ELECTRON BEAM WELDING OF SHEET COMMERCIAL TITANIUM VT1-0, HARDENED BY NITROGEN IN THE PROCESS OF ARC-SLAG REMELTING, AND PROPERTIES OF PRODUCED JOINTS*

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Shown is the efficiency of application of electron beam welding (EBW) for producing full-strength welded joint of commercial titanium rolled metal of 35 mm thickness, hardened by nitrogen of up to 0.1 wt.% in the process of arc-slag remelting (ASR). Data of X-ray spectral analysis prove the uniform distribution of nitrogen, aluminium, titanium, iron, oxygen both in the ASR rolled metal and also in the welded joint. Metallographic examinations confirmed the producing of quality welded joint without cracks, pores and other defects. Weld metal and base metal are characterized by a homogeneous structure. The uniform distribution of hardness *HB* and microhardness *HV* was observed both in the sheet commercial titanium and also in the welded joint. At content of nitrogen of up to 0.1 wt.% in titanium the hard inclusions of titanium nitride are absent both in the sheet ASR rolled metal and also in the weld metal made by the EBW. 13 Ref., 5 Figures.

Keywords: *commercial titanium, arc-slag remelting, titanium hardening with nitrogen from gas phase, sheet rolled metal, electron beam welding, macro- and microstructure, mechanical properties of welded joint*

The new method of remelting of consumable electrode by electric arc, burning between the electrode tip and surface of molten slag pool in a copper water-cooled mould was, developed at the E.O. Paton Electric Welding Institute (PWI) in the beginning of the 1970s and patented in 1982 under the name of the arc-slag remelting (ASR) [1]. Later, the carried out investigations, including those under the plant conditions, showed that in comparison with a traditional electroslag remelting the new method of ASR is economically profitable and allows producing metal, not being inferior to the ESR metal as to the quality.

Figure 1. Macrosections of fillet and butt joints of sheet commercial titanium made by EBW

The first results of investigations of ASR of titanium and its alloys, carried out at the PWI under laboratory and plant conditions, showed [2–4] the challenging future of this method in the solution of problems of reducing the prices in manufacture of semi-products of titanium and its alloys, fist of all, of commercially pure titanium. The feasibility of producing the large-tonnage ASR ingots of rectangular section with a good surface, not requiring the machining for the direct rolling, allows reducing greatly the loss of metal in manufacture of titanium semi-products and decreasing the cost of finished products.

The main factor for reduction of prices of titanium products is also the feasibility of realization of a single-stage ASR process of spongy pressed electrodes [5–7].

Titanium and its alloys are characterized by the better combination of high mechanical prop-

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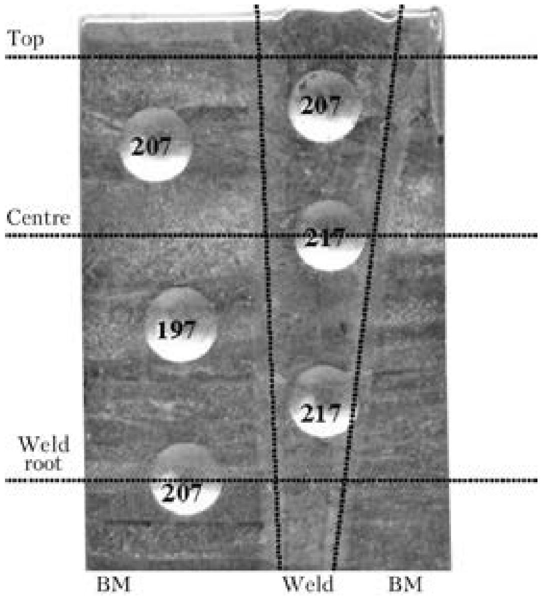

Figure 2. Appearance of specimen of welded joint of sheet commercial titanium and values of Brinell hardness obtained in longitudinal section

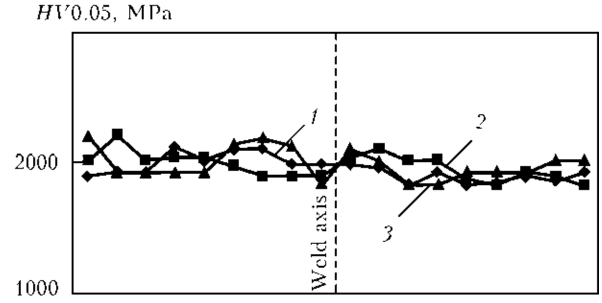

Figure 3. Distribution of microhardness across the EB-welded joint on sheet commercial titanium: *1* — top; *2* — centre; *3* — weld root

erties and low density as compared to other structural materials. Commercial titanium VT1-0 at significant corrosion resistance in different aggressive media has comparatively low strength properties ($\sigma_t \leq 400$ MPa). However, the problem is solved successfully by alloying of titanium with aluminium, vanadium, manganese, molybdenum and other elements, moreover, without noticeable decrease in its ductile properties. As is known, the strength and ductile properties of the commercial titanium are greatly affected by content of oxygen and nitrogen in it [8, 9]. Complex of investigations, carried out at PWI, showed the possibility of increasing the strength characteristics of commercial titanium VT1-0 by its alloying with nitrogen from gas phase in the ASR process [10]. As a result, the commercial ASR titanium was produced, having the strength characteristics at the level or higher than the values of GOST 23755–79 [11].

