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STRUCTURE AND PROPERTIES OF INGOTS PRODUCED FROM SHEET SCRAPS OF VT1-0 TITANIUM BY ELECTROSLAG REMELTING IN AN OPEN MOULD

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ABSTRACT

Analysis of technologies, allowing titanium wastes to be used in the melting process in ingot production, was performed. It is shown that for this purpose, a promising and cost-effective schematic is the one which includes electroslag remelting with preliminary manufacture of a consumable electrode completely from standard wastes of sheet scraps of VT1-0 titanium. The structure and properties of electroslag ingots of titanium of 90×90 mm cross-section and 85 mm diameter was studied. The ingots were produced with application of electroslag remelting in an open mould with sliding current conduit and the slag pool surface protection by argon. Chemical composition of electroslag ingots of unalloyed titanium practically does not differ from that of titanium of VT1-2, VT1-L grades, and a whole range of grades of unalloyed titanium from foreign manufacturers, except for a somewhat higher content of oxygen and nitrogen. Ultrasonic testing of the ingots did not reveal any internal defects. Macrostructure, which was studied on longitudinal and transverse templates, is coarse-crystalline, dense and homogeneous without any defects of technological origin. The angle of inclination of the columnar crystallites to the ingot axis is 40–45°, grain size is 1.8–2.5 mm. The microstructure consists of transformed β-grains of 140–175 μm size. After annealing (620 °C), the mechanical properties of electroslag ingots were as follows: $HB = 224$; $\sigma_t = 590$ MPa; $\sigma_{0.2} = 560$ MPa; $\delta = 7.5$ %; $\psi = 13.5$ %. Technical measures were determined to improve the ductility of electroslag titanium by reducing the content of oxygen and nitrogen in the ingots, and refining the cast grain size. Technological properties of electroslag titanium (cutting treatment and weldability) are on the level of VT1-L. The possibility of pressure treatment (hot forging) was established with deformation coefficients of 40 and 90 % of titanium from electroslag ingots. The manufactured semi-finished products did not have any internal or surface defects.

KEYWORDS: processing, sheet scraps, titanium, electron beam melting, electroslag process, ingot, structure, chemical composition, mechanical properties, technological properties, hot forging

INTRODUCTION

For the development of modern electrometallurgy using secondary raw materials, titanium wastes are of particular importance. The most complete and rational use of wastes is a promising and priority way to make titanium products cheaper, which will undoubtedly strengthen the economic positions of the titanium industry. The use of wastes of titanium and its alloys in melting for production of serial titanium alloys, shaped casting, ferrotitanium and other products is the most rational and effective method of recycling [1].

Despite the additional costs caused by the preparation of wastes for melting, including sorting, determination of the chemical composition and impurities content, cleaning from technological contaminants (lubricating-cooling fluids, oil, oxidized as a result of thermal cutting of the surface), every 10 % of titanium wastes, which are additionally introduced to the charge, will reduce its cost by 5–8–%. Also, producing a one ton of ingot, it is possible to save up to 100 kg of titanium sponge and 5–10 kg of alloy elements [2].

The main methods of titanium melting, which allow using titanium wastes are vacuum-induction and vacuum-skull melts, electron beam and electroslag remelts. Vacuum-induction melting was developed by O.O. Fogel. Equipment for this process was developed in the USA (Retech Systems LLC) [3] and Germany (ALD Vacuum Technologies) [4]. In Ukraine, this technology is currently not applied.

In [1] it is proved that the most effective unit for melting of titanium wastes and its alloys is a vacuum-skull furnace, which operates on the technology of skull-consumable electrode (SCE). The most important economic advantage of the technology and SCE furnaces is a significant reduction in the volume of works on titanium wastes preparation for melting. The SCE technology, which uses titanium wastes, also provides the production of consumable electrodes for further vacuum-arc remelting (VAR). The combination of SCE and VAR technologies replaces a threefold VAR during melting of titanium Ti-10-2-3 and Ti–6Al–4V alloys [1].

