ABSTRACT

to thesis research on **"DEVELOPMENT OF ADVANCED TITANIUM-BASED ALLOYS WITH A HIGH LEVEL OF MECHANICAL AND TECHNOLOGICAL PROPERTIES",** Submitted for the Degree of Doctor of Philosophy PhD Majoring in Materials Science and Technology of New Materials-6D071000

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Assessment of the current state of the solved scientific or technological problem. Currently, it is difficult to imagine the development and further improvement of modern mechanical engineering without the widespread use of titanium alloys. In the near future, we expect not only a twofold increase in the consumption of titanium alloys in the aviation industry, but also an increase in demand for titanium semi-finished products in other industries, such as shipbuilding, medicine, nuclear and chemical industries, automotive industry, production of consumer goods, etc.

The advantages of titanium alloys over other materials are their high specific heat resistance and strength, combined with high corrosion resistance. In addition, titanium and its alloys are well welded and have paramagnetic properties.

To date, several hundred experimental compositions and more than a hundred industrial titanium alloys for various purposes have been developed. Numerous studies have been devoted to the study of their structure and properties, which have repeatedly attempted to establish a quantitative relationship between the mechanical properties and the chemical composition of alloys. However, they did not give unambiguous results due to the high sensitivity of the properties of alloys to their phase composition and structural state, as well as to fluctuations in the content of alloying elements and impurities within the brand compositions.

Among industrial titanium alloys, heat-resistant titanium-aluminum intermetallides with a controlled microstructure are of particular importance, which are used for the manufacture of blades for gas-burning turbines, thermal power plants and aviation gas turbine engines. The use of light alloys based on Ti-Al, which have a density of 4-4. 5 g/cm3,will in the future increase the efficiency of energy-producing turbines by up to 35% and increase the "lift/weight" ratio of aircraft engines by up to 20% compared to modern analogues created on the basis of special Nickel alloys with a density of 8-8.5 g/cm3. Of particular importance are y-TiAl alloys, the use of which has already reduced the mass of turbines and the overall weight of the aircraft, as well as reduced kerosene consumption and CO2 emissions by 15.0%.

Further progress in the use of TiAl intermetallides in aircraft turbines is associated with the sequential replacement of Nickel turbine blades with light–alloy materials in the hotter zones of gas turbine engines. This requires an increase in their heat resistance and heat resistance of new materials to temperatures of 600 °C or more. Intensive research in this area is being conducted in the United States, the European Union, and China. The main reason for the increased interest in

intermetallic alloys on the part of leading industrial giants is related to the optimal combination of operational and technological properties at temperatures typical for the operation of new-generation gas turbine engines.

The basis and initial data for the development of the topic. Kazakhstan produces a sufficient amount of high-quality sponge titanium, which can be the raw material for promising titanium alloys. Output of JSC UKTMK (Ust-Kamenogorsk titanium and magnesium plant)on the domestic market and the use of domestic titanium products in the production of gas-power plants in the oil and gas sector of Kazakhstan, provides for the establishment of production of titanium alloys with high level of quality.

Rationale for the need for research work. Currently, the task of obtaining heat-resistant titanium alloys that can provide long-term operation of machines and mechanisms in the temperature range of 600-700 oC is under development, both in Russia and the CIS countries, and abroad.

New titanium alloys and products made from them must have the necessary complex of technological and operational properties (usually difficult to combine), in particular, high strength, ductility, heat resistance and heat resistance. It is known that as a result of alloying, thermal and thermomechanical processing, it is possible to obtain the desired set of properties of most industrial alloys, including those based on titanium. However, the difficulty of solving this problem is that, unlike most industrial alloys based on iron and Nickel, titanium alloys are characterized by high structural sensitivity to the concentration of alloying elements, thermal and thermomechanical treatment modes.

