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STRUCTURE AND PROPERTIES OF SEMIFINISHED SHEET PRODUCTS MADE OF AN INTERMETALLIC REFRACTORY ALLOY BASED ON Ti_2AlNb

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We study the influence of two-stage thermal treatment on the formation of the phase composition, structure, and mechanical properties of semifinished sheet products made of VTI-4 refractory alloy based on the Ti_2AlNb intermetallic compound. It is shown that, changing the temperature of heating in the first stage of treatment and the temperature of subsequent aging, it is possible to affect the strength and plasticity characteristics of the material in broad ranges. It is demonstrated that, in order to obtain a structure guaranteeing a relative elongation of 8–12%, the temperature of the first stage of treatment must remain in the $(\beta + \alpha_2 + O)$ three-phase region and the procedure of cooling down to room temperature or to the temperature of the second stage of treatment (800–850°C) should be realized together with the furnace. To get high levels of short- and long-term strength at 650°C with preservation of moderate values of plasticity (3–5%), it is necessary to perform cooling after isothermal treatment in the three-phase region in air. The subsequent procedure of aging should be carried out within the temperature range 800–850°C for 7 h.

Keywords: refractory titanium ortho-alloy, thermal treatment, structure, phase composition, strength, plasticity.

Recent years are marked by the extensive investigations and technological advances aimed at the creation and implementation of refractory alloys based on titanium aluminide and intended for long-term operation within the temperature range 600–700°C under the conditions of intense corrosive action of gas atmospheres and high alternating loads. These materials have higher specific strengths at temperatures of up to 700°C than nickel alloys and refractory steels. Moreover, they have better ranges of working temperatures than the commercial refractory titanium alloys [1–3].

To improve the mechanical properties of Ti_3Al and TiAl intermetallic compounds, it is customary to perform their multicomponent alloying with active refractory β-stabilizing elements (Nb, Mo, V, Ta, and W) enhancing the elastic and strength characteristics of the analyzed materials and reducing the intensity of oxidation.

In recent years, the alloys based on TiAl (gamma-alloys) prove to be most promising under the conditions of ultimate working temperatures. They are characterized by high heat resistance but have extremely low characteristics of plasticity at room temperature [4, 5]. The alloys based on the Ti_3Al intermetallic compound (super-alpha-2-type alloys) are deformed in the hot state but only for low levels of strains and rates and have quite poor casting properties [6, 7].

At present, the ortho-alloys based on the Ti_2AlNb intermetallic compound are regarded as be most promising. Moreover, they can be used as an alternative to fire-dangerous titanium alloys [8–10]. The main advantage

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of ortho-alloys over the alloys based on Ti_3Al and TiAl is their higher technological plasticity, which enables one to produce deformed semifinished products and blanks of complex shapes. Among the main technological problems, we can mention not only the necessity to guarantee the homogeneous chemical composition of ingots [11] and optimize the parameters of hot deformation for getting high-quality semifinished products [12, 13] but also the requirement to justify (from the scientific point of view) the choice of the modes of their heat treatment intended to get the desired structural and phase state of the material and a complex of its mechanical properties.

In what follows, we study the influence of the modes of heat treatment on the formation of the structure and properties of semifinished sheet products made of VTI-4 titanium ortho-alloys.

Materials and Methods

As a source material in our investigations, we used semifinished sheet products 10 mm in thickness made of the refractory VTI-4 ortho-alloy based on the Ti_2AlNb intermetallic compound (Ti–11Al–40Nb–1.5Zr–0.75V–0.75Mo–0.2 wt.% Si) obtained by an experimental-industrial technology at the "Chepetskii Mechanical Plant" Joint-Stock Company by forging first in the β-region and then in the (β + O)-region.

Heat treatment was carried out in a SNOL-1,6.2,5.1/9-I4 furnace in an atmosphere of air. The microstructure was studied by metallographic methods with the help of an Axio-Observer-A1m optical microscope. The images of the microstructure were processed by using the ImageExpert Pro-3 specialized software. The X-ray phase-diffraction analysis was carried out in a DRON-7 diffractometer in the filtered CuK_α-radiation.