Due to intensive research works at the PWI of the NASU, in the development of modern equipment and

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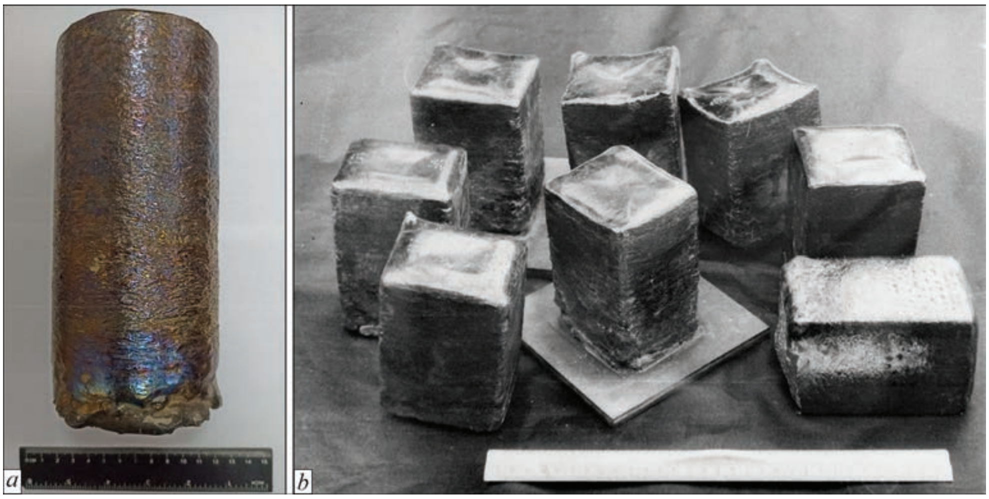

Figure 1. Titanium semi-finished products of two sizes, mm: diameter is 85 (*a*), cross-section is 90×90 (*b*)

technologies in the field of production of titanium ingots and slabs and other titanium products, the leading position was taken by the process of electron beam melting [5–8]. Industrial implementation and further improvement of titanium electron beam melting technology was carried out at such Ukrainian enterprises as SE "Titan Scientific and Production Center" of PWI", LLC "International Company "ANTARES", LLC "ZTMK", as well as in China, Germany, USA and other countries. The technological flexibility of the process of electron beam melting allows a titanium of different grades, shapes and sizes, as well as up to 30–40 % of a low-grade sponge (TG-Tv, TG-op) to be used quite widely in the production. For example, to produce ingots of unalloyed titanium (CP-titanium) of grades VT1-0, Grade 2, the technology of a one-time electron beam melting with an cold hearth was developed. The charge can also be supplemented with specially prepared titanium wastes in the form of chips and bottom parts of slabs [9]. This makes it possible to effectively reduce the cost of products both at the domestic as well as foreign markets.

Electroslag technology is less demanded, which is predetermined by some of the technical and technological nature of the production of commercial titanium ingots. Although, electroslag melting and, especially, the chamber electroslag process are successfully used for melting of low-weight titanium with a fairly wide ability of influencing their chemical composition, structure and properties [10, 11].

Certainly, both scientific and practical interest is represented by the possibility of using 100 % of the wastes of sheet scrap of titanium in the electroslag remelting. In [12], the rationality is substantiated and the fundamental possibility is shown of using the electroslag process in an open mould with a sliding current conduit for melting titanium ingots with the use of consumable electrodes, completely manufactured from the conditional wastes of sheet scrap of VT1-0 titanium. The titanium ingots are melted with 90×90 mm cross-sections and 85 mm diameter (Figure 1).

The further development in this direction [12] consisted in determination of the qualitative characteristics and technological properties of this material, which include: chemical composition, including gases content; physical homogeneity (macrostructure), microstructure; standard mechanical properties. On the basis of the obtained data, it is possible to give recommendations for the manufacture of specific products from electroslag titanium, and the chemical composition will allow establishing a list of aggressive environments, in which products from electroslag titanium are the most rational for operation.

