EFFECT OF ANNEALING TEMPERATURE ON MICROSTRUCTURE OF Ti-Al-V-Mo-Zr SYSTEM ALLOYS

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Abstract: *Quantitative analysis of the phase composition of the Ti-Al-V-Mo-Zr system alloys was carried out during operation using the Thermo-Calc program (TCW5 version, TTTI3 database). Polythermal and isothermal cuts are plotted, design temperature values of liquidus, solidus and transition into β-field during heating are given. Regarding the titanium alloy of the Ti-Al-V-Mo-Zr system the effect of annealing temperature on the microstructure of the alloy as well as on the alloying elements content in α and β–phases was studied using the scanning electron microscopy method.*

KEY WORDS: *TI-AL-V-MO-ZR SYSTEM, TITANIUM ALLOYS, PHASE COMPOSITION, HEAT TREATMENT, MICROSTRUCTURE, ANNEALING*

1. Introduction

Titanium alloys have a number of advantages compared to other alloys: availability of both high strength and ductility, low density ensuring high specific strength; heat resistance of up to 600 ^{o}C, high resistance to corrosion in aggressive environments [1, 3]. The required property package can be attained as a result of alloying of titanium alloys. The alloying elements contained in industrial titanium alloys together with titanium form substitutional solid solutions and change the temperature of allotropic transformation. The alloying of titanium allows increasing its strength by 2 or 3 times and sometimes increasing resistance to corrosion as well.

Polymorphism of titanium creates the opportunity to improve the properties of titanium alloys using heat treatment which allows enhancing their strength considerably with relatively small decrease of their ductility. The distinction of titanium alloys is that unlike steels annealing is the main type of heat treatment and the required strength is achieved during the formation of heterophase structures [3- 4].

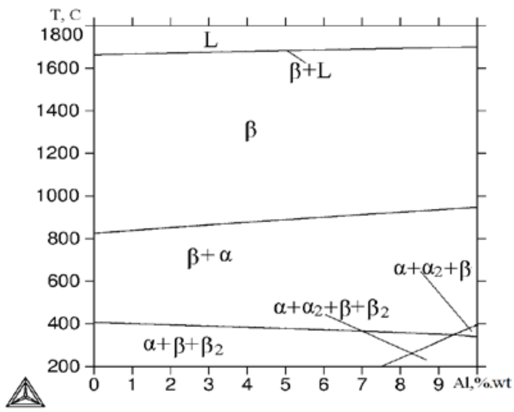
In order to provide the required level of structural condition and properties of the titanium alloys being developed, it is necessary to carry out comprehensive theoretical and experimental research on scientifically based choice of their tailored compositions, advanced casting and treatment techniques. The purpose of the work was to study the Ti-Al-V-Mo-Zr phase diagram and the effect of heat treatment on the phase composition and structure of titanium alloys using both design and experimental methods. This research aims at the creation of a scientific base necessary for the validation of the composition of multi-component titanium alloys.

2. Preconditions and means for resolving the problem

2.1 Quantitative analysis of phase composition of Ti-Al-V-Mo-Zr system alloys

Polythermal and isothermal cuts are used for semi-quantitative assessment of the phase composition of multi-component alloys. For titanium alloys the analysis was carried out using the graphical technique [5]. However the possibilities provided by the graphical technique are rather limited, especially in the case of quaternary and more complicated systems. In this work polythermal and isothermal cuts of phase diagrams based on titanium were plotted with Thermo-Calc. Polythermal cuts provide the opportunity to assess the effect of individual alloying elements on the lines of solidus and liquidos and the formation of the phase composition of the alloy during cooling and heating.

The calculation of polythermal cuts was made using constant concentration of vanadium, zirconium (1,3% V and 2 % Zr) and variable concentration of aluminium, molybdenum, which allows to determine the extent to which these alloying elements affect the temperatures of phase transitions, particularly the transition into the β-field during heating (Tпп). The fragments of polythermal cuts of the phase diagram of the Ti-Al-V-Mo-Zr system are shown in Figure 1.



