

Al – Ti (Aluminum – Titanium)

Phase diagram

A central part of the phase diagram has been investigated by [90 Shu], [96 Din] and [90 Sch] (see Fig. 1). In an enlarged version phase equilibria of this area are given in Fig. 2 [90 Shu].

Fig. 3 gives a schematic view of the formation or transformation in the temperature range of about 1480 K.

Anderson et al. [93 And] especially have determined the liquidus at about 50 at% Al (see Fig. 4). A review of this system has been given by Okamoto [93 Oka] (see Fig. 5), and Suryanarayana et al. [92 Sur].

Minamao et al. [91 Min] have investigated the solubility of Ti in (Al) as a function of pressure (see Fig. 6).

Especially phase equilibria of the Al-Ti system have been determined experimentally several times in the last years (see [87 Mur]). Besides the investigations mentioned above some more works should be shortly reported here. The results were corroborated by thermodynamic calculations [88 Mur]. Pfullmann [88 Pfu] has modified the diagram proposed by [88 Mur]. Order – disorder transformations have been investigated by Hellwig [90 Hel]. The phase diagram thus present in the literature with minor corrections was acknowledged by [99 Bra].

A phase diagram reported by Schuster et al. [90 Sch] is somewhat different from Fig. 5. No severe deviation from results of more recent determinations have been found (see Anderson et al. [93 And], Shull et al. [90 Shu]). Thus, the phase diagram in Fig. 5 at time seems to be the most realistic one. A phase diagram Al-Ti calculated by [90 Sau] and [95 Bra] is shown in Fig. 7.

To ascertain some parts of the phase diagram, Braun [99 Bra] has performed metallographic and X-ray diffraction experiments. The results are given in Fig. 8 to Fig. 10.

Also, Kattner et al. [92 Kat] have calculated the phase diagram. An assessed phase diagram is published by Okamoto [93 Oka].

Investigations of structure and stability of AlTi have been performed by Braun [95 Bra]. Examination of diffusion couples annealed at temperatures between 1423 K and 1673 K have corroborated the known fact, that (α -Ti) solid solutions are existing between the (β -Ti) solid solution and γ -AlTi phase (Ding et al. [96 Din]).

Amorphous alloys

Qi et al. [93 Qi] succeeded in preparing two different amorphous alloys by high-energy milling of mixtures of Al- and Ta powders. The existence of these two amorphous alloys as well as their concentrations are controlled by equilibrium of metastable alloys.

By mechanical alloying Gerasimov et al. [96 Ger] have prepared metastable alloys: In the region of γ -AlTi phase, a metastable hcp structure has been prepared. At the stoichiometry $\text{Al}_{30}\text{Ti}_{70}$ a metastable hcp phase or a metastable bcc phase is produced depending on the intensity of the treatment. At concentrations < 33 at% Ti a metastable tetragonal structure has been found.

Moon et al. [98 Moo] have been able to produce nanocrystalline Al-Ti alloys by ball milling in a hydrogen atmosphere. The obtained powder contains the different phases. In the matrix, consisting of nano-Al, there are inclusions of nano-sized Al_3Ti . At the same time TiH_2 is formed, which preferentially is located on grain boundaries.

Some experimental observations concerning the alloy formation by mechanical alloying of Al- and Ti-powders have been published by [92 El-E].

Crystal structure

AlTi₃

The structure of AlTi₃ is hexagonal (Ni₃Sn – type). It is a superstructure of the hcp Mg-type. The dependence of the lattice parameters from concentration and from temperature is shown in Fig. 11 to Fig. 14, respectively.

AlTi

The structure of this intermediate phase is tetragonal (CuAu - type). The lattice parameters as a function of concentration as well as of temperature, respectively, are given in Fig. 15 to Fig. 18.

Intermediate phase Al_{1-x}Ti_{1-x}

The structure is orthorhombic as Schuster et al. [90 Sch] stated. For $x = 0.28$ there are

$$\begin{aligned}a &= 0.40262 \text{ nm} \\b &= 0.39617 \text{ nm} \\ \text{and } c &= 0.40262 \text{ nm}.\end{aligned}$$

Al₅Ti₃

Its structure is tetragonal with lattice constants:

$$\begin{aligned}a &= 1.1293 \text{ nm} \\ \text{and } c &= 0.4038 \text{ nm}\end{aligned}$$

Miida et al. [82 Mii] (Ga₅Ti₃ – type).