It should also be taken into account that technological, economic and in general the possibility of manufacturing products from electroslag titanium is determined by such properties, such as cutting treatment, weldability and ability of titanium electroslag ingots to deformation treatment. This requires studying the possibility of using these processes for the manufacture of parts and equipment from electroslag titanium.

The aim of this work is to determine the main indices of metallurgical quality and technological properties of titanium ingots produced with the use of electroslag process in an open mould with a sliding current conduit, protecting the surface of the slag pool with argon and using consumable electrodes, produced entirely from the conditional wastes of scraps of VT1-0 titanium.

MATERIALS AND METHODS OF INVESTIGATIONS

The technology, based on which titanium electroslag ingots (Ti — base; C — 0.024 %; Fe — 0.06 %; Si — 0.05 %; O_2 — 0.25 %; N_2 — 0.058 %; H_2 — 0.016 %) were produced, is presented in [12].

In this work, the quality of the ingots was investigated by the following indices: macro- and microstructure; mechanical properties; cutting and pressure treatment; weldability.

The ingots were preliminary mechanically processed in a lathe to a depth of 2.5 mm in order to remove the alphated layer (Figure 2, *a*) for the further ultrasonic testing and pressure treatment. Ultrasonic testing of ingots was performed at the ZTMK LLC with the use of a flaw detector UD4-T and sensor 5K6.

The macrostructure of the ingots was investigated on longitudinal and transverse templates after etching with a 20 % solution of HF + 20 % HNO_3 + 60 % H_2O. The size of the cast grain was determined by the linear secant method of A.A. Glagolev [13]. Microstructure was detected by the same reagent on polished and etched sections and studied in the metallographic NEOPHOT-32 microscope at a magnification of 300–500 times.

Mechanical tests of cast electroslag metal [14] and welded butt joint [15] were performed in the computerized system Instron-8862. The mechanical properties of titanium electroslag ingots were determined after annealing at a temperature of 620 °C. The results were compared with the mechanical properties given for commercial titanium VT1-L, as well as α-alloys TL3 and VT5l in [16].

The cutting treatment during machining, drilling and cutting outer threads was evaluated by comparing technological samples from the electroslag ingots of titanium and VT1-L titanium in the process of manufacture. Melting of ingots from VT1-L titanium with a diameter of 80 mm for comparative cutting treatment characteristics was performed by a vacuum-arc remelting with a nonconsumable electrode in a vacuum-arc skull furnace [17]. The melting was conducted with a copper water-cooled electrode with a tungsten tip in a crucible made of grade MPG-7 graphite. As the starting charge materials waste scraps of conditional VT1-0 titanium were used. Before starting the works, the provided materials were preliminary mechanically ground to a fraction of 5–15 mm.

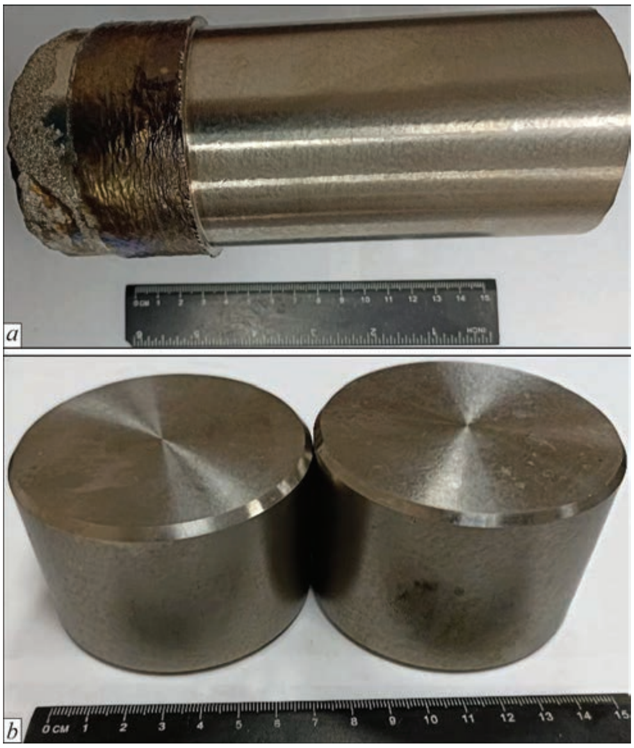

Figure 2. Ingot of 85 mm diameter with the alphated layer removed by lathe (*a*) and specimens for forging produced of this ingot (*b*)

On the technological samples, finished, semi-finished and rough surface treatments were provided. Research procedures, equipment, tools and cutting modes were chosen according to recommendations [18, 19].

