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THE GAS IMPURITIES INFLUENCE ON THE CHARACTERISTICS OF VT1-0 AND VT6 TITANIUM ALLOYS

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This article dials with methods for producing titanium alloys VT1-0 and VT6 and the gaseous impurities effect on plasticity characteristics. It has been shown that electron-beam melting with an intermediate capacity makes it possible to remove a significant number of impurities in titanium alloys VT1-0 and VT6. It has been proven that industrial-scale modification of titanium ingots with a total weight of more than 18 t, followed by their pressure treatment without remelting, allows minimizing the energy costs for obtaining finished semi-finished products.

INTRODUCTION

Since the mid-1960s, in Ukraine and abroad, using the method of electron beam melting (EBM), titanium alloys have been smelted and refined, which are used to manufacture condensers and rotor blades of steam turbines, heat exchange equipment in the nuclear power industry. After that, it became possible to improve the properties of metals by removing harmful impurities [1–13]. Abroad and in Ukraine, they began to produce commercial ingots from titanium smelted by the electron beam method. This direction is promising. As a rule, commercial ingots are produced by the duplex method: EBM + vacuum arc remelting (VAR). But at the same time, the direction of increasing the level of plasticity of titanium alloys remains insufficiently studied. It is of practical interest for researchers in the field of titanium alloys and makes this research topic relevant. Therefore, the goal is to determine ways to improve the plastic characteristics of titanium alloys VT1-0 and VT6 used for the manufacture of working blades of steam turbines in the nuclear power industry, as well as the effect of smelting by the electron beam method on the mechanical characteristics of this alloys.

METHODOLOGY

The research materials were VT1-0 and VT6 titanium alloys manufactured at the Electron Beam Metallurgy Plant (Kyiv). The structures and characteristics of commodity massive ingots weighing 1 and 2 t (D – 430 and 640 mm) were studied. The metal of nine industrial ingots of both VT1-0 and VT6 alloys was smelted by VAR and electroslag remelting methods. Data in relation to the VT1-0 alloy are given in Table 1 and Fig. 1 according to DSTU 3079-95 "Titanium of sponge parts. Technical mind".

RESEARCH RESULTS

It was shown that even after one remelting according to the original technology developed at the electron-beam metallurgy plant, the metal has a sufficiently high purity of impurities, a fine-grained uniform structure over the cross section of the ingots. This made it possible to make an assumption about the possibility of forging these industrial ingots after one, and not two, remelting, as is customary. The high purity of the metal from gas impurities was supposed to ensure, with comprehensive pressure treatment, the welding of small pores and impracticalities that were present in the volume of the ingots. In the literature at the disposal of the authors, there are no descriptions of precedents for the processing of large-sized titanium ingots obtained by EBM with an intermediate capacity (EBM) from a single remelt. Therefore, it was necessary for the two alloys under study (VT1-0, VT6) to determine the points of phase and structural transformations, the temperature regions of intense gas evolution and gas absorption during heating of the metal in order to establish the temperature regimes for forging ingots and preliminarily deformed of them blanks. In addition, it was necessary to develop a scheme and modes of metal pressure treatment along the entire technological chain based on the obtained scientific results.

The metal of nine industrial ingots of both VT1-0 and VT6 alloys has an increased purity of impurities. Data in relation to the VT1-0 alloy are given in Table 1 and Fig. 1 [14–18].

The total amount of impurities according to DSTU 3079-95 "Titanium sponge parts. 2 Tekhnichni umovi" in the VAR VT1-0 alloy is ~ 3.3 times higher than in real industrial ingots of the VT1-0 alloy of EBM. Moreover, gas impurities were removed more intensively, the total amount in electron-beam production ingots turned out to be 4.7 times lower, and metal impurities (Fe, Al, Si) – 2.85 times less. In this case, a comparison was made of the chemical composition of real ingots of electron-beam production and those regulated by GOST 19807-91.

Similar data were obtained for ingots of titanium alloy VT6, which were melted by the EBM and VAR methods. The weight of the ingot is 1.1 t. The chemical composition is given in Table 2.

In the VT6 alloy, the total amount of impurities is also significantly less after EPP melting (ΣD VDP/ΣD EBM = 3.8), especially gas components (by ~ 5.1 times), Fig. 2.

