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Translation of "Fazovyye perekhody v uporyadochennom
soyedineniy TiAl i splavakh na ego osnove," Metallofizika,
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16. Abstract The combined effect of alloying and heat treatment on the order-disorder transition in TiAl of stoichiometric composition and in alloys in which niobium is introduced instead of titanium or aluminum atoms is studied, including the temperature dependences of the thermal expansion coefficient, hardness, internal friction and elasticity modulus of TiAl and alloys of the type (Ti, Nb)Al and Ti(Nb, Al). It is concluded from the data obtained that the TiAl I to TiAl II transition is a phase transition of the second kind. A phase transition is observed in TiAl of equiatomic composition in the 450-550°C temperature range. The introduction of niobium into the ordered compound TiAl of stoichiometric composition, instead of titanium or aluminum atoms, leads to partial softening. In this case, the effect of niobium atoms on softening of the alloys is greater when the niobium is introduced in place of aluminum atoms.

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PHASE TRANSITIONS IN THE ORDERED COMPOUND TiAl AND IN ALLOYS HAVING IT AS A BASE

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The properties of the ordered intermetallic phase of TiAl were studied in [1, 2]. An effort was made in [3] to suppress the ordering process by alloying. The effect of neutron bombardment on the "order-disorder" transitions in the compound TiAl was studied in [4]. As a result of these studies, it was concluded that the compound TiAl does not undergo any transformations, right up to the melting temperature, and that there is little likelihood of significant ordering as a result of alloying and irradiation. /99*

In this article, the combined effect of alloying and heat treatment on the "order-disorder" transition in the compound TiAl of stoichiometric composition, as well as in alloys in which niobium was introduced instead of titanium or aluminum atoms was studied. The composition of the alloys is presented in the Table.

a Номер сплава	b Сплав	c Состав сплава		
		d Титан, ат.%	e Ниобий, ат.%	f Алюминий, ат.%
1	TiAl	50	—	50
2	(49Ti + 1Nb) Al	49	1	50
3	(48Ti2Nb) Al	48	2	50
4	(45Ti5Nb) Al	45	5	50
5	(40Ti10Nb) Al	40	10	50
6	Ti (1Nb49Al)	50	1	49
7	Ti (2Nb48Al)	50	2	48
8	Ti (5Nb45Al)	50	5	45
9	Ti (10Nb40Al)	50	10	40

Key: a. Alloy No.
b. Alloy
c. Alloy composition
d. Titanium, atom %
e. Niobium, atom %
f. Aluminum, atom %

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*Numbers in the margin indicate pagination in the foreign text.

The initial materials for preparation of the alloys were titanium iodide, ABOOO aluminum and 99.8% pure niobium. The alloys were melted in a vacuum arc furnace in an argon atmosphere. Annealing was carried out in vacuum at 1100°C for 50 hours and cooling, at a rate of 2.5 degree/min. Thermal expansion was studied in a Shevenar system dilatometer. Structural studies were conducted in a URS-50I diffractometer in copper radiation. The lattice parameters were calculated by the least squares method. Internal friction was measured in an improved UIMD-2 installation [5]. /100

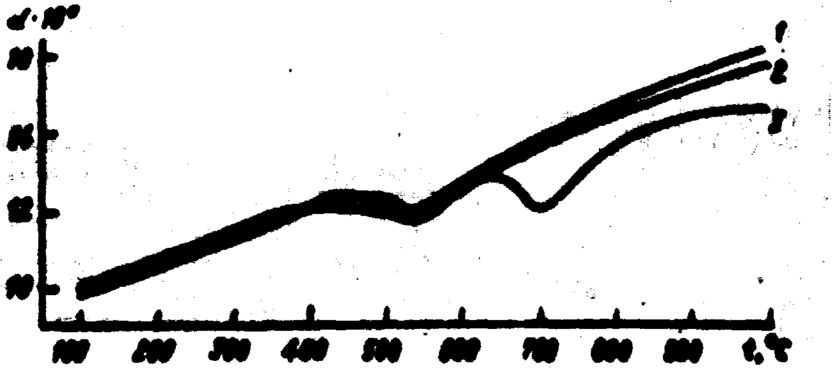

Fig. 1. Temperature vs. thermal expansion coefficient of compound TiAl: 1. hardened from 1200°C; 2. annealed at 1100°C for 50 hours; 3. hardened from 1300°C.

