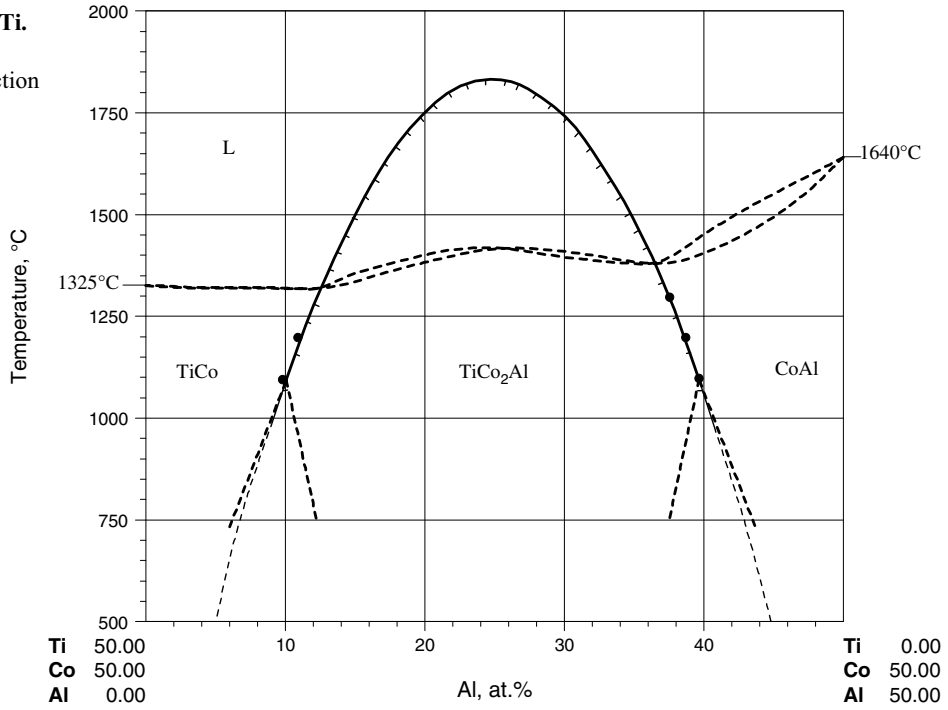


Fig. 12: Al-Co-Ti. TiCo - CoAl pseudobinary section [2002Ish1]

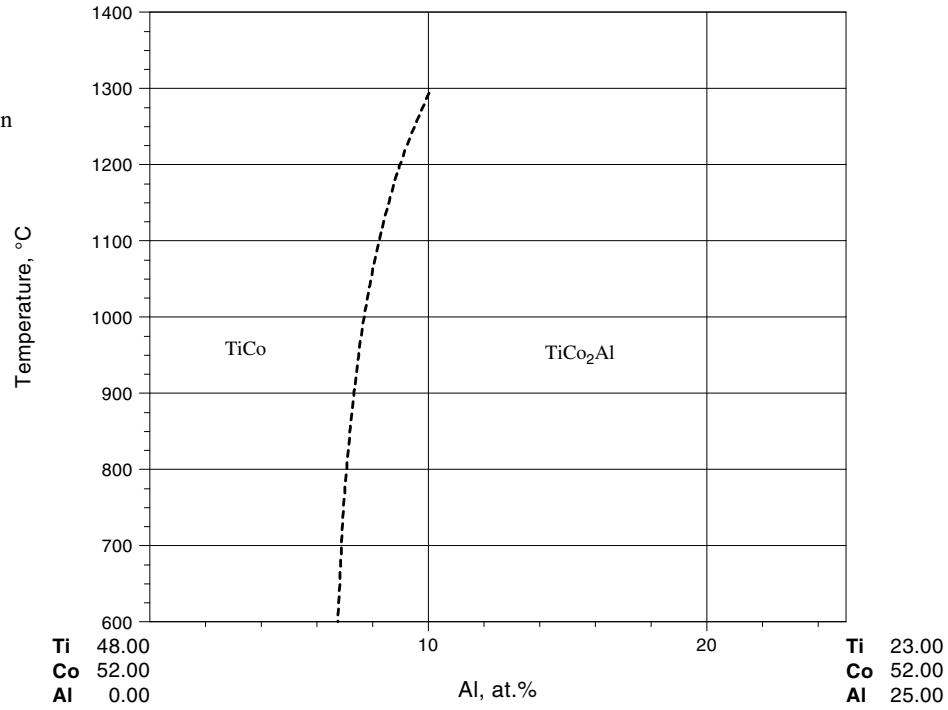


Fig. 13: Al-Co-Ti. Part of the $TiCo$ - $TiCo_2Al$ pseudobinary section (Co = 52 at.%) [2003Kaw]