MHD TECHNOLOGIES OF ELECTROSLAG WELDING AND MELTING OF TITANIUM ALLOYS FOR AEROSPACE INDUSTRY

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The basic tendency in improvement of titanium alloys is the need in increase of a specific strength of structures of aerospace engineering. Owing to the strength of advanced alloys Ti-10-2-3 (USA) and VT22 (Russia), reaching 1300-1400 MPA, titanium is used wider and wider in the load-carrying airframes and most loaded parts of engines of the modern airplanes "Boeing", "Airbus", "Antonov", "Ilyushin " and others. The present task is the development of alloys with tensile strength of 1600 MPa and higher [1].

The present tendencies in the further strengthening of aviation titanium alloys are realized in the process of metallurgical melting of ingots (in welding of titanium structures, respectively). The further increase in the level of alloying of high-strength alloys should be accompanied by:

- reduction in content of harmful impurities and inclusions in their metal;
- increase in chemical and physical homogeneity of alloys;
- maximum refining of crystallites of cast metal of ingots and welds.

Hydrodynamics of the metallurgical melt in electroslag remelting (ESR) does not only refine the ingot crystallites, but does not provide the necessary homogeneity of distribution of the master alloy and fine-dispersed inclusions in multi-component high-alloy alloys either.

As far back as in the 70's of the last century, young researchers E.V. Shcherbinin, Yu.M. Gelfgat from the Institute of Physics (Latvia) and Ya.Yu. Kompan from the E.O. Paton Electric Welding Institute (Ukraine) made the first attempts in joint efforts to realize, by means of magnetohydrodynamics, the welding of titanium large-sized products without chamber, in the air, with local protection of the welding zone by inert gas [2, 3].

The distinguishing features of the method of magnetically-controlled electroslag welding (MEW), if compared with the canonical method of electroslag welding (ESW), are the direction and the intensity of the welding molten metal movement [3]. Spontaneous slag movement in ESW from the electrode downwards, deepening the central part of the metal pool, promotes the unfavorable radial orientation of crystallites and weld. Controlled upward flows to the electrode in MEW in a longitudinal field, deepening the periphery areas of the pool, promote the favorable axial orientation of the growth of crystallites (Fig. 1*a*).

Another specific feature of the MEW is the high intensity of movement of the welding molten metal in the pool, its movement rates reach 1 m/s and more. To initiate these flows, the interaction of the electric current with a natural magnetic field is not sufficient, as the action of more powerful external magnetic fields is necessary. These fields in MEW are the longitudinal and transverse magnetic fields. Consequently, the first field creates a secondary reverse rotation of the

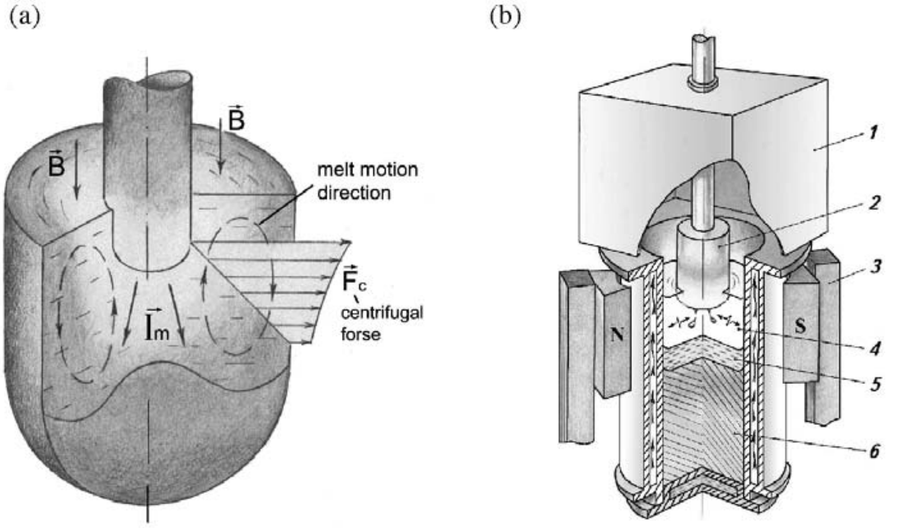

Fig. 1. (*a*) – Welding (melting) in a longitudinal magnetic field; (*b*) Melting in a transverse magnetic field: *1* – vacuum chamber, *2* – electrode, *3* – electromagnetic system, *4* – slag pool, *5* – metal pool, *6* – ingot.

molten metal when interacts with the welding current (Fig. 1*a*). The second, a transverse field, adjusts the electric eddy toroidal rotation of the molten metal, replacing it by a reciprocal movement using vibration (Fig. 1*b*).

The high performance of welds of the MEW technology (in 1.5–2 times higher than in ESW metal), tested on full-scale samples and under the real service conditions of underwater and air vehicles, showed the efficiency of conversion application of magnetohydrodynamic features (know-how) of welding technology in melting of ingots.

Projects of the Science and Technology Center in Ukraine (STCU) No. 336, 1542 and 99(j) on the creation of new methods of the magnetically-controlled electroslag melting (MEM) have won at the competition of conversion projects and since 1996 are financed by the USA and Canada.

The conversion nature of new technological processes of MEM was inspired by the need in rational use of scientific-technical developments of the related technology of welding (MEW) of titanium in them.