Fig. 1-4 show the temperature dependence of the thermal expansion coefficient (KTR) of the annealed and hardened TiAl alloys (Ti, Nb)Al and Ti(Nb, Al).

Study of the thermal expansion of the compound TiAl, as well as alloys of the types (Ti, Nb)Al and Ti(Nb, Al) revealed a common regularity, regardless of the type of alloy and niobium content. During heating, uniform expansion takes place initially and, then, in the 400-500°C temperature range, the thermal expansion coefficient decreases sharply.

Comparison of the anomalous effects at 400-550°C for the TiAl alloys Ti(Nb, Al) and (Ti, Nb)Al with varied niobium content and different preliminary heat treatment shows that the minimum effect appears in the compound TiAl. As a result of subsequent hardening from temperatures of 1000-1300°C, on the $\alpha = f(t^{o})$ curves (see Fig. 1), a tendency is observed towards some increase in the effect. The introduction of niobium into the compound TiAl has a similar effect. The higher the niobium content, the more distinctly expressed is the effect for the annealed alloys (see Fig. 2, 4 curve 3).

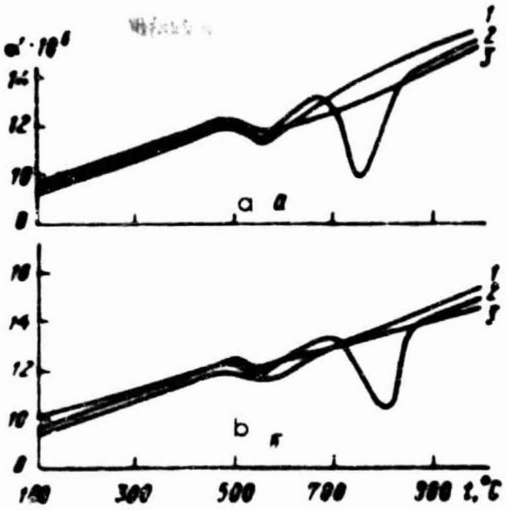

Fig. 2. Temperature vs. thermal expansion coefficient: 1. hardened from 1200°C; 2. hardened from 1300°C; 3. from 1100°C for 50 hours; a. (40 atom % Ti, 10 atom % Nb)Al; b. (45 atom % Ti, 5 atom % Nb)Al.

The hardness of the annealed alloys of the (Ti, Nb)Al type vs. temperature shows that, in the temperature interval in which a sharp change of the thermal expansion coefficient is observed on the dilatometer curves, the hardness of the alloys increases (Fig. 5).

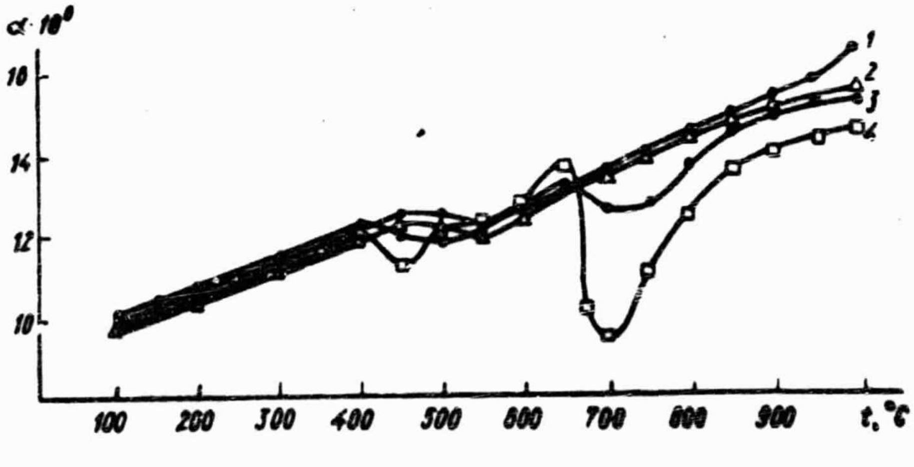

Fig. 3. Temperature vs. thermal expansion coefficient of [Ti(1 atom % Nb, 49 atom % Al)]: 1. annealed at 1100°C for 50 hours; 2. hardened from 1100°C; 3. hardened from 1200°C; 4. hardened from 1300°C.

