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The preparation of the Ti-Al alloys based on intermetallic phases

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Abstract. This article deals with a method of obtaining materials in the Ti-Al system. Research was carried out in accordance with the phase diagram of the system state. It was established, that both single-phase and multiphase systems, containing finely dispersed intermetallic compositions of phases Ti_3Al, TiAl and $TiAl_3$, are formed. Additionally, it was found that the pure finely dispersed (coherent-scattering region (CSR) up to 100 nm) intermetallic compound $TiAl_3$ is formed at molar ratio of Ti:Al = 1:3. Experimentally proved the possibility of produce the complex composition of alloys and intermetallic compounds and products based on them.

1. Introduction

The titanium and titanium alloys are widely used in industrial production due to their properties such as: prevalence in nature, low density, high specific strength, corrosion and heat resistance.

It is known, that aluminum is the main alloying element for titanium that is associated with the ability to increase the temperature of titanium allotropic transformation and to enhance the solubility of isomorphous and eutectic-forming β-stabilizers.

The alloys obtained by aluminum doping have the significant advantages over The other alloying components. The density of the aluminum is much less than the density of titanium, so the addition of aluminum increases the specific strength of alloys. Moreover, under enhancing of aluminum content in alloys the heat resistance of the alloys and the elastic modulus are increased, and the tendency to hydrogen embrittlement is decreased. In addition, it makes titanium alloys more sensitive to the salt corrosion and it reduces their technological plasticity [1].

The system Ti-Al is the basis system of the many titanium alloys due to its high functional properties. This system is widely used in aerospace, chemical and petrochemical industries. Alloys of Ti-Al system, based on intermetallic compounds, are more perspective materials for the engines of new generation. The layered metal-intermetallic titanium-aluminum composites, including intermetallic phases, are particularly attractive for industries and scientists. It is related to the fact that these composite materials are able to operate at high temperatures and mechanical loads [2, 3].

Depending on the temperature of the intermetallic interlayers formation under the thermo-power influences on the original layered titanium-aluminum the composite aluminide layers can be produced. They can be singlphasic or biphasic, consisting of an aluminum matrix and the ordered particles of the thermodynamically probable of the aluminide $TiAl_3$ [4].

At the different temperatures of the intermetallic interlayers formation, under thermo-power influences on the original layered titanium-aluminum composite, various types of aluminide layers can be produced. Such as: singl- and biphasic layers

According to the Ti-Al phase diagram, in the system can be up to seven stable intermetallic phases. The most stable intermetallic phases, that increase the physico-mechanical properties of titanium aluminide, are γ-TiAl, α2-Ti_3Al and γ-TiAl + α2-Ti_3Al [4 - 6]. Sometimes in modern diagrams of binary alloys of titanium – aluminum system, not only four well-established phases α2(Ti_3Al), γ(TiAl), $TiAl_2$ and $TiAl_3$, but also Ti_5Al_{11}, Ti_2Al_5 are present [5].

The presence of thermodynamically stable intermetallic phases in composite materials permits significantly enhances the physical and mechanical characteristics of the systems. The direction, connected with the choice of an optimal method of producing composite Ti-Al system based on intermetallic phases, is important [4, 6, 7]. In traditional metallurgy of titanium its alloys with aluminum are prepared by melting the components or by method of powder metallurgy. The common method for obtaining Ti-Al alloys is aluminothermic reduction by out-of-furnace method [8]. The inability to precisely control the parameters of the process during the melting, the high cost of a large number of thermite additives, which consumes aluminum, low productivity of the process all these components are very important disadvantages of the out-of-furnace metallurgy.

The examined method of obtaining the alloys of refractory metal is to compact the mixture of powders of metal hydrides with further dehydrogenation [9, 10]. On the other hand this method has some disadvantages which are connected with the technological peculiarities and the high energy consumptions.