Low densities of the electric current in electrodes, of 1–2 $\mathrm{A/mm^2}$ order, require the use of more powerful external magnetic fields than in welding. This is required to provide the hydrodynamic refining of cast crystallites of the ingot.

Densities of the electric current in welding with a plate electrode exceed in several times the current densities in a consumable electrode in ingot melting. And the densities of the current in wire electrodes of 4 and 5 mm diameter at boosted welding conditions can reach 100 $\mathrm{A/mm^2}$, i.e., by 2 orders can exceed the similar characteristics in melting.

Melting of titanium alloys by the MEM method in a transverse magnetic field is one of the most technologically adaptable processes of melting (Fig. 1*b*).

The use of the alternating current of melting at induction $B \leq 0.12$ T energizes only the melt vibration, not changing radically the electric eddy flow (only some its braking is possible). At the external field $B = 0.12$–0.2 T the vibration suppresses the rotational movement in the metallurgical pool, contributing to the purification of molten titanium from harmful impurities and inclusions using a flux.

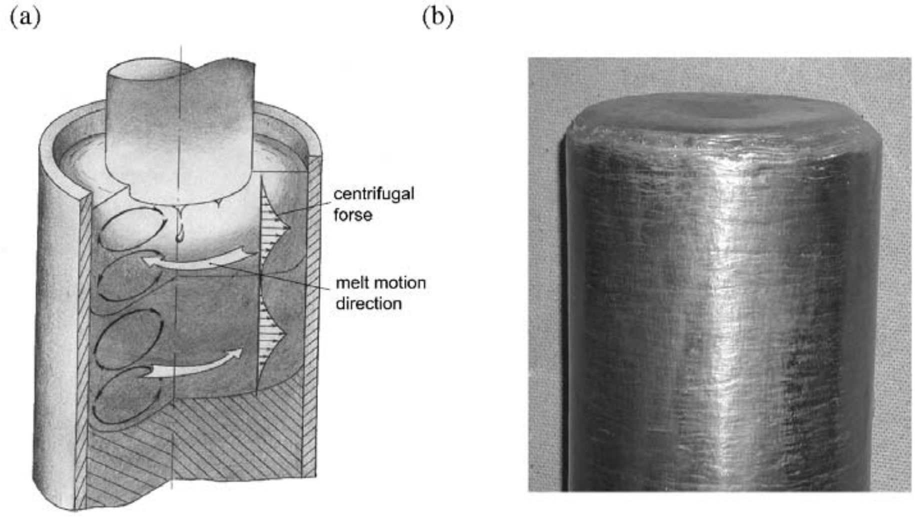

Fig. 2. (*a*) – Melting in a radial magnetic field; (*b*) – MEM ingots are characterized by a smooth lateral surface.

In addition, the conditions of ingot crystallization are improved: the unfavorable radial orientation of growing crystals is changed closer to the axial orientation, some refining is observed. The best conditions of metal purification, assurance of its chemical and physical homogeneity at a uniform fine-crystalline structure are created at induction $B = 0.2–0.25$ T.

Similarly to welding (MEW), the melting in a longitudinal field is accompanied by a secondary rotational movement of the melt (Fig. 1*a*). Upward melt flows to the electrode activate the processes of metal purification from harmful impurities and inclusions, increase the homogeneity of distribution of the master alloy and microinclusions in the ingot, contribute to refining of crystallites along the front of crystallization. Under the action of the field a more intensive formation of nuclei of crystallites is occurred if compared with the intensity of their growth. The action of powerful electric eddy flows of the melt on the branches of crystallites, coming beyond the front of crystallization, refines them and fragments of crystallites, entered the melt, play the role of new centers of crystallization.

At melting in a radial magnetic field, the interaction of the electric current in the pool with variable, in the induction direction, radial magnetic fields drives the movement of slag and metal melt in the form of several tores (Fig. 2*a*). This hydrodynamics increases, first of all, the trajectory of the movement of electrode metal drops in a slag pool. This, in its turn, activates the thermodynamic processes of chemical interaction and purification at the metal-slag interface. This, more complex and elongated trajectory of the molten electrode metal in the slag pool promotes a more complete dissolution and uniform distribution of the master alloy and foreign inclusions in the crystallizing alloy. Fig. 2*b* shows an ingot of the MEM technology.

The methods of welding MEW and melting MEM are protected by Ukrainian and foreign patents for invention [4, 5, 6]. Technological processes, based on their use, are protected additionally by an appropriate "know-how".

Conclusions.

1. The process of the magnetically-controlled electroslag melting (MEM) of titanium alloys are based on the conversion investigations of the magnetically-controlled welding (MEW).

2. Source and reserve of improvement of titanium alloys (increase in their strength, ductility and serviceability) are the magnetohydrodynamic refining, homogenization and refining of cast metal structure.
3. Application of radial and transverse external magnetic fields in MEW and MEM allows replacement of non-controlled electric eddy flows of the melt by the controlled rotational and reciprocal movement in the pool.
4. The performance of cast metal of MEW and MEM is 1.5-2.0 times increased under the conditions of alternating dynamic stresses if compared with traditional metal of arc, electron beam and electroslag technologies.
5. Improvement of means of magnetohydrodynamic action on melting and crystallization of metal of MEM technology is challenging for the development of titanium alloys with 1600 MPa strength and higher.

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