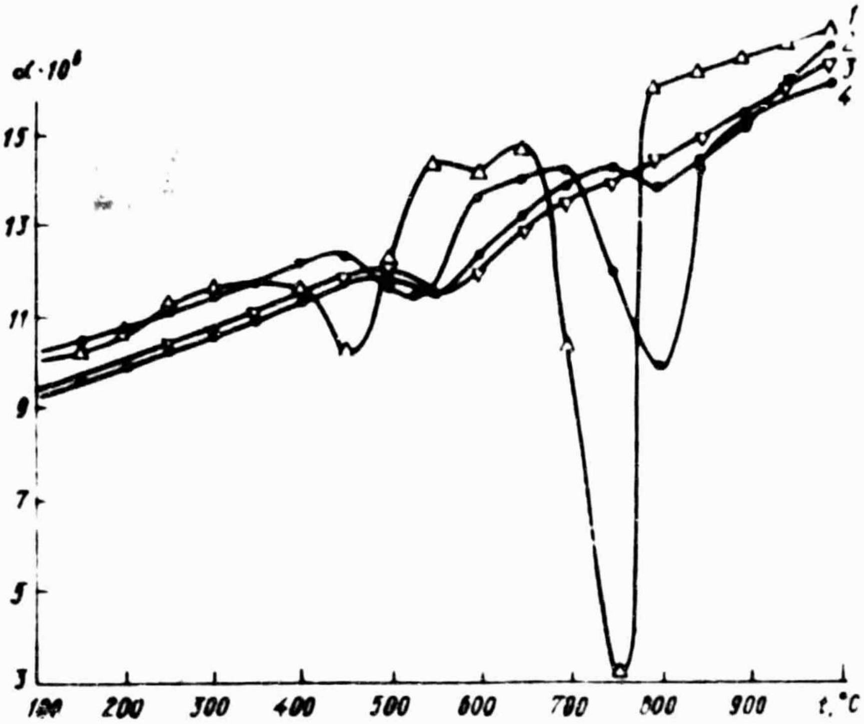

Fig. 4. Temperature vs. thermal expansion coefficient of Ti(10 atom % Nb, 40 atom % Al): 1. hardened from 1300°C; 2. hardened from 1100°C; 3. annealed at 1100°C for 50 hours; 4. hardened from 1200°C.

The temperature dependence of internal friction and elasticity modulus of the annealed alloys No. 6 and 8 (see table) is presented in Fig. 6.

Studies of temperature vs. electrical resistance show that, in the 400-500°C interval, some increase of resistance is observed, both in the annealed and in the hardened alloys (Fig. 7).

Thus, it can be concluded that the anomalous behavior of the coefficient of thermal expansion, hardness, internal friction, modulus of elasticity and electrical resistance, which appear in the 400-550°C range, indicates that, at some temperature (T_{cr}), a TiAlI→TiAlII transition occurs in the compound TiAl and alloys having it as a base. /101

The X-ray phase analysis method we used did not bring out any

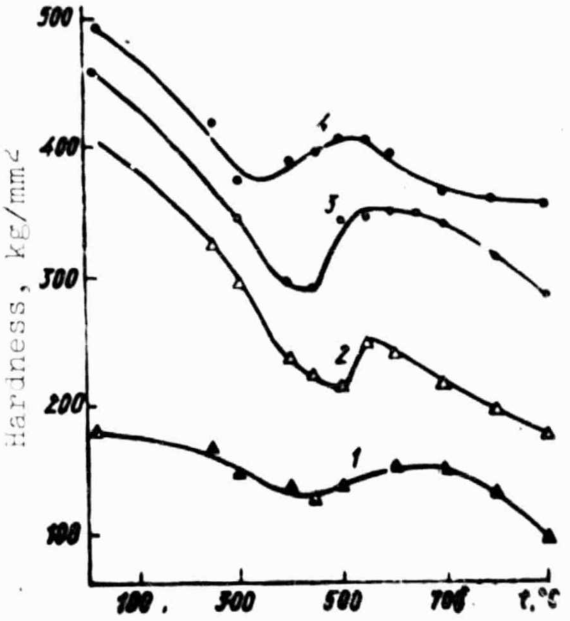

Fig. 5. Temperature vs. hardness: 1. TiAl; 2. (48 atom % Ti, 2 atom % Nb)Al; 3. (40 atom % Ti, 10 atom % Nb)Al; 4. (45 atom % Ti, 5 atom % Nb)Al.

differences in the diffraction pattern of specimens annealed and hardened from $T>T_{cr}$. In both cases, a $L1_0$ type superstructure was observed. On thermograms of the compound TiAl and alloys having it as a base, there are no effects connected with the absorption or the release of heat at $T=T_{cr}$.