Machining was performed by cutters with hard-alloy plates from VK-8 alloy of the following geometry: $\gamma = 0°$, $\alpha = 12°$, $\varphi = 14°$, $\varphi_1 = 45°$. The cutting rate is 30 m/min, the feed rate is 0.5 mm/rev, the cutting depth is 2.5 mm.

Drilling was performed with a 20 mm diameter drill of a quick-cutting steel P9F5 with the following geometry: $\gamma = 3°$, $\alpha = 12°$, $2\varphi = 120°$, $2\varphi_0 = 75°$, the angle of inclination of a spiral groove is 27°. The cutting rate is 20 m/min, the feed rate is 0.1 mm/rev.

Metric thread was cut by cutters with hard-alloy plates of VK-8 alloy with a cutting rate of 25 m/min.

The studies of weldability were performed according to the recommendations [20] on specimens with the sizes of 55×30×5 mm made of electroslag titanium ingots. The specimens were welded by a double-sided butt weld using nonconsumable electrode argon-arc welding with titanium filler (wire VT1-00 GOST 27265–87) on the following modes: current — 110–130 A, voltage — 12–18 V, argon (A class) flow rate is 12–16 l/min. Mechanical properties of the weld were determined according to GOST 6996–66, type of the specimen is XX IV. The produced joints were also tested for tightness by the kerosene sample according to GOST 3242–79. One side was coated with a water suspension of chalk and dried. The opposite side was moistened 2–3 times with kerosene. They were exposed during four hours.

Pressure treatment was performed by the method of hot forging at the SE "UkrNDIspetsstal" in the hydraulic forging press with an effort of 2 MN. For this purpose, from one of the ingots, the specimens (Figure 2, *b*) were produced, which were subjected to varying degree of deformation of 45 and 90 %. The forging technology was accepted the same as for standard ingots of VT1-0 titanium [21] by the following technological mode:

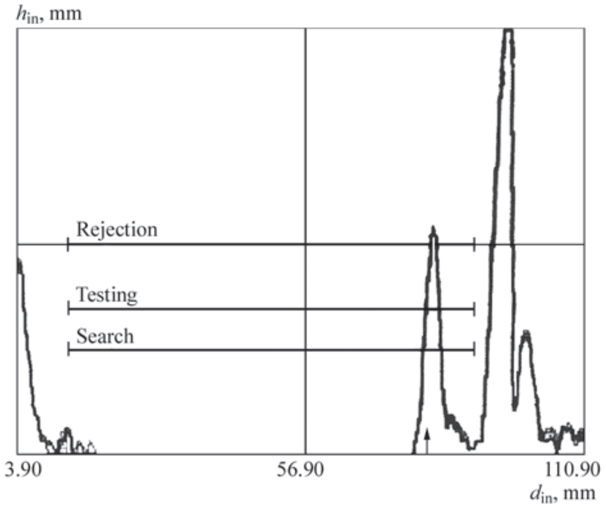

Figure 3. Scan of ultrasonic testing: T_A = 27.6 μs; y_A = 86.2 mm

preheating of heads before forging, °C	200–220
heating the billets in the furnace to temperature, °C	900–930
deformation of billets in a one pass, %–20–22	
temperature of forging end is not less than, °C	750
annealing temperature, °C	620–660
cooling of billets	in air to the environment temperature

RESEARCH RESULTS AND THEIR ANALYSIS

Ultrasonic testing showed that there are no internal defects and large non-metallic inclusions in the ingots. The presence of small-sized shrinkage cavities on the upper ends of the ingots (Figure 3) was recorded, which is predetermined by the fact that after the end of the melting, the shrinkage operation was not performed.