In this paper, a new method of producing complex composite materials of Ti-Al system is proposed. This method allows to prepare the systems with predetermined composition and with thermodynamically stable intermetallic phases of Ti-Al system, according to the phase diagram of the binary system. The preparation of the materials consists of three consecutive stages: obtaining of the titanium hydride; pressing the powders of hydride and aluminum; kilning at the predetermined temperature.

This article presents the data on the obtaining of samples of alloys of Ti-Al under varying the weight ratio of titanium and aluminum (from 55.83 to 100 wt. % Al). The purpose of this work is to obtain the new materials of Ti-Al system, investigate its structure and phase composition.

2. Materials and Methods

The titanium hydride was produced from titanium sponge (CAS 7440-32-6). A weighed amount of the titanium was placed in a quartz boat and heated in a furnace (Nabertherm RS 120/750/13) in the hydrogen stream. The heating rate of the furnace was 10°C / min to 375-450°C with a hydrogen volume flow 500-800 ml/min. This sample was held for 0.5-1.5 h at this temperature, then it was heated to 800-1050 C at the hydrogen volume flow 1000-2000 ml/min, after that it was cooled down to room temperature. The obtained titanium hydride was mixed with a nano-dispersed aluminium powder (according to the manufacturer, the average size of AlNP particles was 115 ± 10 nm, specific surface area – 19.4 ± 3 m^2/g, loading of active aluminium – 80.8 ± 0.6 %) and pressed (HERZOG TP-60) under a pressure 10-20 tones/sm^2. A round plate with a diameter of 20 mm and a thickness of 2 mm was formed. These samples were exposed to the thermo-programmed heat-treating (800-1050 °C) in the quartz boat.

The samples were obtained in a vacuum system. X-ray analysis of the titanium-based composites were carried out with diffractometer Rigaku Miniflex 600 with CuKα-radiation in the range of 10º-90º

(2θ) with a step scan 0.02º and the rate of registration - 2 deg/min. Identification of the diffraction peaks, calculation the areas of coherent scattering (CSR) were carried out via JSPDS database.

3. Results and Discussions

A series of samples, under variation of the ratio of the elements, were obtained by the method described above (Table 1). The choice of components and composition of the mixture corresponds to the phase diagram of Ti-Al.

Table 1. The composition of the alloys of the system Ti-Al

Sample	Mixture, wt.%		Molar relation in mixture
	Ti	Al	
1	100	0	Ti
2	44.17	55.83	5Ti : 11Al
3	36.72	63.28	Ti : 3Al
4	34.31	65.69	3Ti : 10Al
5	23.5	76.5	2Ti : 11Al
6	0	100	Al

Figure 1 (Ti-Al phase diagram) shows which phases are to be expected at equilibrium for different combinations of aluminium content (expressed in atomic %) and temperature (in °C). For farther investigation and for synthesis were chosen composition that marked at the Figure 1: samples N1, 2, 4, 5, 6 were exposed to annealing at temperature of 1050° C, sample N3 – at 800 °C.

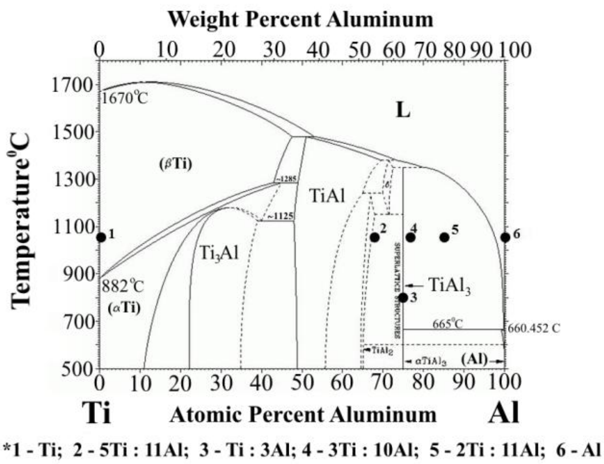

Figure 1. Ti-Al phase diagram. The synthesized systems: *1* – Ti, T_{an} =1050 °C; *2* - 5Ti: 11Al, T_{an} =1050 °C*; 3* - Ti: 3Al, T_{an} =800 °C; *4* - 3Ti: 10Al, T_{an} =1050 °C; 5 - 2Ti: 11Al, T_{an} =1050 °C*; 6* – Al, T_{an} =1050 °C.