The lack of a thermal effect, the abrupt change of the linear expansion coefficient in the phase transition interval and the impossibility of supercooling the high temperature TiAlII phase in the region of existence of the TiAlI phase permit the TiAlI→TiAlII transition to be classified as a phase transition of the second kind 6 .

Hardening of the alloys from $T>T_{cr}$, in all cases, leads to an increase of the effect, compared with the annealed state (see Fig. 1-4) and, for alloys No. 6-9 (see table) hardening from T=1300°C leads to a decrease of the transition onset temperature to 400°C (see Fig. 3 curve /102
4, Fig. 4 curve 1). In the Ti alloy (40 atom % Al, 10 atom % Nb), a decrease of the transition onset temperature is observed after hardening from T=1200°C.

A similar decrease of the onset temperature of the transition TiAlI TiAlII is connected with the fact that hardening takes place from a temperature above the "order-disorder" transition temperature, i.e., from the partially disordered state.

The replacement of titanium or aluminum atoms in the compound TiAl of equiatomic composition by niobium atoms leads to an increase in the

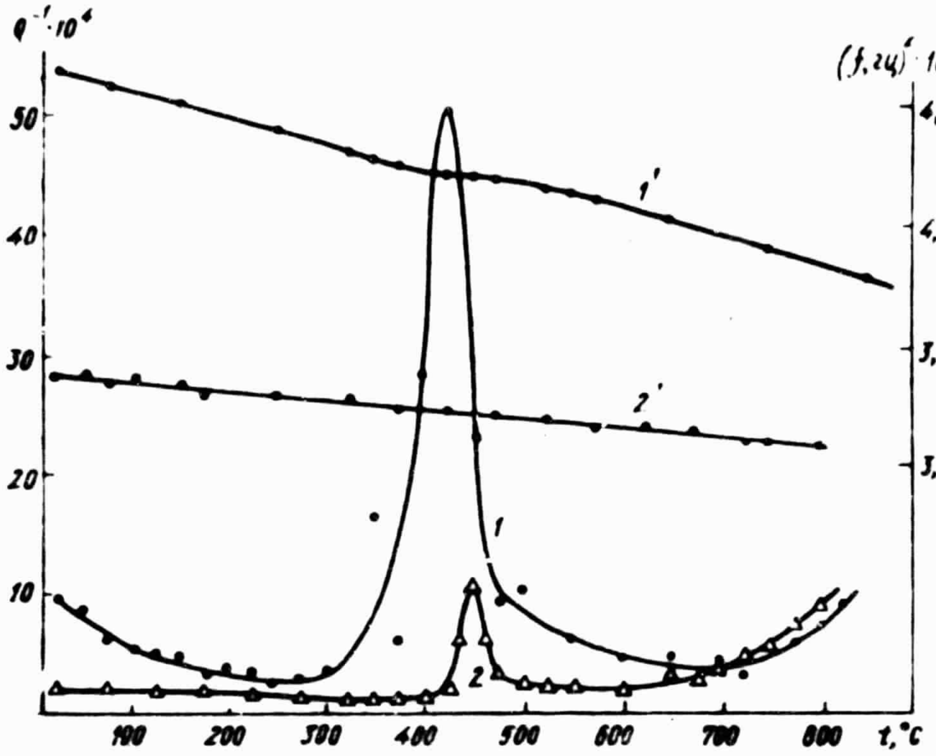

Fig. 6. Temperature vs. internal friction and square of frequency for annealed alloys: 1., 1'. Ti(1 atom % Nb, 49 atom % Al); 2, 2'. Ti(5 atom % Nb, 45 atom % Al).