Macrostructure is coarse-crystalline, dense, homogeneous, there are no defects of technological origin (Figure 4). The size of the cast grain was 1.8–2.5 mm. The angle of inclination of columnar crystals to the ingot axis is 40–45° (Figure 4, *a*), which is typical for electroslag ingots produced on the optimal surfacing rate.

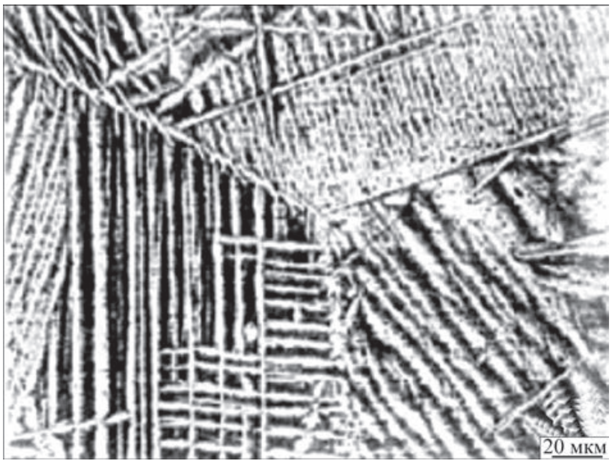

Figure 5. Microstructure of electroslag ingot of titanium

Microstructure (Figure 5) is typical of the cast titanium, i.e. transformed β-grain size from 140 to 175 μm consisted of α-plates.

In the study of the mechanical properties of electroslag titanium, it was established that the characteristics of strength σ_t and $\sigma_{0.2}$ is higher by 1.7 and 1.8 times respectively, than in commercial VT1-L titanium (Table 1). However, in terms of ductility, electroslag titanium is inferior. To increase strength, in α-alloys, TL-3 and VT5-L (σ_t and $\sigma_{0.2}$), alloying with aluminium is used (4.1–6.2 %), however, at the same time, their ductility is reduced (δ and γ). Comparing the mechanical properties of experimental titanium with the mechanical properties of TL-3 and VT5-L alloys, we can conclude that their difference is insignificant.

The lower characteristics of the ductility of the experimental ingots are determined not only by an increased content of oxygen and nitrogen, but also by a coarse-crystalline structure of cast titanium (Figure 4). For our conditions, it is possible to reduce the size of cast grain in ingots in the following way:

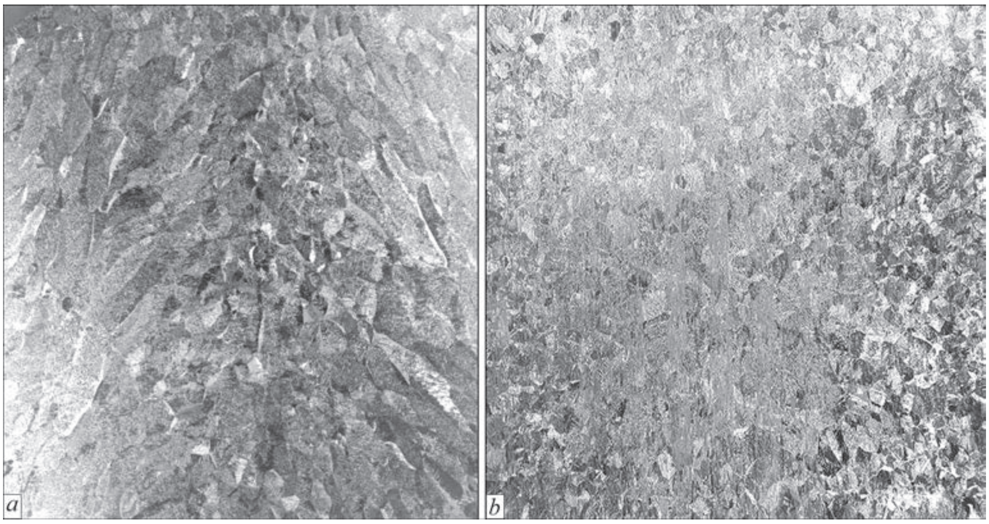

Figure 4. Macrostructure of electroslag ingots of titanium with 90×90 mm cross-section: *a* — longitudinal, ingot centre; *b* — transverse, 1/2 height of the ingot