We used a TIRA-Test-2300 general-purpose testing machine for short-term mechanical tensile tests at normal temperature (according to GOST 1497-84), an IR-5113 machine for short-term mechanical tensile tests at a temperature of 650°C (according to GOST 9651-84), and a ZST2/3-VIET machine for the investigation of long-term strength at 650°C (according to GOST 10145-81).

Results and Discussion

The procedure of heat treatment of refractory titanium alloys must guarantee the formation of thermally stable structures. It usually includes two stages: a high-temperature stage and a low-temperature stage. Moreover, in the second stage, the temperature must be higher than the operating temperature by at least 50–100°C [14]. We studied the influence of the temperatures of both stages on the formation of the structure and the properties of the semifinished sheet products of VTI-4 alloy.

We used the method of trial hardening to determine the temperature ranges of its phase regions [15]. Indeed, at temperatures above 1050°C there exists a β(B2) region; the biphase $(\beta + \alpha_2)$ region exists within the range 1000–1050°C, the three-phase $(\beta + \alpha_2 + O)$ region exists at 980°C, and the biphase $(\beta + O)$ region is formed within the range 950–800°C. These data are used as basic in choosing the temperature of heat treatment of semifinished sheet products.

After the high-temperature stage of treatment (at a temperature lower than the temperature of polymorphic transformation), a metastable phase is formed in the structure of the alloy. The higher the temperature of heating, the greater the amount of high-temperature metastable phase recorded in the alloy in the case of accelerated cooling. This is why we choose two temperatures: 1020°C corresponding to the biphase $(\beta + \alpha_2)$ region, and 980°C corresponding to the three-phase $(\beta + \alpha_2 + O)$ region. After heating, the castings were held for 1 h, cooled in air to normal temperature (Fig. 1), and then aged at 800°C for 7 h.

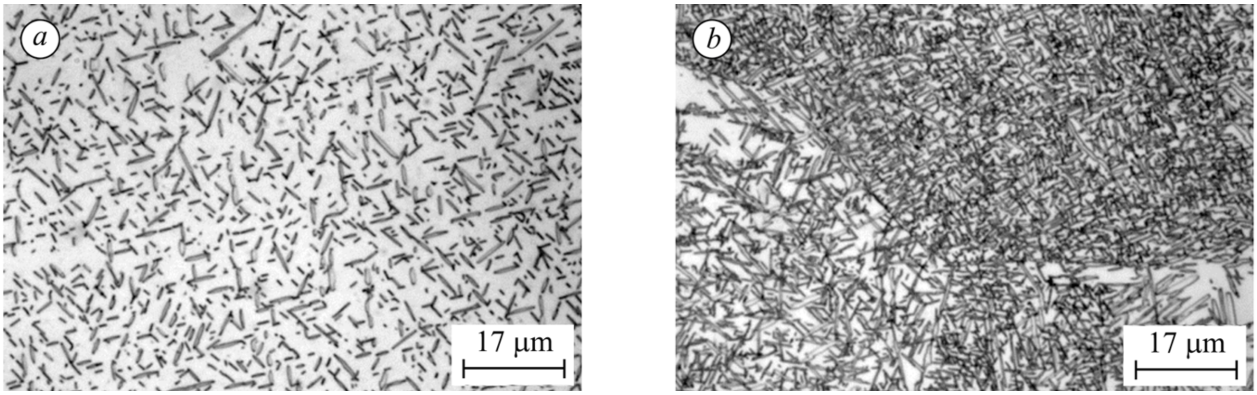

Fig. 1. Microstructures of VTI-4 alloy after cooling in air from temperatures of 1020 (a) and 980°C (b).