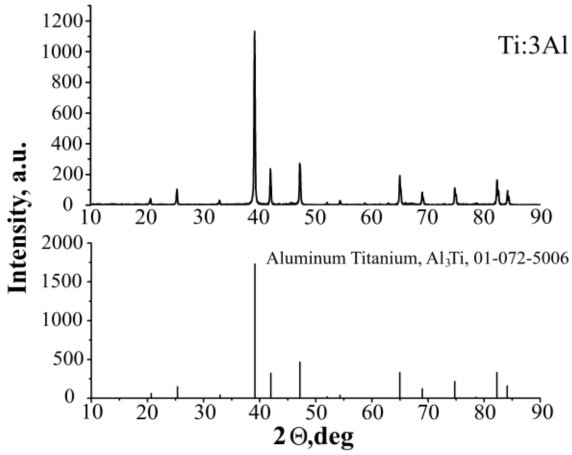

Figure 2. X-ray diffraction of Ti-Al alloy at the molar ratio Ti : 3Al. T_{an} = 800 °C.

Using this method the sample was obtained in a molar ratio Ti: 3Al. $TiAl_3$ compound was obtained under synthesis conditions described earlier, and a yield was about 100% (Figure 2). According to the X-ray phase analysis it is a single-phase product $TiAl_3$ (PDF № 01-072-5006) with dimetric system and lattice parameters: a = b = 3.8503 nm and c = 8.6091 nm. CSR calculation showed that there are particles with size from 39 to 74 nm in this sample.

According to the data presented on Figure 3 the sample with molar ratio Ti:Al=3:10 is a mainly (99 %) stable AlTi3 phase presented (PDF № 00-052-0859). It has dimetric system and lattice parameters: a = b = 5.7968 nm, c = 4.6567 nm. The CSR are from 8 to 24 nm.

The sample that was synthesized at a molar ratio Ti:Al=2:11, according to XRD, contains the next mixture of phases: 16 wt. % $TiAl_3$ (PDF number 01-079-5718) with dimetric system (a = b = 3.7994 nm and c = 8.4566 nm), 18 % mass. Ti_3Al (PDF number 00-052-0859) with hexagonal system (a = b = 5.8083 nm and c = 4.6595 nm), 64 wt. % Ti (PDF number 00-044-1299) with hexagonal system (a = b = 2.9703 nm and c = 4.6837 nm) and 2 % mass. $AlTi_2$ (PDF number 00-029-0095 with hexagonal system (a = b = 2.9947 nm, c = 13 5861 nm). At the molar ratio Ti:Al=2:11 the sample is presented as the mixture that contains: 58 wt. % $TiAl_2$ (PDF № 01-072-9142) with tetragonal system (a = b = 3.7994 nm, c = 24.2955 nm), 40 wt. % Ti_3Al_5 (PDF № 03-065-9789) with orthorhombic system (a = 4.0322 nm, b = 3.9135 nm, c = 4.0483 nm) и 2 wt. % (PDF № 01-075-9784) with hexagonal system (a = b = 2.9905 nm, c = 13.5660 nm). It should be noted that the all phases correspond to the state diagram. They are characterized by the parameters of the crystal lattice according to the theoretical values. According to the analysis of XRD spectra it was show that the all phases are characterized by CSR to 100 nm and the low degree of stress. This fact shows that by this method the difficult composition, containing dispersed intermetallic phases of Ti-Al system, could be obtained. The presence of Ti_3Al and TiAl is associated with thermodynamics of the phases formation. The formation of these phases is characterized by a minimum of Gibbs energy [11].