Table 1. Mechanical properties of cast electroslag titanium, commercial VT1-L titanium and α-alloys TL-3, VT5-L and the quantity of impurities in them

Alloy	Mechanical properties				Quantity of impurities, %					
	σ_t, MPa	$\sigma_{0.2}$, MPa	δ, %	ψ, %	O_2	N_2	H_2	C	Fe	Si
Experimental titanium after annealing	590	560	7.5	13.5	0.25	0.058	0.0016	0.12	0.28	0.10
VT1-L* (commercial alloy)	<343	<297	<10.0	<20.0	<0.20	<0.05	<0.015	<0.15	<0.30	<0.15
TL-3* (Ti + 4.5 % Al)	<588	<539	<8	<16	<0.15	–”–	–”–	–”–	–”–	–”–
VT5-L* (Ti + 6.2 % Al)	<586	<627	<6	<14	<0.20	–”–	–”–	<0.20	<0.35	<0.20
*According to [19].										

- adjust the melting mode (current, voltage, deposition rate, amount of flux) to reduce the depth of the metal pool and increase the crystallization rate;
- modify the ingot by boron, lanthanum or yttrium [22–24].

It is also advisable to provide more effective protection against oxygen and nitrogen of air of a heated part of the consumable electrode and the surface of the slag pool. The application of these measures alone or in complex should significantly improve the ductility of the cast electroslag titanium.

In the study of technological properties, it was established that electroslag titanium is well subjected to mechanical treatment by cutting. No significant difference in cutting treatment was detected compared to VT1-L titanium. This was evidenced by both the nature of cutting (small twisted chips), as well as producing the required class of surface roughness and configuration of technological samples (Figure 6).

The appearance of the welded joint of the specimens produced from electroslag ingots is shown in Figure 7, *a*.

It was found that the formation of welds and the joint itself occurred normally, despite a somewhat increased oxygen and nitrogen content in the specimens, in the fusion area no pores were detected. When studying the welded joint macrostructure, its structural uniformity should be noted. Therefore, in the whole joint, the structure of cast titanium (Figure 7, *b*) is inherent. The strength characteristics of the weld are slightly lower than those of the base metal (electroslag cast titanium) and the ductility is higher (Table 2). The fracture of welded joint in the static tension test occurred over the weld, which is predetermined by the higher purity of the filler wire compared to the base metal. Therefore, in welding of cast commercial electroslag titanium a homogeneous and equal strength joint can be produced if alloyed filled wires, such as OT4sv or OT4-1sv are used. The spots on the chalk coating did not protrude, which evidenced to the tightness of the weld. This indicates that cast electroslag titanium can be used in sealed products.

Figure 6. Parts of electroslag titanium after mechanical cutting treatment, ×0.5

One of the main types of titanium and titanium alloys is pressure treatment. The variety of technologies and methods of pressure treatment allow receiving a wide nomenclature of titanium semi-finished products for industrial needs. Electroslag ingots of titanium have a slightly increased oxygen and nitrogen content and low ductility characteristics. This can impair the deformation capacity of cast electroslag titanium. Therefore, it became necessary to investigate it.