Key: a. $(f, Hz)^2 \cdot 10^{-5}$

effect on the $\chi=f(t^{\circ})$, $H=f(t^{\circ})$ curves.

The phase transition onset temperature in this case is shifted toward higher temperatures (for TiAl, 450° C, for alloys with 10 atom % Nb, 500°C).

X-ray phase analysis of the "order-disorder" transition in the compound TiAl and alloys having it as a base shows that the introduction of niobium into TiAl and an increase of its content to 10 atom % leads to partial concentration disorder (in this case, the alloy remains single phase): the degree of tetragonality changes from 0.989 for 50 atom % Ti, 50 atom % Al to 0.994 for the alloy (40 atom % Ti, 10 atom % Nb)Al. In this case, just as for the alloy CuAu [6], upon approaching the "order-disorder" transition point, parameter a of the tetragonal lattice decreases, while parameter c increases.

The sharp increase of the thermal expansion coefficient of hardened alloys in the 650-800°C region (see Fig. 1-4) is connected with ordering of the partially disordered alloys. An increase in niobium content leads to an increase in the effect and a decrease in the "order-disorder" transition temperature in Ti(Nb, Al). type alloys.

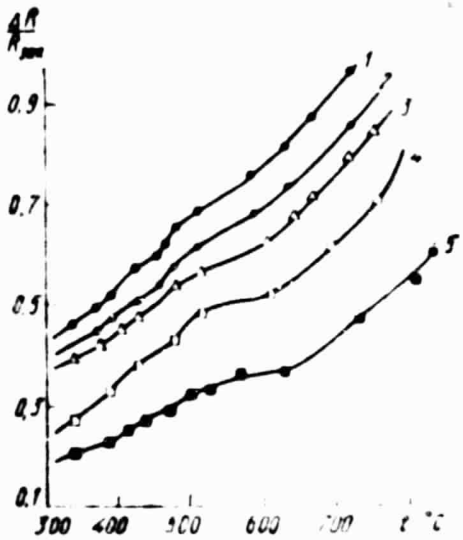

Fig. 7. Temperature vs. electrical resistance of alloys hardened from 1000°C: 1. TiAl; 2. (49 atom % Ti, 1 atom % Nb)Al; 3. (48 atom % Ti, 2 atom % Nb)Al; 4. (45 atom % Ti, 5 atom % Nb(Al; 5. (40 atom % Ti,10 atom % Nb)Al.

A comparison of the results of study of the ordering process in alloys of the (Ti, Nb)Al and Ti(Nb, Al) types reveals a stronger effect of niobium in the "order-disorder" /103 transition, in the case of substitution of aluminum atoms by niobium. While, in (Ti, Nb)Al type alloys, disordering begins in the 1200-1300°C interval (Fig. 2, curve 1), in which an increase of niobium content from 1 atom % to 10 atom % does not significantly affect disordering, in Ti(Nb, Al) type alloys, the introduction of even 1 atom % Nb leads to a decrease of the disordering onset temperature to ~1150°C and, in the Ti(10 atom % Nb, 40 atom % Al) alloy, disordering begins at ~980°C.

This effect of niobium may be associated with the dimensional factor (radius of the titanium ion is 0.64 A, niobium 0.78 A, aluminum 0.57 A), according to the data of [7].

The decrease in "order-disorder" transition temperature in Ti(Nb, Al) type alloys with increase in niobium content indicates that, as follows from 6 , the niobium atoms occupy the place of aluminum atoms in the lattice and energies $_{\mathrm{Ti,\ Nb}}$ and $_{\mathrm{Al,\ Nb}}$ are close to each other.

Conclusions

1. A phase transition is observed in the compound TiAl of equiatomic composition, in the 450-550°C interval.

2. Hardening from $T > T_{cr}$ does not fix the high temperature phase, and it does not change the nature of the $\alpha = f(t^{o})$, $H = f(t^{o})$ curves, but an increase of the hardening temperature and the introduction of niobium into the compound TiAl lead to some increase in the effect.

3. The introduction of niobium in place of titanium or aluminum atoms in the ordered compound TiAl of stoichiometric composition leads to partial disordering. A stronger effect of the niobium atoms on disordering of the alloys was found, in the event niobium was introduced in place of aluminum atoms.

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