Al₂Ti (r)

The structure of this intermediate phase is tetragonal (Ga₂Hf – type). Braun [99 Bra] found the lattice parameters:

$$\begin{aligned}a &= 0.3970 \text{ nm} \\ \text{and } c &= 2.4309 \text{ nm}.\end{aligned}$$

The lattice parameters a and c as a function of temperature are given in Fig. 19 and Fig. 20, respectively.

Al₂Ti (h)

The structure of this intermediate phase is orthorhombic (Ga₂Zr – type). The lattice parameters as determined by Braun [99 Bra] are:

$$\begin{aligned}a &= 1.2131 \text{ nm} \\b &= 0.3942 \text{ nm} \\ \text{and } c &= 0.4016 \text{ nm}.\end{aligned}$$

Al₁₁Ti₅

Its structure is characterized by one-dimensional antiphase structures Al_{3-x}Ti_{1+x}. The lattice parameters of the substructure are:

$$\begin{aligned}a &= 0.3937 \text{ nm} \\ \text{and } c &= 0.4129 \text{ nm}.\end{aligned}$$

The dependence of the lattice constants a and c as a function of concentration is shown in Fig. 21 and Fig. 22, respectively.

Al₃Ti (h)

Its structure is tetragonal (Al₃Ti – type); superstructure. There is:

$$\begin{aligned}a &= 0.38488 \text{ nm} \\ \text{and } c &= 0.85982 \text{ nm}.\end{aligned}$$

[90 Sch]. Braun [99 Bra] determined:

$$a = 0.3849 \text{ nm}$$

and $c = 0.8609$ nm.

The lattice parameters as a function of temperature are shown in Fig. 23 and Fig. 24.

Al₃Ti (r)

This intermediate phase has a tetragonal structure (Al₃Ti – type). At about 840 K the lattice constants are:

$$a = 0.38771 \text{ nm}$$

$$\text{and } c = 3.3828 \text{ nm}$$

[99 Bra].

Ti-rich phases

At Al-contents up to about 45 at% Al disordered solid solutions (α -Ti(Al)) are existing [99 Bra]. β -Ti(Al) solid solutions are not retained at room temperature. In the range of concentrations between 55 and 65 at% Al intermediate phases AlTi, AlTi (m) and Al₁₁Ti₅ have been found by splat cooling.

Lattice parameter a summarized from all found phases after splat cooling are given as a function of concentration in Fig 25. Fig. 26 shows the analogous diagram for c -lattice constant.

Thermodynamics

By high-temperature calorimetry Meschel et al. [93 Mes] have determined the standard enthalpy of formation of Al₃Ti. It has been found the value

$$\Delta H_{298} = -36.6 \pm 1.2 \text{ kJ g-atom}^{-1}$$

By high-temperature calorimetry Kubaschewski et al. [60 Kub] have determined the enthalpy of formation of some alloys. The results are collected in Table 1.

Table 1. Al–Ti. Enthalpies of formation of solid alloys [60 Kub].

Concentration [at% Al]	Enthalpy of formation k[J g-atom ⁻¹]
25	- 6.04
35	- 7.17
45	- 8.35
50	- 8.695
55	- 8.95
60	- 9.27

Fig. 1. Al-Ti. Central part of the phase diagram (from 24 to 52 at% Ti) [90 Sch].