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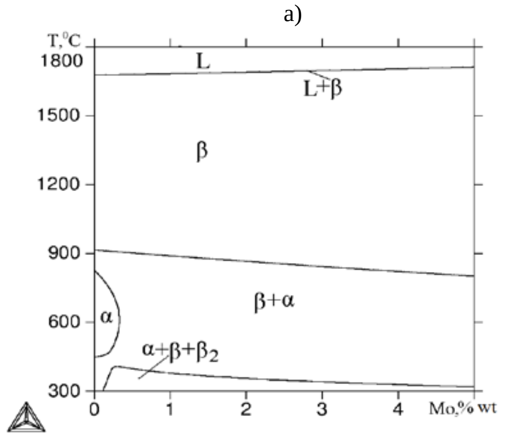

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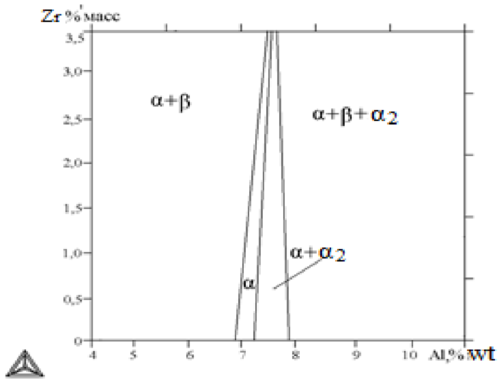
Figure 1 *– Fragments of polythermal cuts of Ti-Al-V-Mo-Zr system phase diagram* *a* –1.3 % V, 2 % Zr, 1.3 Mo; *b* –6.5 % Al, 1.3 %V, 2 % Zr

Simulation demonstrated that when temperature is decreased a series of intermetallic phases is formed in the alloys being studied, in which case the alloys pass from a single-phase β – field via a two-phase β+ α field into a three-phase α+ β+ β_2 field and even a four-phase α+α_2+ β+ β_2 field.

The significant characteristics of all alloys are the lines of solidus and liquidus that determine the melting, casting and heat treatment conditions. As indicated in the figure the interval does not exceed 5-6 C in the Al and Mo concentration field being studied.

Imperfect crystallization, especially of titanium alloys, generally results in considerable deviation of individual sections of casting from the average value. Thus, castings are subjected to annealing; during the annealing a composition, which is close to an equilibrium composition, is formed.

Joint effect of aluminum, molybdenum and zirconium (β – stabilizers) on the phase composition of the alloys being studied was also calculated for the Ti-Al-V-Mo-Zr system. The fragments of isothermal cuts of the phase diagram of this Ti-system at 800 °C are shown in Figure 2.



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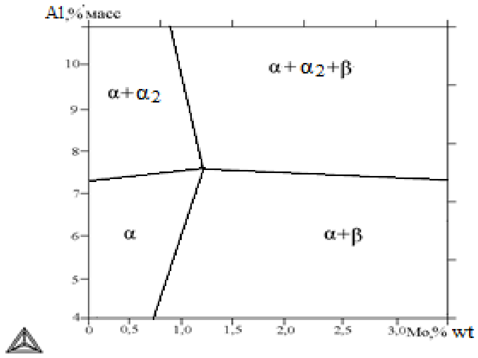

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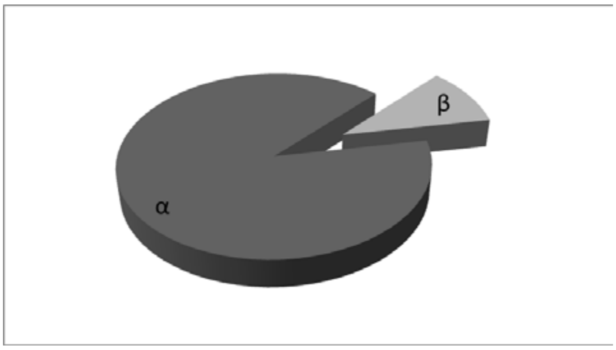
Figure 2 *– Fragments of isothermal cuts of phase diagram of Ti-Al-V-Mo-Zr system at 800 °C:*
a – 1.3 % V and 1.3% Mo; b – 2 % Zr and 1.3 %V

Thermo-Calc program enables the calculation of a huge number of cuts in short time. Making such assessment using the graphical technique is unfeasible for more complicated systems. In this case calculation of the phase composition characteristics at preset concentration of alloying elements and temperatures becomes necessary.