Due to the multi-factor dependence of the structural and phase composition and properties of titanium-based alloys, a comprehensive study of the features of the physical and chemical interaction of the components of titanium alloys at the stage of their preparation in the liquid - solid state and subsequent cooling is necessary. This problem can be solved by constructing phase diagrams of multicomponent systems based on titanium and studying the laws of phase transformations depending on their composition and temperature. Knowledge of phase diagrams also allows us to establish optimal scientifically-based modes of preliminary and final processing of the corresponding titanium alloys and products made from them, including different types of thermal and deformation effects for the formation of their specified structural and phase state and properties.

Information about the planned scientific and technical level of development, patent research and conclusions from them. The analysis of scientific and technical and patent publications, including 109 names of literature sources in the field of development of titanium-based alloys with a high level of mechanical and technological properties, was carried out.

The planned scientific and technical level of development assumes,

that the structural-phase state, which provides the necessary level of properties of modern titanium alloys, is mainly achieved by complex alloying with refractory metals in combination with certain modes of thermal, thermo-mechanical and thermo-deformation processing. The disadvantages of titanium alloys include their thermal instability during long-term operation and low heat resistance (alloys are oxidized when heated above 500 °C), and they are characterized by a rather low processability. To date, the problem of creating a new generation of industrial titanium alloys has not been completely solved. Therefore, the creation of promising titanium alloys and the development of advanced technologies that provide a high level of mechanical and operational characteristics requires a new approach to the choice of composition, methods and means of external influence at all stages of their technological cycle.

Information about the metrological support of the dissertation. When conducting scientific research the following metrological support:

Nust MISIS (Russia, Moscow, Department "Technology of foundry production") - ArcastArc200 vacuum arc furnace with a cooled copper hearth by scanning electron microscope Tescan Vega 3 LM c prefix EDX, Oxford X-Max80, a universal testing machine Zwick Z250 universal hardness DIGI-TESTOR 930 HB 250 kgf;

RSE "national center for complex processing of mineral raw materials of the Republic of Kazakhstan" (Kazakhstan, Almaty) - vacuum induction furnace (IPP-18KW), muffle furnace (Type 1300, ModelFB1315M), drying Cabinet (Model 615);

Institute of Industrial engineering named after A. Burkitbaev Department of "machine-tool Construction, materials science and technology of machine-building production" - electronic scanning microscope with energy-dispersion prefix. Jeol, JSM 6490 LA, DRON-4 diffractometer, x-ray diffractometer X, Pert MPD PRO, METAM LV-31 metallographic microscope (LOMO).

All equipment and devices used are certified and documented by the relevant control organizations. Metrological studies were performed on control and measuring devices certified in accordance with regulatory documents.

Relevance of the topic. High performance titanium and its alloys, reducing the weight of the equipment, increase the acid resistance and corrosion resistance of machine parts and mechanisms, improvement of heat resistance open up opportunities for their use in aerospace, oil and gas and chemical industry of the Republic of Kazakhstan. In the near future, in the conditions of more severe operation of modern machinery and equipment, the need for high-quality titanium alloys on the world market will only increase, and the requirements for their quality will continuously increase. Therefore, the development of scientific bases for the creation and processing of high-quality titanium alloys of a new generation from domestic raw materials becomes an urgent problem.

To develop promising titanium alloys, it is necessary to carry out a scientific search for new principles of alloying multicomponent alloys, modes of their thermal and deformation treatment to expand the range of operating temperatures, ensure heat resistance, and increase corrosion resistance in aggressive environments. The priority in setting up and organizing research work in this direction is to reduce the labor costs associated with the selection of the optimal complex of alloying elements, development of optimal technologies for thermal, thermomechanical and thermo-deformation processing of alloys and products made from them.

The need to complicate the chemical composition to ensure the performance of alloys and the transition to multicomponent systems makes the task of developing alloys difficult to perform with standard methods and techniques. Its solution is possible only with the use of modern computer modeling methods, calculation methods and software, for example, Thermo-Calc. It is based on the study of the laws of physical and chemical interaction in multicomponent systems in the liquid-solid state and during subsequent cooling of alloys.