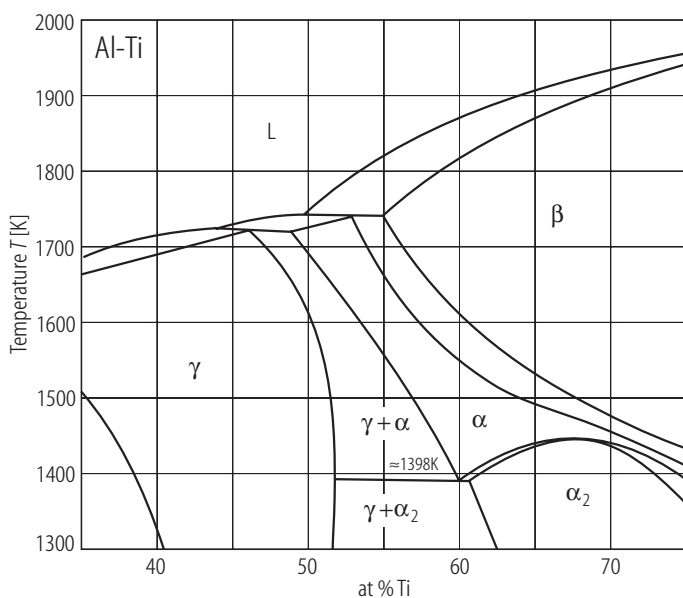


Fig. 2. Al–Ti. Central part of the phase diagram (from 35 to 75 at% Ti) (enlarged version) [90 Shu].

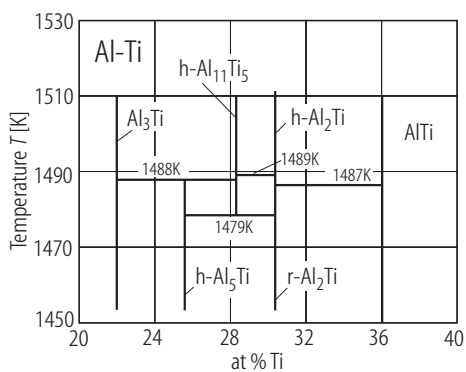
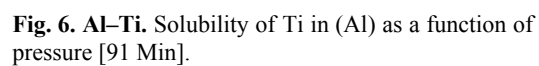
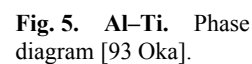
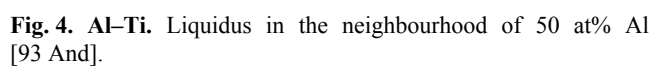


Fig. 3. Al-Ti. Explanation of the temperature of formation or transformation in the range between 20 and 40 at% Ti [90 Sch].



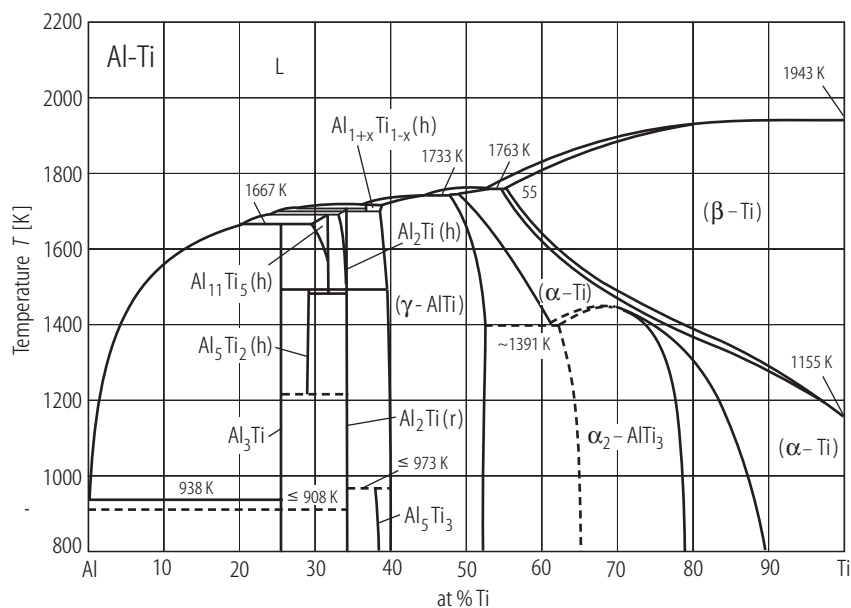


Fig. 7. Al-Ti. Calculated phase diagram taken from Braun [99 Bra].