Table 1

Chemical composition of ingots VT1-0 of electron-beam with intermediate capacity and VAR

Size, mm DxL	Weight, kg	Chemical composition, %							
		Fe	Al	Si	O	N	C	H	Σ impurities
627x1500	2080	0.069	0.1	0.03	0.01	0.0 1	0.047	0.005	0.271
620x1535	2086	0.088	0.12	0.03	0.01	0.01	0.045	0.0050	0.308
624x1548	2130	0.096 _	0.1	0.03	0.01	0.01	0.047	0.0050	0.298
624x1462	2007	0.086	0.13	0.03	0.01	0.01	0.046	0.0050	0.317
616x1608	2036	0.084	0.1	0.03	0.011	0.005	0.040	0.0050	0.275
624x1608	2212	0.089	0.1	0.03	0.011	0.005	0.040	0.0050	0.280
625x1588	2202	0.100	0.12	0.03	0.012	0.005	0.040	0.0040	0.311
624x1490	2052	0.100	0.10	0.03	0.012	0.005	0.045	0.0050	0.293
Averages	–	0.089	0.109	0.03	0.0108	0.0075	0.044	0.0049	0.294
DSTU 3079-95	–	0.250	0.3	0.10	0.2	0.0 4	0.070	0.0100	0.970

Table 2

Chemical composition of VT6 alloy ingots smelted by EBM and VAR

Alloy	Chemical composition, %											
	Ti	Al	V	Fe	Si	Zr	O	N	H	C	ΣLE	ΣP	∑P gas.
VT6 EBM	89.7	6.38	3.65	0.176	0.043	-	-	0.007	0.005	0.023	10.25	0.274	0.052
VT6 VRT	88	6.40	3.60	0.300	0.100	0.30	0.20	0.050	0.015	0.100	10.70	1.065	0.265

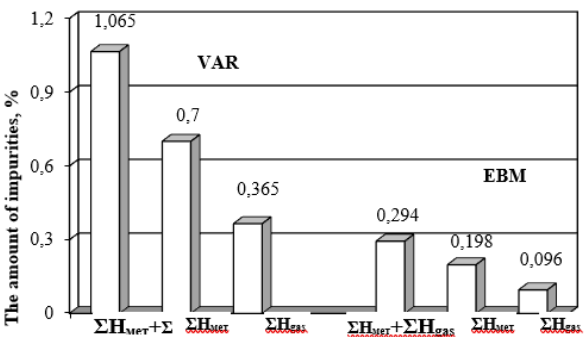

Fig. 1. The content of the total amount of impurities, metal and gas impurities in industrial ingots of the VT1-0 alloy, smelted by VDP and EBM

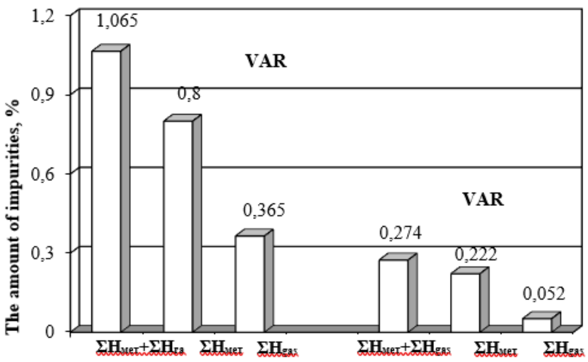

Fig. 2. The content of the total amount of impurities, metal and gas impurities in industrial ingots of VT6 alloy, smelted by VDP and EBM

Apparently, EBM with an intermediate capacity makes it possible to remove a significant (from 3.3 to 3.8 times) impurities amount, both in unalloyed (VT1-0) and alloyed (VT6) titanium alloys. This is due to the more flexible EBM smelting process compared to the traditional HFF smelting developed and widely used in the last 60 years. In EBM, the molten metal is in a vacuum chamber with a residual pressure of 1.33 to 0.013 Pa, while in VAR it is possible to realize the maximum rarefaction in the space between the consumable electrode made of pressed titanium sponge with ligatures and the melt bath is 3 Pa. Otherwise, enhanced evaporation of the molten metal occurs and the arc can close to the mold with extreme consequences: burning through the water-cooled mold and explosion due to the ingress of vapors into the working space of the melting chamber [5, 6, 13, 19–21].