Figure 3 demonstrates the distribution the phase composition of the Ti-Al system by varying the mass content of aluminum and the annealing temperature.

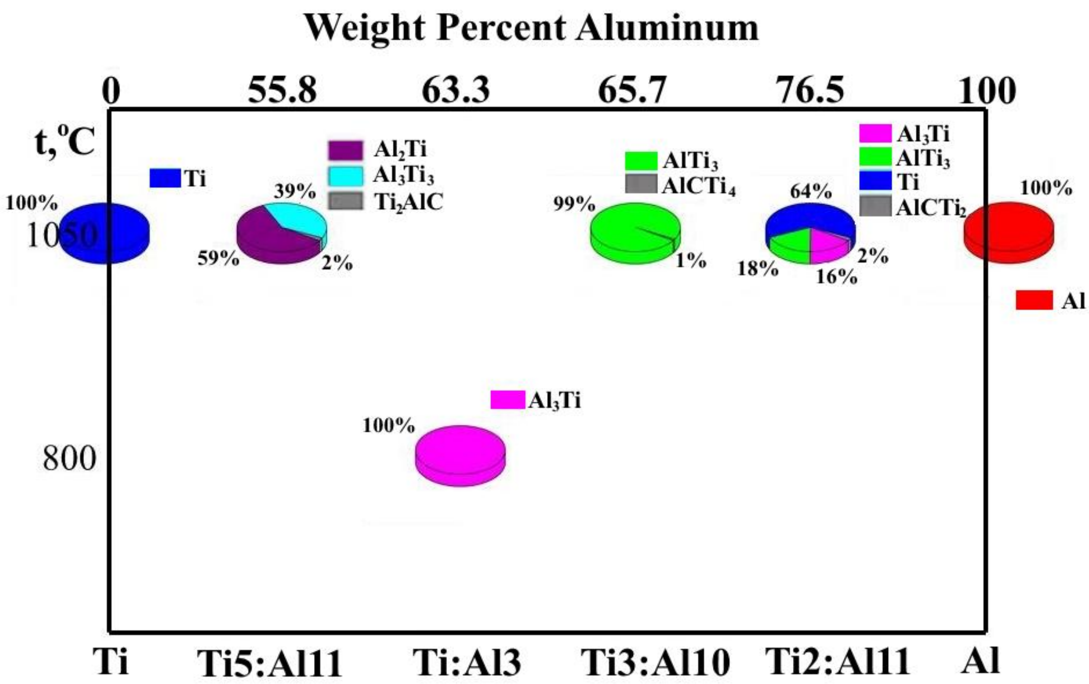

Figure 3. Phase composition of the Ti-Al system (Weight present aluminum) at different mass content of aluminum and annealing temperature.

As Figure 3 illustrates different systems are formed at the various content of aluminum (in wt.%). So, when the content of aluminum to 60 wt. % mainly the phase Ti_3Al is formed; at the 64-66 wt.% - single-phase system; at 80 wt.% – multiphase system. The obtaining these phases does not converge with the data the phase diagram of Ti-Al. Therewith, the formation of Ti_3Al and TiAl phase composition is the most thermodynamically advantageous, because they have minimal Gibbs energy.

So, the proposed technology of obtaining the alloys from the metals powders could be used for synthesis of materials with specified composition.

4. Conclusion

In current work the new method of obtaining of materials based on the Ti-Al system was suggested. Materials containing from 55.83 to 100 wt.% of aluminum were obtained. The phase composition of the samples was investigated. The formation of intermetallic phases of Ti_3Al, TiAl, $TiAl_3$ was established. Both single-phase and multiphase intermetallic systems were prepared by this method. It was determined that pure finely dispersed (CSR up to 100 nm) intermetallic compound $TiAl_3$ is formed at molar ratio of TiAl=1:3.

The study promotes application of this method to obtain of high strength alloys and functional materials of new generation.

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