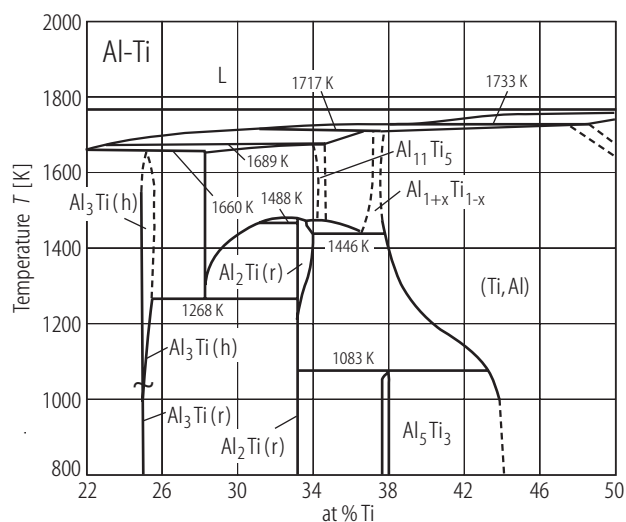


Fig. 8. Al-Ti. Phase equilibria at concentrations between 22 and 50 at% Ti taken from [99 Bra].

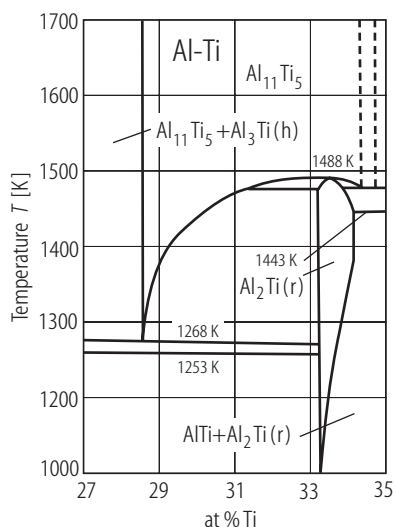


Fig. 9. Al-Ti. Phase equilibria at concentrations between 27 and 35 at% Ti [99 Bra].

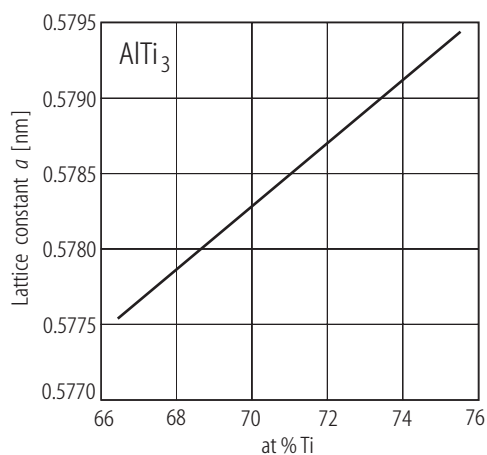


Fig. 11. Al-Ti. Lattice constant a of AlTi_3 as a function of concentration [99 Bra].

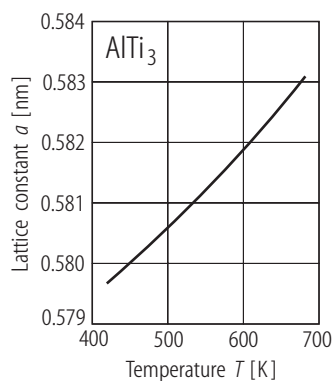


Fig. 13. Al-Ti. Lattice constant a of AlTi_3 as a function of temperature [99 Bra].

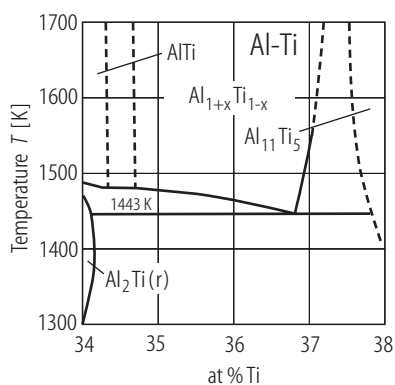


Fig. 10. Al-Ti. Phase equilibria in the concentration range between 34 and 38 at% Ti taken from [99 Bra].

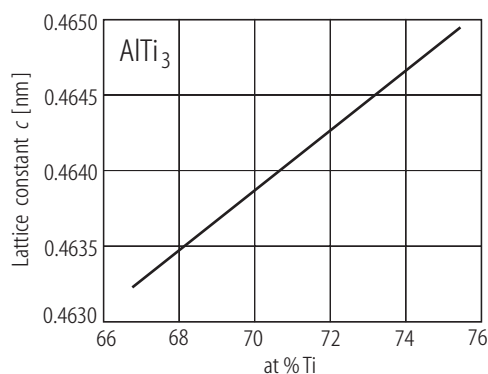


Fig. 12. Al-Ti. Lattice constant c of AlTi_3 as a function of concentration [99 Bra].