Table 1. Influence of the Temperature of Heating in the First Stage of Heat Treatment on the Mechanical Properties of the Specimens of VTI-4 Alloy after Aging at 800°C for 7 h

Heating temperature, °C	σ_u	$\sigma_{0.2}$	δ	ψ
	MPa		%	
980	1170	1080	3.0	5.6
1020	1190	1120	1.4	3.0

The specimens for the metallographic and X-ray phase-diffraction analyses and for the determination of the short-term mechanical properties at normal temperature were cut out from the blanks. It was established that the strength of material increases with the temperature of heating in the first stage of treatment. This is explained by the increase in the amount of the metastable β (B2)-phase in the structure. Moreover, this phase may decay in the course of subsequent aging (Fig. 1). Note that the level of plasticity decreases as the strength of the material becomes higher (Table 1).

After preheating to 980°C, the specimens acquire the maximum values of the relative elongation and relative narrowing. This is why the influence of the temperature of aging on the mechanical properties of VTI-4 alloy was investigated on specimens heated, in the first stage of treatment, to 980°C. The procedure of aging at 750°C for 7 h leads to a noticeable increase in the characteristics of strength accompanied by a decrease in the relative elongation to 0.4%, which is explained by the finely-divided structural state of the O-phase formed under the conditions of isothermal holding (Fig. 2a).

As the aging temperature increases to 850°C, the strength gradually decreases but the level of plasticity δ increases (for up to 5%) due to the growth of the structural components of the α_2- and O phases (Figs. 2b, c; and Table 2).

Thus, it is shown that, by varying the temperature of heating in the first stage of treatment and the temperature of subsequent aging, one can change the strength and plasticity characteristics of the VTI-4 alloy in broad ranges. In this case, the closer the temperature of the first stage of treatment to the temperature of polymorphic transformation, the higher the strength of the alloy after aging and the lower the plasticity of the alloy.

Alloys based on titanium and titanium aluminides are quite sensitive to rates of heating and cooling. In view of the low thermal conductivity, high thermal stresses leading to the distortion or even cracking of the specimens

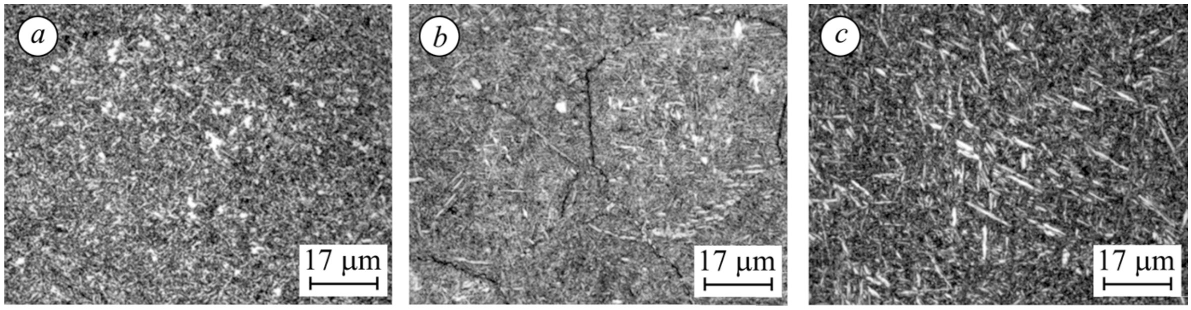

Fig. 2. Microstructures of the specimens of VTI-4 alloy after aging for 7 h at 750 (a), 800 (b), and 850°C (c). The specimens were preliminarily cooled in air from 980°C.

Table 2. Influence of the Temperature of Aging on the Mechanical Properties of the Specimens of VTI-4 Alloy

Temperature, °C	Cooling after holding for 1 h at 980°C	σ_u	$\sigma_{0.2}$	δ	ψ
		MPa		%	
750	In air	1310	1295	0.4	2.2
800		1170	1080	3.0	5.6
850		1090	960	5.0	9.4
750	With the furnace, down to room temperature	1030	920	7.4	9.4
800		1010	830	8.0	10.5
850		990	790	12.0	14.8

may appear in the material in the course of accelerated heating or cooling. This is why, in what follows, we investigate the formation of structures and their influence on the mechanical properties of specimens subjected to furnace cooling (after high-temperature treatment).