The novelty of the topic - phase transformations in multicomponent titanium alloys have been studied for the first time using the Thermo-Calc software product.,

Ti-Al-Nb-Mo and a model system for which a complete correspondence was found between the calculated and experimental values of the boundaries of temperature-concentration regions;

- polythermal and isothermal sections and projections of the liquidus and solidus surfaces of the corresponding multicomponent state diagrams are calculated and constructed;

- it is established that the concentration regions of the stable state of the γ-phase occur at a lower content of the main alloying element aluminum (40-43%) compared to known standard industrial alloys (44-52%);

- based on the established regularities of phase transformations, the choice of the optimal composition of the ti-43Al-4Nb-1Mo titanium alloy is scientifically justified, and optimal modes of melting, casting, and heat treatment are proposed;

-concentration dependences of physical characteristics (melting point, density, heat capacity, thermal conductivity, electrical conductivity) of Nb-Al and Mo-Al systems are constructed and optimal compositions of ligatures are determined that guarantee effective assimilation of alloying elements and their uniform distribution in the melt volume.

-multicomponent γ-titanium alloys of the Ti-Al-Nb-Mo system were obtained, the composition of which was calculated using the Thermo-Calc software product, and their structure, phase composition, mechanical and technological properties were determined at room and elevated temperatures.

- the optimal mode of thermal and thermomechanical processing of the developed titanium-based alloys is proposed, which ensures the production of a non-porous material with increased mechanical and technological properties at operating temperatures.

Connection of this work with other research works. The results of the dissertation published 10 publications, including 3 in journals recommended by Committee for control in education sphere and science MES RK, 2 articles in scientific journal included in the database Web of Science Core Collection (Metal Science and Heat Treatment with impact factor 0,215). The main provisions and results of the work were presented at International conferences in the form of oral and poster presentations: international scientific and practical conference "Scientific and personnel support of innovative development of the mining and metallurgical complex". April 27-28, 2017, Almaty, Kazakhstan; XIV INTERNATIONAL SCIENTIFIC CONGRESS MACHINES. TECHNOLOGIES.

MATERIALS: Year I, Issue 4(4), Vol. IV, TECHNOLOGIES. VARNA, BULGARIA. 13-16. 09. 2017, 2nd international forum "electron – beam technologies for microelectronics". October 9-21. 2017. Moscow.

Received a patent.

The work was carried out within grant financing of scientific researches of MES of RK on the topic 4521/ГФ4 for 2015-2017, G. G., "Development of advanced titanium alloy with high strength and workability".

The purpose of the work the goal is to develop promising titanium-based alloys with a high level of mechanical and technological properties from Kazakhstan raw materials using computational methods of computer modeling and quantitative analysis of the structural and phase state of multicomponent systems.

The objects of research they are multicomponent titanium alloys doped with aluminum and refractory metals-niobium, molybdenum, vanadium; ligatures of the Nb-Al and Mo-Al systems.

The subject of research thermodynamic calculations of temperature-concentration regions of existence of phase components on ti-Al-Nb-Mo state diagrams; determination of structures of multicomponent titanium alloys, optimal chemical and phase compositions; methods for their preparation, modes of thermal and deformation treatment of alloys that provide a high level of mechanical and technological properties.

The objectives of the study, their place in the implementation of research work as a whole: 1) Calculate using the Thermo-Calc software product and construct polythermal and isothermal sections of industrial titanium alloy Ti-Al-V-Zr and show the correlation between its calculated and actual phase composition.

2) Calculate using the Thermo-Calc software product and construct polythermal and isothermal sections of a multi-component titanium alloy of the Ti-Al-Nb-Mo system and establish the optimal composition of alloying elements to obtain a stable state of the γ-alloy.

3) Determine the composition of NB-Al and Mo-Al ligatures that meets the basic requirements for ligature alloys in terms of melting point, density, thermal conductivity and electrical conductivity, ensuring maximum assimilation of alloying elements.

4) Prepare experimental multi-component titanium alloys of the Ti-Al-Nb-Mo system in accordance with the composition calculated by the Thermo-Calc program, determine their structure, phase composition and properties after casting, annealing and Hypo-processing.