In EBM, the zones of heating, melting and crystallization are separated in space. The charge in EBM units heating as a result local heating of the charge by powerful electron beams makes it possible to melt the metal under conditions of a deeper vacuum (from 0.133 to $1.3 \cdot 10^{-4}$ Pa). At the same time, it undergoes deep refining from gases, non-metallic inclusions, and contaminants. To date, melting electron-beam installations of various designs with powerful electron guns, which are automatically controlled by magnetic fields, have been created. In Ukraine there are EBM plants that allow producing titanium ingots weighing 10 t. This direction is the future of titanium metallurgy. However, we do not have specially created rolling, forging and other types of equipment and workshops for processing titanium by pressure, with the exception of a pipe plant. Little research has been done on the properties of ingots and billets of various types.

The presence of such impurities in spongy titanium, most of which are unregulated, namely: Al, V, Mo, Sn, Zr, Mn, Cr, Fe, Ti, Si, Cl, Mg, Na, Ca, K, S, Ni, As, Sc, Sb, Bi, Au, Ag. Their concentrations are very low, but as a result of their interaction with titanium and with each other, a noticeable change is possible, primarily in plastic properties.

The dependence graphs titanium of the elasticity saturated vapor and its impurities on temperature are plotted. From the analysis of changes in the elasticity values of the saturated vapor of elements in titanium, it was found that at a residual pressure in the melting chamber from 0.133 to $1.33 \cdot 10^{-3}$ Pa at the titanium melting temperature. Evaporation process develops selectively in the sequence: Cl → S → K → As → Na → Mg → Ca → Bi → Sb → Mn → Ag → Ni → Al → Sc → Si → Cr → Fe → Au.

Removal of these impurities from titanium alloys in the solid state is impossible. At the same time, it was found that titanium and vanadium (an alloying element of the VT6 alloy) evaporate at the melting temperature of titanium 10^3 times weaker than Fe, Cr, Si, 10^4 times weaker than Al, and 10^5 times weaker than Mn.

Thus, the possibility of liberation of titanium alloys from the majority of contaminants in the molten state has been shown, and melting modes (P_{ost} and T) for deep metal refining have been proposed.

In the process of repeated remelting, titanium is additionally contaminated with harmful impurities from the environment, therefore, an experiment was carried out on an industrial scale on titanium ingots with a total mass of more than 18 t to treat them by pressure without a second remelting. This minimized the energy costs for the production of ingots and semi-finished products from them.

Large-sized ingots obtained by the EBM method according to the original technology, after the first remelting, were a new material. They had a several times smaller amount of impurities, a fine-grained homogeneous structure with a high dispersion of phase components (VT6 alloy). In this regard, new tasks have arisen:

– study of the temperatures of phase and structural transformations, physicochemical processes accompanying the heating of the metal;

– development of temperature-time modes of heating for pressure treatment;

– development of the scheme and deformation modes from the ingot to the finished product;

– study of metal gas saturation.

By derivatographic study of cast samples of VT1 and VT6 alloys on a Q-1500 derivatograph and by the method of hardening and hardness determination, the main reference points of phase transformations, the beginning of gas saturation, and gas release were established. These data are presented in Table 3.

The temperature of the beginning of the polymorphic transformation of the VT1-0 alloy (EBM) is lower than in the serial alloy of VAR due to its significantly higher purity in terms of all types of impurities.

Table 3

Processes and transformations during heating of samples of alloy VT1-0 (EBM)

Temperature, ºC	Processes
90 to 120	Removal of moisture and degassing of adsorbed gases
200 to 230	Decomposition of unstable phases formed upon cooling in air
200 to 380	Decomposition of titanium hydrides
250 to 470	Relaxation of internal stresses
580 to 743	Recrystallization
680	Beginning of gas absorption
900	Harvest recrystallization
860 to 930	Polymorphic transformation

Similar data were obtained for the VT-6 (EBM) alloy, but with different phase and structural transformation temperatures due to its increased degree of alloying.

Based on these data, as well as the results of measuring the hardness of hardened samples, the temperatures of heating under deformation for the VT6 alloy (EBM) were determined. They differ from the data for serial titanium alloys of the same grades, but smelted by the vacuum-arc method. The substantiation of the time regimes of processing is made on the basis of the results of a study of structural and phase transformations in the studied cast samples of VT1-0 and VT6 alloys (EBM).