The next stage of investigations was the evaluation of possibility for producing a full-strength welded joint of 35 mm thickness on sheet rolled metal of commercial titanium VT1-0, hardened with nitrogen of up to 0.1 % from the gas phase in the ASR process (further, the sheet commercial titanium), made by EBW.

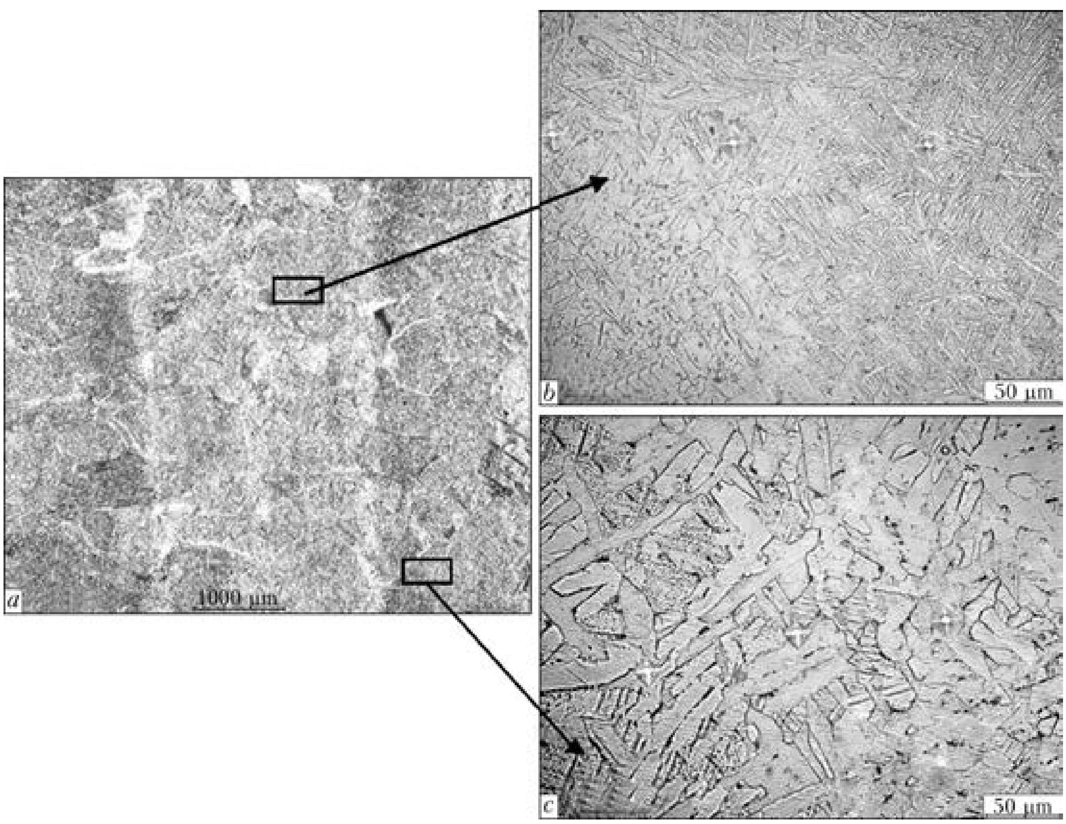

Figure 4. Microstructure of joint zone (*a* — ×25), weld (*b* — ×400) and base metal (*c* — ×400)

It is known that when the titanium is alloyed with nitrogen from the solid phase, the nitrides of different chemical composition are formed, in particular, in the process of remelting of titanium sponge and next producing of titanium alloys. Alongside with titanium nitrides the hard inclusions, enriched with nitrogen, can form. Therefore, one of the tasks consisted of evaluation of the probability of formation of hard inclusions of titanium nitride in sheet commercial titanium and its welded joint in EBW. The possibility of dissolution of hard particles of titanium nitride in molten titanium was also studied [12].

The fillet and butt joints of the sheet commercial titanium were made, the appearance of which is shown in Figure 1. In both cases a good formation of weld and the absence of any defects in weld metal and near-weld zone were noted.