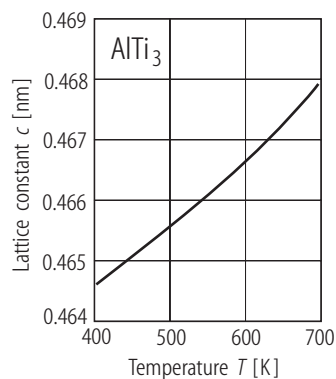


Fig. 14. Al-Ti. Lattice constant c of AlTi_3 as a function of temperature [99 Bra].

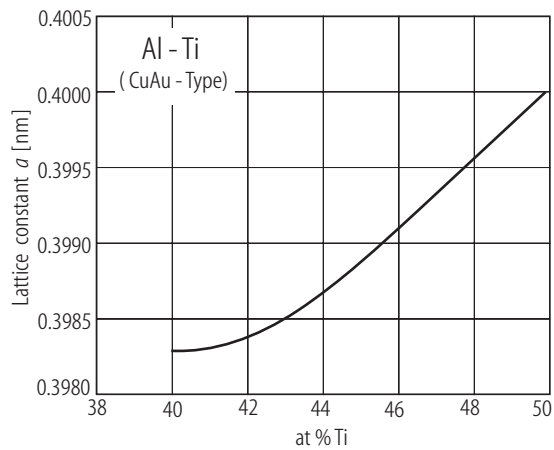


Fig. 15. Al-Ti. Lattice constant a of AlTi as a function of concentration [99 Bra].

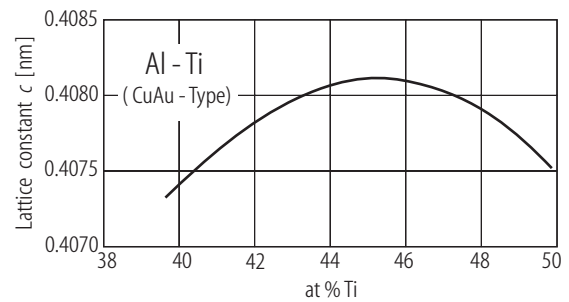


Fig. 16. Al-Ti. Lattice constant c of AlTi as a function of concentration [99 Bra].

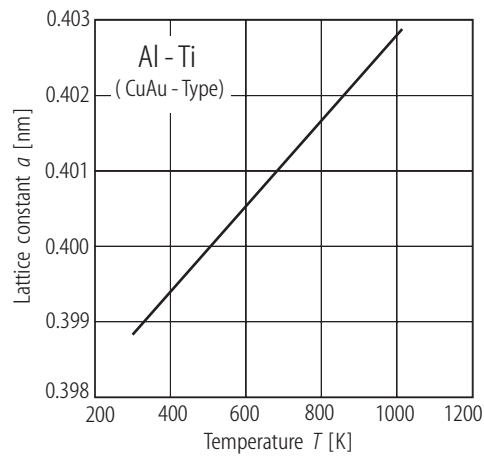


Fig. 17. Al-Ti. Lattice constant a of AlTi as a function of temperature [99 Bra].

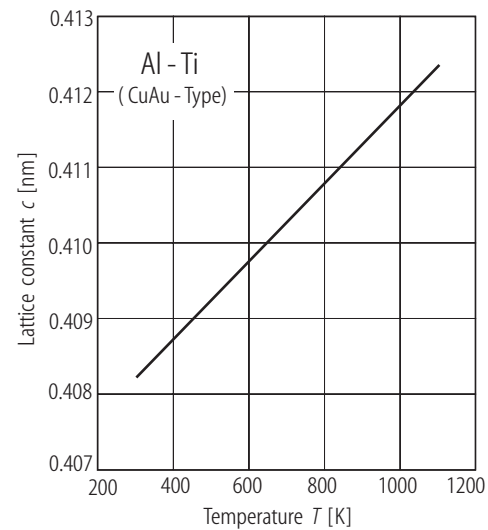


Fig. 18. Al-Ti. Lattice constant c of AlTi as a function of temperature [99 Bra].

