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Effect of Heat Treatment on the Structure and Properties of Large Semifinished Products of BT3-1 Alloy

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The causes of reducing the mechanical properties of large-sized products from titanium alloy VT3-1 were studied. The schemes of thermostrengthening processing of BT3-1alloy taking into account the workpieces optimization.

Keywords: TITANIUM ALLOY, HEAT TREATMENT, STRUCTURE, MECHANICAL PROPERTIES

Introduction

Titanium alloys are widespread structural and corrosion-resistant materials for aerospace, shipbuilding, chemical, defense industries. Their use is most promising in large-sized products due to the high specific strength, which is greater than of most alloy steels. This saves a lot of metal and reduces structural weight.

However, heat treatment modes, developed and successfully applied to parts of small sections [1], often do not provide the desired combination of properties of large workpieces. It is caused by the heterogeneity of the chemical composition, structure and properties of the metal [2, 3], which is determined by both the technology features of titanium alloy (melting and cooling of the billets in vacuum) [4], and the properties of titanium [5] - low thermal conductivity and high specific heat (heat conductivity of titanium is 16 W/m • K, while of iron it is 73.3 W/m • K, aluminum 238 W/m • K, the specific heat of titanium is 519 J/kg • K, iron - 444 J/kg • K, aluminum - 900 J/kg • K. At each stage of heat treatment in such metal phasal and structural transformations occur not simultaneously with the formation of different phases with the uneven distribution of alloying elements in them. The processes of heat treatment of titanium alloys are complicated by their complexity, sufficiently high content of alloying elements, formation of substitutional solid solutions, the need for diffusion redistribution of α- and β-stabilizers between the phases due to differences in solubility [6, 7]. In order to improve the characteristics of large semifinished products, as a rule, special schemes and modes of heat treatment are developed.

The objective of this study was to investigate the causes of decline in the level of mechanical properties and the development of methods of heat treatment of large-sized products from titanium alloy BT3-1 that provide increase and stabilize the properties.

Results and Discussion

The authors studied large forgings of BT3-1 alloy - one of the most applicable to large-sized products of titanium alloys. The interval of the content of alloying elements in the semifinished products is shown in **Table 1**.

Table 1. Change in the concentration of alloying elements and impurities in the investigated semifinished products from alloy BT3-1

Mass content of elements, %								
Al	Mo	Cr	Fe	Si	O_2	C	N_2	H_2
5,9-6,8	2,1-2,6	1,3-1,8	0,29-0,56	0,25-0,35	0,07-0,12	0,01-0,04	0,01-0,03	0,002-0,015

BT3-1 alloy is doped by α-and β-stabilizers, both isomorphic (Mo), and eutectoid-forming: Cr, Fe, Si. This led to the formation of concentration inhomogeneities, on the basis of which metastable phases with different alloying degree were formed. The uneven distribution of alloying elements made it impossible to realize the level of mechanical properties, corresponding the mean values of the content of alloying elements.

As a result of metallographic studies, the authors established features of the structure of large forgings and stampings, leading to a decrease in properties. Averaged mechanical properties and structure parameters for different types of semifinished products (forgings and stampings) in the initial state are shown in **Table 2**.

Table 2. Mechanical properties and structure parameters of large semifinished products from titanium alloy BT3-1 in the initial.

Semifinished product	Structure parameters			Mechanical properties		
	Grain size, mm	Colony size, μm	α-plates thickness, μm	σ_B, MPa	δ, %	ψ, %
BT3-1(stamping)	5-10	150-300	1,3-3	1050	9	20,3
BT3-1(forging)	1-5	60-220	0,3-2,8	1030	9	20,5

According to Hall-Petch relation, large grains of semifinished products of both types significantly decreased the strength properties of the metal. Large grains provided the formation of large colonies of α + β-phase with small angles of mutual orientation. It also reduced strength, as the crack crossed the colony as a whole, its development was slowed only when passing from one colony to another. At the points of contact during mutual alignment of grains there appeared significant stress concentration, density of impurities segregation increased, what also contributed to intergrain fracture, caused a decrease of mechanical properties.

Presence of rough boundary separation of brittle α-phase in the structure of forgings (**Figure 2c**), which has a hexagonal crystal lattice with a small number of gliding planes, caused intercrystalline fracture, what led to a sharp drop of all mechanical properties. The heterogeneity of the structure, typical for all types of semifinished products, contributed to the appearance of stress raisers and premature failure of the product.

It is impossible to eliminate the rough boundary separations of α-phase, a significant heterogeneity of the structure and the uneven distribution of alloying elements with heat treatment in α + β-area at the same time. Therefore, a scheme of heat treatment (**Figure 1**) for forging was suggested, the first stage of which was processing by β-solid solution.

It is established that holding at a temperature higher than the temperature of full polymorphic transformation in 20-30°C for 30 min was sufficient to eliminate these drawbacks. At higher temperatures, collective recrystallization and gas absorption was intensified.

With the help of holding in the β-area it was managed to:

- grind the grain structure of billets in 3-5 times, depending on the degree of deformation of the parent metal (**Figure 2**);
- eliminate the rough boundary release of α-phase, obtain a homogeneous β-solid solution;
- achieve a reduction of heterogeneous distribution of alloying elements in the β-solid solution.

For providing maximum strength of the metal in combination with satisfactory ductility there were optimized temperature and time parameters of the subsequent processing of α + β-area [8].