In the process of hot forging, in the manufactured specimens (Figure 2, *b*), technological difficulties that would require special modes and additional techno-

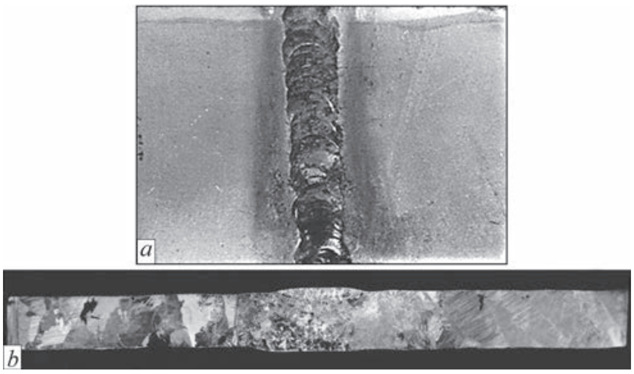

Figure 7. Welded specimen from electroslag titanium, ×1: *a* — appearance; *b* — macrostructure

Table 2. Mechanical properties of welded joint of cast electroslag titanium

Specimen	σ_t, MPa	$\sigma_{0.2}$, MPa	δ, %	ψ, %	*HB*
Base metal	590	560	7.5	13.5	224
Weld metal	556	530	8.9	15.8	218

Figure 8. Appearance of deformed titanium semi-finished products with varying degrees of deformation, %: *a* — 45; *b* — 90

logical measures, were not revealed. The produced two semi-finished products, the appearance of which is shown in Figure 8. No surface cracks and other surface defects were detected by outer inspection. During ultrasonic testing of deformed semi-finished products inner defects were also not found.

Thus, in the course of carried out works on the determination of technological properties, it is shown that the produced titanium is well subjected to deformation treatment (hot forging), cutting treatment and have a good weldability.

The further studies will be aimed at developing and using design and technical means for improvement of titanium protection against interaction with air, improving the process of melting in order to improve the ductility of titanium, study of influence of hot deformation of ingots on the structure and properties of produced titanium semi-products.

CONCLUSIONS

1. While studying the structure of the produced ingots, it was established: macrostructure is coarse-crystalline, dense, homogeneous, defects are absent. The angle of inclination of columnar crystals to the ingot axis was 40–45°, the size of the grains was 1.8–2.5 mm; microstructure represents transformed β-grains with the size from 140 to 175 μm consisting of α-plates.

2. When comparing the mechanical properties of titanium of electroslag ingots with similar characteristics of the most common grades of unalloyed cast titanium, it was found out: the characteristics of the strength of titanium of electroslag ingots (σ_t = = 610 MPa, $\sigma_{0.2}$ = 580 MPa) are higher by 70 % than those of unalloyed VT1-L titanium; a decrease in ductility in the experimental titanium is explained by an increased content of oxygen and nitrogen, as well as a large crystalline structure; the difference in the mechanical properties of the electroslag titanium and α-alloys TL-3 and VT5-L is insignificant.

3. Investigations of technological properties of titanium of electroslag ingots proved its good cutting treatment and weldability.

4. The fundamental possibility of pressure treatment (hot forging) of titanium of electroslag ingot of 85 mm diameter with the degrees of deforming of 45 and 90 % was established.

REFERENCES

1. Kolobov, G.A. (2013) Recycling of titanium and titanium alloy wastes. *Novi Materialy i Tehnologii v Metalurgii ta Mashynobuduvanni,* **1**, 138–140 [in Russian].
2. Garmata, V.A., Petrunko, A.N., Galitsky, N.V., Olesov, Yu.V. (1983) *Titanium: Properties, raw materials, physical and chemical bases and methods for the preparation.* Moscow, Metallurgiya [in Russian].
3. https://www.retechsystemsllc.com
4. https://www.ald-vt.com
5. Paton, B.E., Akhonin, S.V., Berezos, V.A. (2018) Development of technologies of electron beam melting of metals at the E.O. Paton Welding Institute of the NAS of Ukraine. *Sovrem. Elektrometal.,* **4**, 19–35 [in Russian]. DOI: http://dx.doi.org/10.15407/sem2018.04.01
6. Akhonin, S.V., Kruglenko, M.P., Kostenko, V.I. (2010) Removal of refractory inclusions from titanium in electron beam melting by the precipitation mechanism. *Advances in Electrometallurgy,* **4**, 232–236.
7. Paton, B.E., Trigub, N.P., Akhonin, S.V., Zhuk, G.V. (2006) *Electron beam melting of titanium*. Kyiv, Naukova Dumka [in Ukrainian].
8. Paton, B.E., Trigub, N.P., Akhonin, S.V. (2008) *Electron beam melting of refractory and high-reactive metals*. Kyiv, Naukova Dumka [in Russian].
9. Kalinyuk, A.N., Derecha, O.Ya., Telin, V.V. et al. (2018) Peculiarities of production of slab-type cast billets of VT1-0 and GRADE 2 types of low-grade spongy titanium. *Sovrem. Elektrometal.,* **3**, 20–26 [in Russian]. DOI: https://doi.org/10.15407/sem2018.03.03
10. Ryabtsev, A.D., Troyansky, A.A. (2001) Production of ingots of titanium, chromium and alloys on their base in chamber electroslag furnaces using “active” metal containing fluxes. *Problemy Spets. Elektrometallurgii***, 4**, 6–9 [in Russian].
11. Protokovilov, I.V., Nazarchuk, A.T., Petrov, D.A., Porokhonko, V.B. (2018) Technological and metallurgical peculiarities of melting the titanium alloy ingots in chamber-type electroslag furnaces. *Sovrem. Elektrometal.,* **2**, 45–50 [in Russian]. DOI: https://doi.org/10.15407/sem2018.02.06