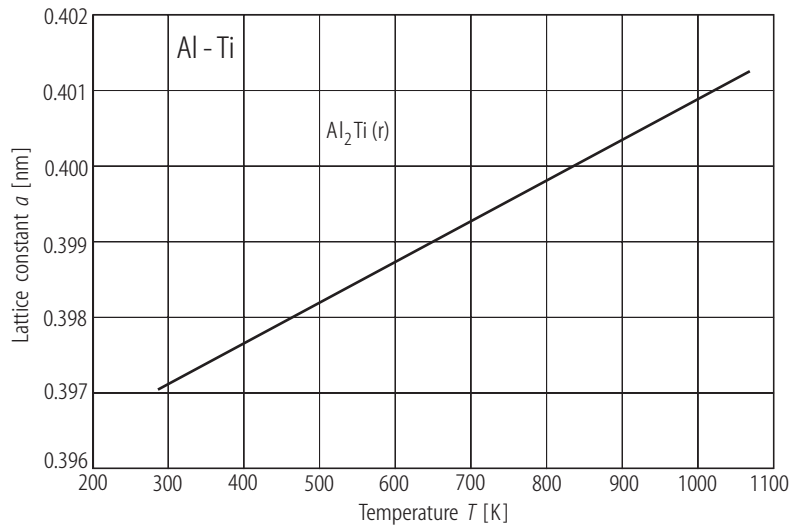


Fig. 19. Al-Ti. Lattice constant a of $\text{Al}_2\text{Ti} (r)$ as a function of temperature [99 Bra].

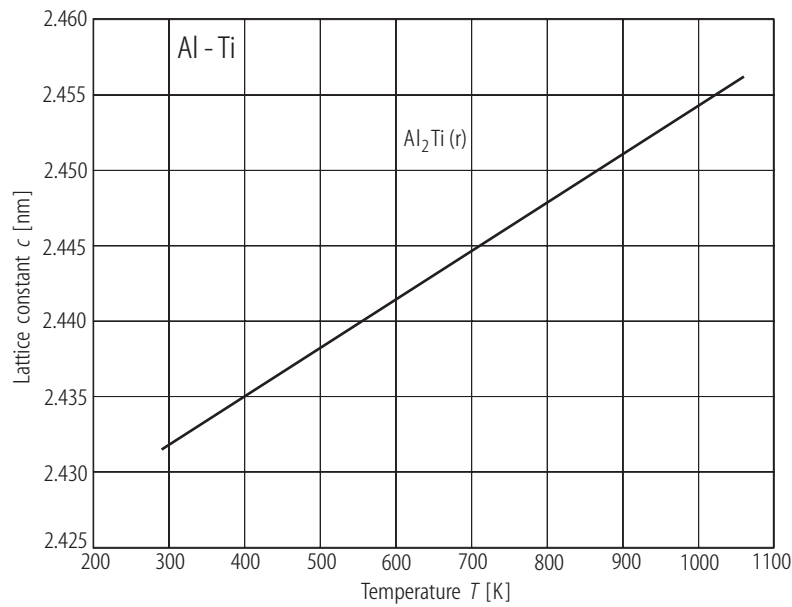


Fig. 20. Al-Ti. Lattice constant c of $\text{Al}_2\text{Ti} (r)$ as a function of temperature [99 Bra].

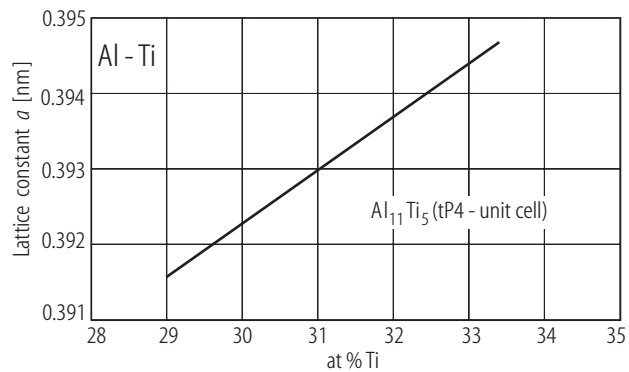


Fig. 21. Al-Ti. Lattice constant a of $\text{Al}_{11}\text{Ti}_5$ as a function of concentration [99 Bra].