The specimens were treated according to two schemes: The first scheme includes heating to 980°C, furnace cooling down to room temperature with subsequent aging at 750, 800, and 850°C. According to the second scheme, the specimens were cooled from 980°C to the temperature of the second stage and held for 7 h. In both cases, the specimens were cooled from the temperature of the second stage of treatment to room temperature in air. The procedure of furnace cooling after holding for 1 h at 980°C results in a more complete realization of phase transformations and the release of larger amounts of the O-phase as compared with the procedure of cooling in air from the same temperature (Figs. 3a and 2b). In the case of slow cooling from the high-temperature stage of treatment followed by aging at different temperatures, we observe the formation of structures of almost the same type (Fig. 3). As a result, we get close values of strength of the alloy (Table 2). However, the level of plasticity noticeably increases as the temperature of aging increases (Table 2).

After slow cooling from the high-temperature stage to the temperature of aging and subsequent isothermal holding, we observe the formation of the same structures and properties as in the case of furnace cooling to room temperature with subsequent aging.

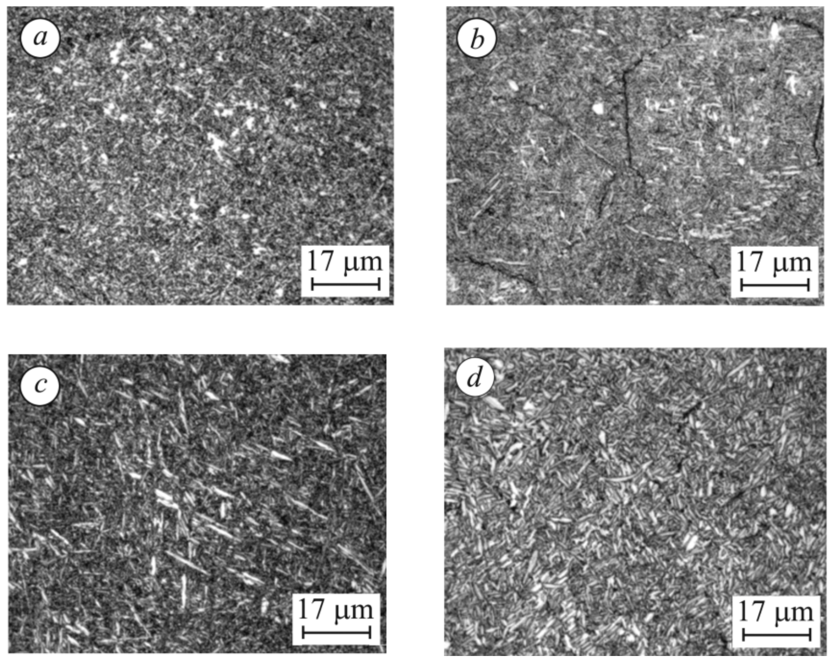

Fig. 3. Microstructures of the specimens of VTI-4 alloy after furnace cooling from 980°C down to room temperature (a) with subsequent aging for 7 h at 750 (b), 800 (c), and 850°C (d).

We now assess solely the refractory properties of the alloy. For this purpose, we choose two modes of treatment: heating to 980°C, holding for 1 h with subsequent cooling in air to room temperature and aging at 800 and 850°C for 7 h. The investigations for short-term strength carried out at 650°C show that the specimens fail under stresses of 910 and 880 MPa, respectively.

We also performed long-term strength tests for the specimens after heat treatment in the chosen modes for 100 h at 650°C under a load of 350 MPa. They all failed after holding for more than 100 h.

CONCLUSIONS

Thus, we conclude that, in order to get the elevated plasticity of VTI-4 alloy, it is necessary to perform the first stage of treatment in the three-phase region $(\beta + \alpha_2 + O)$ with subsequent slow cooling to the temperature of the second stage. To attain high values of the short- and long-term strengths at elevated temperatures, it is necessary to cool the specimens after isothermal holding in the three-phase region in air and perform aging within the range 800–850°C.

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