Isothermal cuts at 800 ºC make it possible to analyze the joint effect of the two elements Al, Zr and Al, Mo on the formation of various phases. Calculations show that apart from α and β phases this alloy may contain the intermetallic phase α_2 (Ti_3Al) which is not desirable as its presence leads to a decrease in ductility [5, 6]. Interest here is also generated by the determination of the proportions of excess phases (Q_M) affecting considerably the performance characteristics of castings, which is difficult to perform experimentally. The design values of α and β phases ratio are given in Figure 3.



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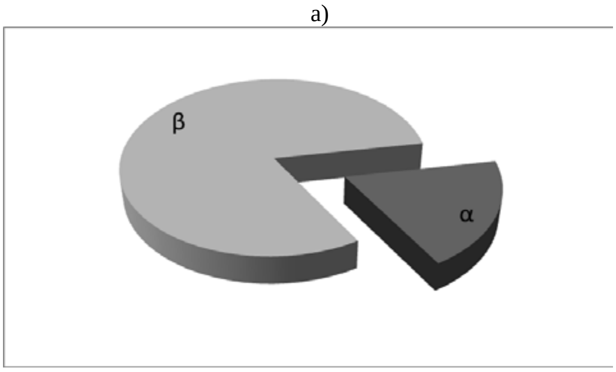

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Figure 3*- Design values of α and β phases ratio of Ti-Al-V-Mo-Zr system alloys.*
a - 800°C; b - 950°C

As indicated in the figure, in the temperature interval from 800 to 950 ^{0}C the quantity of β-phase increases by 8 times (from 10 to 80%), which suggests the presence of a phase tran mass this temperature region. Based on the above, it was dec the obtained calculation results shall be checked using experimental samples of the Ti-Al-V-Mo-Zr system alloys containing (%): 6.5 Al, 1 V, 1 Mo, 2 Zr, and annealing at the temperature of 800°C and 950°C.

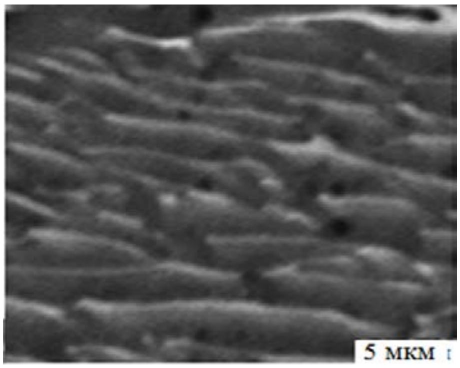
2.2 Experimental research technique

The research subjects were the casting fragments (“corbel” type) of the Ti-Al-V-Mo-Zr system alloy of industrial production. 10x10x15 mm specimens cut from a casting were annealed in a muffle furnace at 800 and 950^{0}C. In order to provide protection from corrosion during annealing, protective coating was applied to the surface of the specimens in accordance with the plasma-electrolytic oxidation process. After holding the specimens were cooled down using two options: cooling in the furnace and quenching in cold water.

The microstructure of the specimens was examined using an optical microscope Axio Observer MAT and electron scanning microscopes (SEM): JSM-6610LV and TESCANVEGA 3. The latter are complete with an energy-dispersive add-on micro-analyzer INCA SDD X-MAX manufactured by Oxford Instruments and software (INCA Energy and Aztec) for microanalysis, construction of composition sections, element distribution maps. The specimens for metallographic research were prepared by means of mechanical polishing. Polished sections were subjected to chemical etching in a reagent containing 1 ml HF, 1.5 ml HCl, 2.5 ml HNO_3, 95 ml H_2O, during 15 s.