12. Bilonik, D.I., Ovchynnykov, O.V., Bilonik, I.M. et al. (2022) Electroslag melting in an open mould of ingots from sheet scrap wastes of titanium VT1-0. *Suchasna Elektrometal.,* **1**, 34–39 [in Ukrainian].
13. Bogomolova, N.A. (1978) *Practical metallography.* Moscow, Vysshaya Shkola [in Russian].
14. (2019) DSTU ISO 6892-1:2019. *Metallic materials. Tensile testing.* Pt 1. Method of test at room temperature [in Ukrainian].
15. (1967) GOST 6996–66. *Welded joints. Methods of determination of mechanical properties* [in Russian].
16. Bibikov, E.L., Glazunov, S.G., Neustruyev, A.A. et al. (1983) *Titanium alloys. Production of shaped castings from titanium alloys.* Moscow, Metallurgiya [in Russian].
17. Ovchynnykov, O.V., Kapustian, O.E. (2020) Technology for smelting zirconium alloy ingots by vacuum arc remelting with a non-consumable electrode in a skull furnace. *Suchasna Elektrometal.,* **4**, 32–38 [in Ukrainian]. DOI: https://doi.org/10.37434/sem2020.04.06
18. Dreval, A.E., Skorokhodov, E.A., Ageev, A.V. (2005) *Guick reference guide of metalworker.* Moscow, Mashinostroenie [in Russian].
19. Glazunov, S.G., Vazhenin, S.F., Zyukov-Batyrev, G.L., Ratner, Ya.L. (1975) *Application of titanium in national economy.* Kyiv, Tekhnika [in Russian].
20. Paton, B.E. (1974) *Technology of fusion electric welding of metals and alloys.* Moscow, Mashinostroenie [in Russian].
21. Nikolsky, L.A., Figlin, S.Z., Bojtsev, V.V. (1975) *Hot stamping and pressing of titanium alloys.* Moscow, Mashinostroenie [in Russian].
22. Samsonov, G.V., Kashchuk, V.A., Cherkashin, A.I. (1970) Effect of transition metals on the grain size of titanium. *Metallovedenie i Termich. Obrabotka Metallov*, **11**, 30–32 [in Russian].
23. Grigorenko, G.M., Akhonin, S.V., Loboda, P.I. et al. (2016) Structure and properties of titanium alloy doped with boron, produced by the method of electron beam remelting. *Sovrem. Elektrometal.,* **1**, 21–25 [in Russian]. DOI: https://doi.org/10.15407/sem2016.01.03
24. Goltvyanchuk, V.S., Bankovskyi, O.B., Tsyvirko, E.I. (2009) Modifying titanium-aluminium cast alloys by boron. *Novi Materialy i Tehnologii v Metalurgii ta Mashynobuduvanni*, **1**, 86–88 [in Ukrainian].

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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