Fig. 3 shows a graph of heating under deformation of large-sized ingots with a diameter of 640 mm of VT1-0 alloy (EBM), developed based on the results of studies of transformation temperatures, their flow time, thermal conductivity of the alloy, and a preliminary study of the deformation of alloy samples.

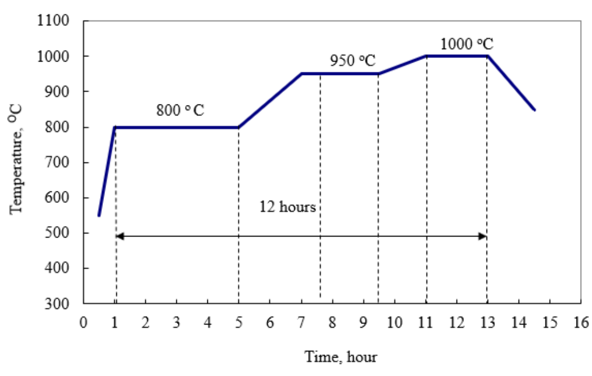

Fig. 3. The heating chart of ingots VT1-0 (EBM) ø 640 mm for deformation on an ISW 200 mc press

The final heating temperature for deformation on an ISW 2000 (Fig. 3) tf press was reduced for VT1-0 alloy (EBM) by 50 ºC, the duration was reduced by 4 h compared to the temperature-time modes of processing VT1-0 alloy ingots of similar sizes, but obtained by VAR.

The ingots were deformed into workpieces 250 mm on a 2000-ton ISW press according to the scheme – with the workpiece rotated by 90º and one intermediate heating.

Such a non-standard technology of deformation of the ingot into a billet made it possible to cut it into measured lengths for subsequent forging on hammers in a cold state. At the same time, not only energy consumption decreased, but also the loss of a more valuable metal – titanium. Before the final deformation, the alpha layer was removed from the workpieces on machines. The subsequent pressure treatment of the tubular billet was carried out by forging on hammers with one intermediate heating, a decrease in the initial and final re-forging temperatures by 50 ºC compared to the standard forging technology of the same VT1-0 alloy, which obtained by VDP. On hammers, the metal was then deformed according to the scheme to obtain pipe blanks and bars with a diameter of 120 to 60 mm and a length of 1500 mm. The rods were annealed to relieve stress at 700 °C for 1 h. The mechanical properties of the bars are given in Table 4.

Similar studies on the creation of a technological process for the pressure treatment of an ingot VT6 (EBM) on bars with a diameter of 50 mm and its heat treatment were carried out on the existing equipment for the deformation of ferrous metals at PC "Dneprospetsstal". These results are presented in more detail in our paper [20]. The mechanical properties of the VT6 (EBM) alloy for heat-treated bars with a diameter of 50 mm from ingots with a diameter of 430 mm at PC "Dneprospetsstal", are presented in Table 5.

All commercial rods and tubular blanks made of titanium alloys VT1-0 and VT6, made from ingots (18 t) of electron-beam remelting, after pressure treatment and heat treatment, had high properties and 100% yield.

In the study of various types of semi-finished products of VT6, VT6S, VT3-1, VT23 alloys, it turned out that the stability of the mechanical properties of products depends on the dimensions of the types of hot pressure treatment (Tables 6, 7).

Table 4

Mechanical characteristics of a pipe billet Ø 120 mm from alloy VT1-0 (EBM)

Alloy	Mechanical characteristics			
	$\sigma_в$, MPa	δ, %	ψ, %	KCU, MDzh/m^2
VT1-0, EBM	460	26.0	64.0	1.52
Same	460	28.0	59.0	1.92
-"-	370	27.0	59.0	2.08
VT1-0, VDP	380	20.0	42.0	1.00

Table 5

Comparative mechanical characteristics of the VT6 alloy manufactured by the EBM and VDP methods