Ti-Al-V-Mo-Zr system alloy structure belongs to the conventional transformed β–type [7] and consists of the α-phase of solid solution of alloying elements and additive agents in titanium with hexagonal close-packed lattice, and of a small quantity of the β –phase of solid solution of alloying elements and additive agents in titanium with bulk-centered lattice.

Titanium alloys are hardened by heat treatment: quenching or ageing. When annealed or quenched they have good ductility, and high strength and resistance to heat after ageing [8, 9]. The more β-phase is contained in the alloy structure, the stronger it is in the as-annealed condition and the more it is hardened during heat treatment. The typical alloy microstructure after heat treatment with different content of additive agents is shown in Figure 3.



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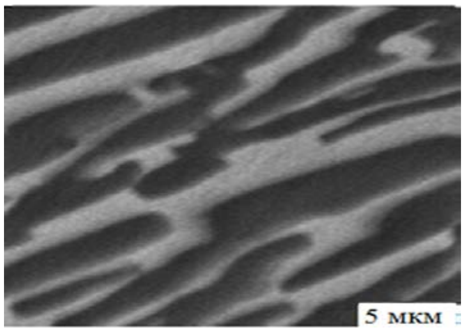

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***Figure 3**- Ti-Al-V-Mo-Zr system alloy microstructure after heat treatment;*
a) 800°C, b) 950°C

Use of electron scanning microscopes enables more reliable phase identification compared to optical microscopy which does not reveal changes during heat treatment as the phase contrast is due to the difference in atomic numbers. Particularly molybdenum-dressed (the heaviest element in the alloy composition) β-phase looks lighter. Besides due to higher resolving power an electron scanning microscope makes it possible to determine the sizes of the plates having the thickness of less than 1 μm.

The microstructure of the specimens obtained after annealing at 800°C demonstrates small dark submicron α –phase plates formed during cooling in the process of polymorphic transformation and shaped like colonies and oriented in various directions, as well as a small quantity of β–phase (Fig. 3 a). An increase of up to 950ºC in the annealing temperature results in the increase of the size and thickness of the α-plates and their orientation in one direction, as well a 5 μm crease of the proportion of β-phase (Fig. 3 b).

For the purpose of experimental determination of phase composition several polished sections were analyzed. The results are given in Table 1.

***Table 1**- Phase composition of the Ti-Al-V-Mo-Zr system alloy under consideration*

Components	Component content in phases at temperatures			
	800 ^{0}C		950 ^{0}C	
	α	β	α	β
Al	6.7	4.9	7.6	6.2
Zr	2.1	2.5	1.7	2.2
Mo	0.8	8.2	0.2	1.8
V	1.4	4.9	0.7	2.0
Ti	89.1	79.5	89.7	87.8

As shown in the table the most significant difference in the distribution between α and β phases is typical for molybdenum and vanadium β-stabilizers. Particularly molybdenum concentration in β-phase decreases from 8.2 to 1.8% as the temperature rises from 800 to 950^{0}C, vanadium – from 4.9 to 2.0%, while the change in zirconium concentration in this phase is insignificant which is due to the fact that zirconium is an analogue of titanium and isomorphically substitutes it in these alloys.

3. Conclusion

Using the Thermo-Calc program isothermal and polythermal cuts of Ti-Al-V-Mo-Zr system were calculated, which enables the assessment of the joint effect of two alloying elements on the phase composition of the alloy being studied.

The conducted research of the structural condition of the Ti-Al-V-Mo-Zr system alloys at various annealing temperatures has shown that within the temperature range of between 800 and 950°C the β-phase content sharply increases to 90%. In the meantime the concentration of β-stabilizing elements Mo and V decreases in both α and β-phases, and the content of aluminium and zirconium (isomorphic analogue of titanium) changes insignificantly.

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