5) Develop modes of casting, thermal and thermomechanical processing that provide the necessary structural and phase state and a set of operational and technological properties of the new titanium alloy.

Methodological base of scientific research: The following modern devices were used in the research process:

1) AXIO Zeiss–A. 1 optical microscope for recording the microstructure of experimental alloys;

2) electronic scanning scanning microscope JEOLJXA-8230 (Japan) for studying the fine structure of dispersed systems;

3) x-ray diffractometer DRON-4 for determining the phase composition.

The following standard laboratory equipment was used

1) vacuum resistance furnace VE-3-16 with graphite heater and vacuum maintenance 5×10-5 mm Hg;

2) laboratory vacuum arc furnace Arc200 (USA);

3) muffle electric furnace SNOL-1,6. 2,3. 0,8/9-M1 with an accuracy of maintaining the temperature of about 10K;

4) BUEHLER Phoenix grinding and polishing machines;

5) universal Electromechanical testing machine Zwick Z250;

6) universal hardness tester DIGI-TESTOR 930 HB 250 kgf based on the results of hardness measurement, software product of computer modeling "Thermo-Calc", based on the database of physical and chemical interactions in multicomponent systems based on titanium.

The main provisions to be defended: 1) Phase composition in polythermal and isothermal sections of standard industrial titanium alloy VT20L (Ti-Al-V-Zr system) and correlation between calculated and experimental data.

2) Phase composition and temperature-concentration regions of stable existence of the γ-phase in a newly developed multicomponent titanium alloy of the Ti-Al-Nb-Mo system containing 40 and 43% aluminum.

3) the Composition of NB-Al and Mo-Al ligatures that meets the basic requirements for ligature alloys in terms of physical and chemical properties – melting temperature, density, thermal conductivity and electrical conductivity.

4) the Structural and phase state and operational and technological properties of the newly developed titanium alloys and the choice of the optimal concentration of the main alloying element – aluminum.

5) the Mode of thermal and thermomechanical (thermo-deformation) processing, which ensures the production of high-quality multi-component titanium alloy with the necessary level of structure, operational and technological properties.

The practical significance of the work it consists in the fact that new titanium alloys with high strength and manufacturability were obtained for the first time on the basis of the phase diagrams of new systems constructed in this work. Their optimal compositions, melting, casting and processing modes have been developed. Shaped castings of alloys and deformed semi-finished products from them were obtained.

The ability to control the phase state and structure of titanium alloys based on the phase diagrams constructed in the work contributes to the development of the scientific basis for creating new high-quality alloys, and is of important scientific and practical importance. They serve as the basis for the development of new, science-based technologies for the production, casting and heat treatment of titanium alloys.

Publications. The main provisions of the dissertation work were published in 10 scientific articles, 2 of which were published in indexed in Scopus database, 3 articles were published in journals recommended by Committee for control in education and science of RK; 4 papers published in the proceedings of international conferences 1 patent.

Approbation of the work. The results of the dissertation published 10 publications, including 3 in journals recommended by Committee for control in education sphere and science MES RK, 2 articles in scientific journal included in the database Web of Science Core Collection (Metal Science and Heat Treatment with impact factor 0,215). The main provisions and results of the work were presented at International conferences in the form of oral and poster presentations: international scientific and practical conference "Scientific and personnel support of innovative development of the mining and metallurgical complex". April 27-28, 2017, Almaty, Kazakhstan; XIV INTERNATIONAL SCIENTIFIC CONGRESS MACHINES. TECHNOLOGIES. MATERIALS: Year I, Issue 4(4), Vol. IV, TECHNOLOGIES. VARNA, BULGARIA. 13-16. 09. 2017, 2nd international forum "Technojuniti-Electron beam technologies for microelectronics". October 9-21. 2017. Moscow.

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The structure and scope of the dissertation. The thesis consists of an introduction, 4 sections, conclusion, list of references and Appendix. The main text of the work is presented on 115 pages of typewritten text, contains 52 figures, 30 tables, the list of references consists of 113 titles.