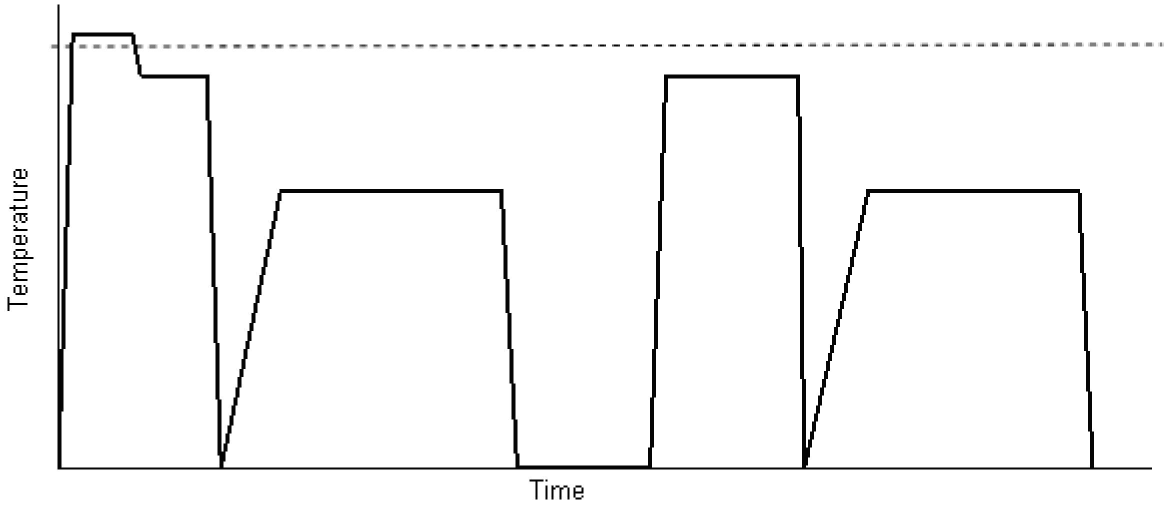
At this stage of heat treatment we achieved:

- fixation of the fine grain structure of α-phase releases, preventing further growth of the grains (**Figure 2d**);
- the optimal ratio of α-and β-phases of favorable shape and size;
- a certain alloying degree of β-phase for fixation by quenching for its collapse during aging with the formation of fine α-phase separation.

Subsequent aging caused the collapse of metastable phases with a uniform separation of fine secondary α-phase.

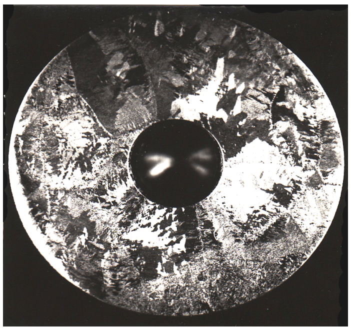
As a result of microroentgen spectral sounding there was shown an increase in the degree of uniformity of distribution of α-and β-stabilizers in the α-plates and β-layers in heat-treated metal compared to the original. The heterogeneity of distribution of β-stabilizers (iron, molybdenum, and chromium) decreased most significantly.

Figure 2 shows the macro-and microstructure of the forgings from alloy BT3-1 in the initial state and after the heat treatment according to a developed mode. **Table 3** presents the average mechanical properties of large heat-treated forgings and stampings. As follows from the above data, grain refinement, increasing homogeneity of the structure, the removal of rough boundary separations provided an increase in strength while maintaining sufficient flexibility.

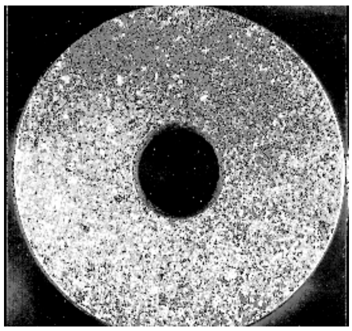


a **b**

Figure 1. Scheme of heat treatment of large forgings (a) and stampings (b) from alloy BT3-1



a



b

c

d

Figure 2. Macro- (a,b) and microstructure (c,d) of the forgings from BT3-1 alloy in the initial state and after the heat treatment

Table 3. Mechanical properties of large-sized semifinished products from BT3-1 alloy after heat treatment

Semifinished product	Mechanical properties				Semifinished product	Mechanical properties			
Forging	$\sigma_в$ MPa	δ,%	Ψ, %	KCU MJ/m^2	Stamping	$\sigma_в$ MPa	δ,%	Ψ, %	KCU MJ/m^2
	1235	7,5	16,0	0,4		1212	6,2	16,6	0,32

The stamping metal was more homogeneous, differed by the absence of border edging brittle α-phase, the presence of more β-phase, a more uniform distribution of alloying elements. In this case, the required level of mechanical properties was achieved without the use of previous endurance in the β-area by optimization of temperature and time parameters of quenching and aging. The mechanical properties of large stampings from BT3-1 alloy after heat treatment in the optimal mode: 890°C ±10°C, 90 min, quenched in water, 630°C ±10°C, 180 min, air cooling are shown in Table 3. In some cases stampings that do not meet the technical requirements to the alloy were subjected to repeated thermostrengthening processing. After that, all billets of BT3-1 alloy, including having coarse, heterogeneous rough sheet structure, had the level of properties corresponding to the specifications.

Conclusions

Thus, depending on the degree of homogeneity of the original metal, the structure, distribution of alloying elements various schemes of thermal processing of large semifinished products from titanium alloy BT3-1 were suggested (Figure 1), the temperature and time of each operation were optimized.

The developed heat treatment modes provided the increase of the mechanical properties of both forged and stamped semifinished products to the required level and their stabilization.

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Влияние термической обработки на структуру и свойства крупногабаритных полуфабрикатов из сплава ВТ3-1

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Изучены причины снижения уровня механических свойств крупногабаритных изделий из титанового сплава ВТ3-1. Разботаны схемы термоупрочняющей обработки сплава ВТ3-1 с учетом оптимизации структуры заготовок.