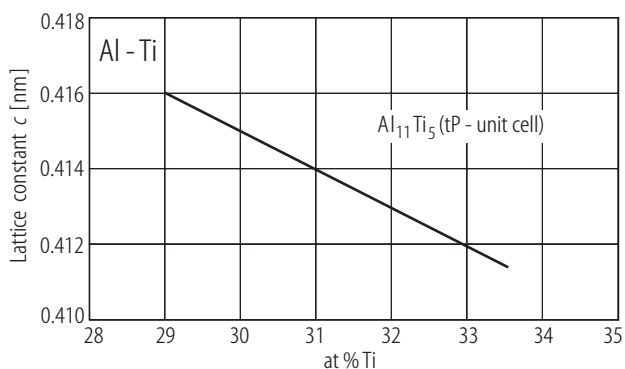


Fig. 22. Al-Ti. Lattice constant c of $\text{Al}_{11}\text{Ti}_5$ as a function of concentration [99 Bra].

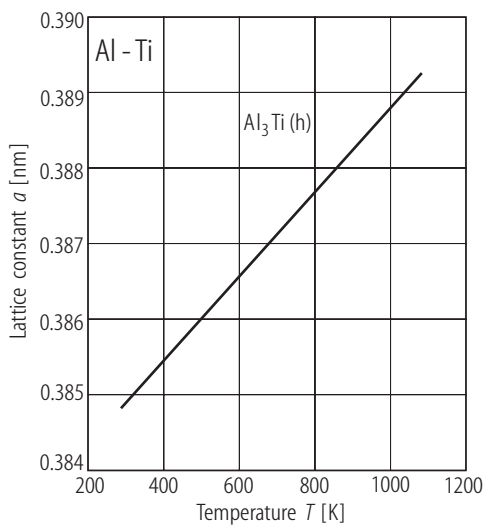


Fig. 23. Al-Ti. Lattice constant a of Al_3Ti (h) as a function of temperature [99 Bra].

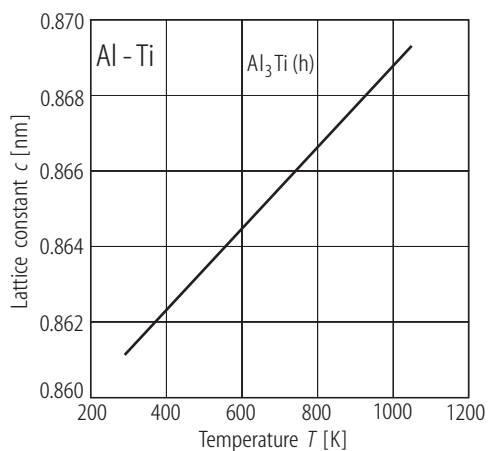


Fig. 24. Al-Ti. Lattice constant c of Al_3Ti (h) as a function of temperature [99 Bra].

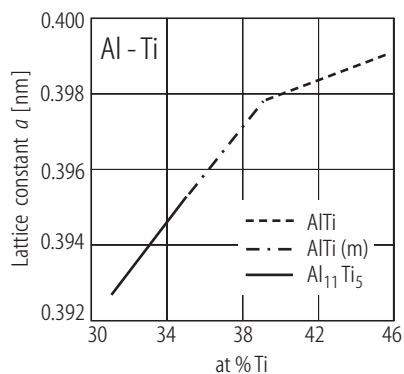


Fig. 25. Al-Ti. Lattice constant a of splat cooled samples as a function of concentration [99 Bra].

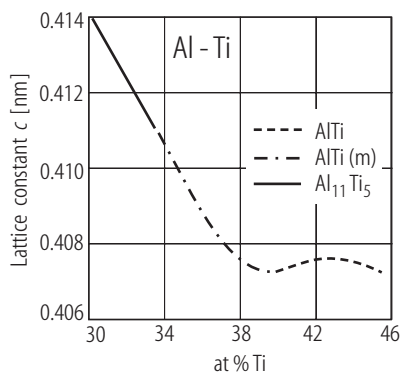


Fig. 26. Al-Ti. Lattice constant c of splat cooled samples as a function of concentration [99 Bra].

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