Semifinished	Alloy	Mechanical characteristics				
		$\sigma_в$, MPa	$\sigma_т$, MPa	δ, %	ψ, %	KCU, MJ/m^2
Rod Ø 50 mm	VT6, EBM	1066	955	18.0	61.5	0.50
Same	Same	995	941	18.0	61.5	0.52
-"-	-"-	1050	940	18.0	61.5	0.51
-"-	-"-	980	941	15.0	52.0	0.50
-"-	-"-	1000	967	16.0	51.0	0.50
-"-	-"-	1000	963	17.0	52.0	0.50
Average value	-"-	1015	951	17.0	56.6	0.51
Rod Ø 49 mm	VT6, VDP	988	885	14.7	44.7	0.52
Rod Ø 50 mm	Same	1024	930	11.8	44.0	0.52
Same	-"-	982	880	14.4	42.0	0.49
-"-	-"-	999	890	14.6	49.0	0.52
Rod Ø 52 mm	-"-	963	870	13.8	48.0	0.53
Average value	-"-	991	891	13.9	45.5	0.51

Table 6

The variation coefficients in the values of the mechanical properties of semi-finished products of various types from titanium alloys

Alloy	The semi-finished product type	Dimensions	Coefficients variation			
			$\sigma_в$	δ	ψ	KCU
VT6S	Letter	Thickness from 1 to 10 mm	0.011…0.073	0.024…0.179	–	–
VT6	Rod	Diameter from 10 to 250 mm	0.018…0.056	0.10…0.20	0.09…0.22	0.11…0.57
VT3-1	Forging	Diameter 500 mm	0.068	0.461	–	–
VT23	Stamping	Weight 1500 kg	0.025	0.186	0.28	–

Table 7
Average values and coefficients of variation of the mechanical properties of titanium alloys VT6 and VT6S within one workpiece compared with the coefficients of variation of sheet steel 09G2S

Semifinished	Tensile strength		Relative extension		Relative contraction	
	average meaning, MPa	coefficient variations	average meaning, %	coefficient variations	average meaning, %	coefficient variations
Sheet 10 mm heat 866	935.3	0.008	9.34	0.12	29.9	0.11
Sheet 10 mm heat 866	866.9	0.007	12.3	0.07	34.9	0.07
Sheet 10 mm heat 707	927.7	0.009	12.7	0.07	38.7	0.09
Sheet 3 mm heat 772	919.4	0.036	eleven	0.11	22.1	0.21
VT6 bar Ø 100 mm	973.9	0.01	11.5	0.15	34	0.12
VT6 bar Ø 100 mm	950.8	0.013	12.34	0.17	33.6	0.10
Steel 09G2S sheet 10 mm	544.3	0.012	28.3	0.02	-	-

CONCLUSIONS

In this article the main scientific novelty of the research results, technologies for the production and processing of titanium alloys VT1-0 and VT6 (EBM) was as follows:

– smelting of massive (2.2 and 1.1 t) EBM ingots according to the method of Electron Beam Metallurgy Plant OJSC from one remelting;

– production of alloys of high purity by impurities with a homogeneous fine-grained macrostructure and a microstructure of increased dispersion, with shifted critical points of phase transitions towards lower temperatures;

– an increase in the ductility of both alloys by 24% and a significant improvement in the deformation of the alloys;

– creation of an original scheme for the processing by pressure of large-sized massive ingots of VT1-0 and VT6 alloys on the existing equipment for the deformation of ferrous metals at two different industries;

– development of energy- and resource-saving temperature-time modes and technologies of deformation and heat treatment, which provided higher mechanical properties ($\sigma_в$, δ, ψ, KCU) of finished products from two titanium alloys of EBM compared to serial alloys of vacuum-remelting arc.

The development of modes of heating for deformation and heat treatment was carried out taking into account comprehensive studies of gas saturation of compact titanium and titanium powders of various production methods.

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ВПЛИВ ГАЗОВИХ ПРИМІСІВ НА ВЛАСТИВОСТІ ТИТАНОВИХ СПЛАВІВ ВТ1-0 І ВТ6

С.А. Полішко

Розглядаються способи одержання титанових сплавів ВТ1-0 і ВТ6 та вплив газоподібних домішок на характеристики пластичності. Показано, що електронно-променева плавка з проміжною потужністю дозволяє видалити значну кількість домішок у титанових сплавах ВТ1-0 і ВТ6. Доведено, що промислова модифікація титанових зливків загальною вагою понад 18 т з подальшою їх обробкою тиском без переплаву дозволяє мінімізувати енергетичні витрати на отримання готових напівфабрикатів.