The level of Brinell hardness was evaluated in the specimen longitudinal section. Measurements were carried out at 3000 kg load by a ball of 10 mm diameter. Weld metal had *HB* 207–217, base metal – *HB* 197–207 (Figure 2). Microhardness was measured in LECO hardness meter M-400 at 50 g load and 100 μm pitch in different zones of the welded joint. As the measurements showed (Figure 3), the values are rather uni-

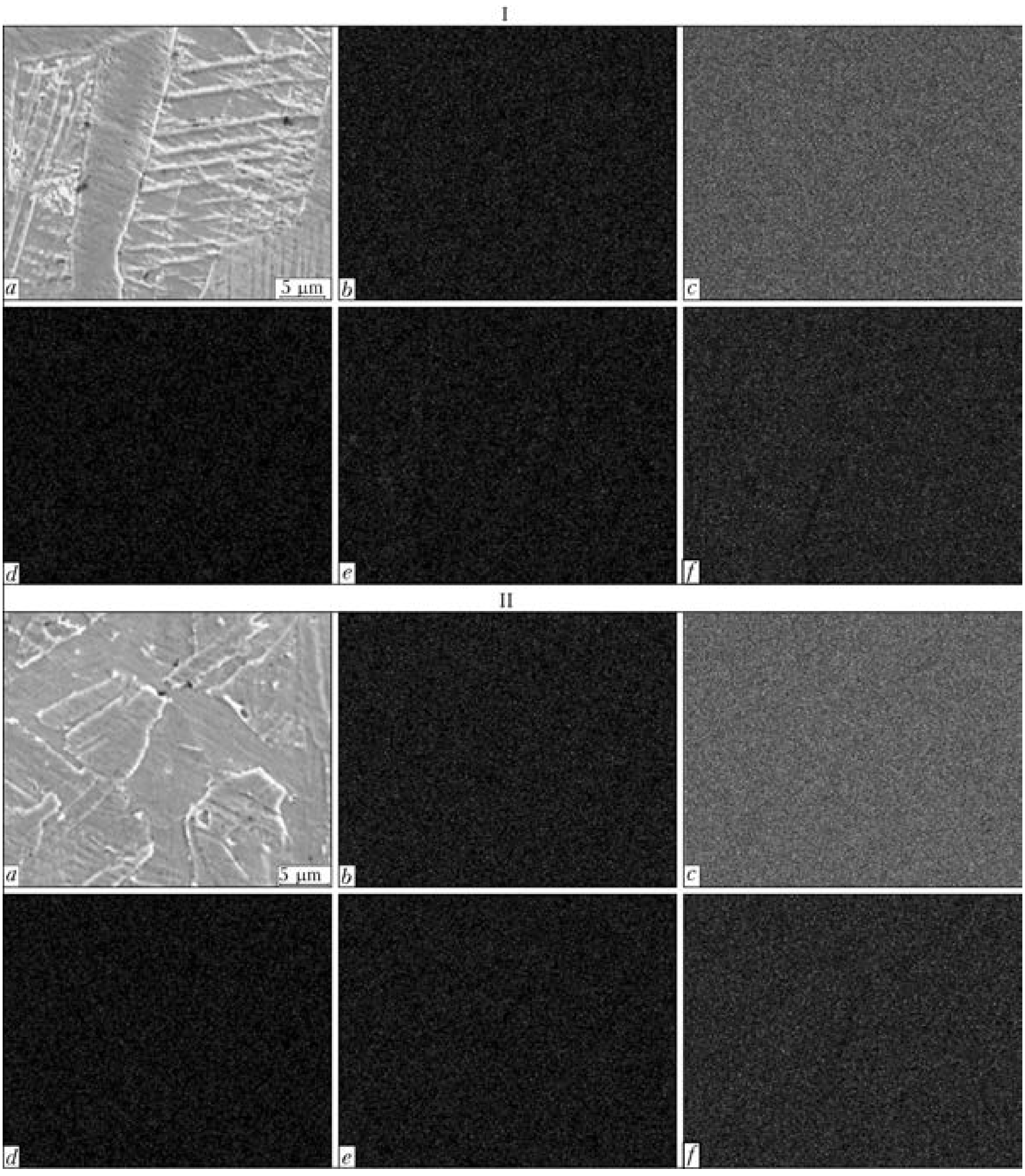

Figure 5. Microstructure (×2000) of base metal (I, *a*), weld metal (II, *a*) and concentration maps of distribution of aluminium (I, II, *b*), titanium (*c*), iron (*d*), oxygen (*e*) and nitrogen (*f*)

formly distributed in the entire volume of the welded joint and amount in the weld upper part to *HV* 1830–2120, in the center — to *HV* 1830–2210 and in the root — to *HV* 1830–2200 MPa.

To examine the microstructure of specimens of welded joints, the chemical etching by reagent $HCl + HNO_3 + H_2O$ was applied and microscope Neophot-32 was used. Structure of the zone of joint, weld and base metal is given in Figure 4. Metallographic examinations* showed that the quality defectless welded joint with a homogeneous structure was produced. Weld of about 3 mm width has an acicular structure with needles of different length (15–40 μm), located at 60° angle. The base metal contains a coarser grain (50–100 μm), the main structural component is α′-phase.

The analytic complex for X-ray spectral examinations was used, which consists of a scanning electron microscope JSM-35CF (JEOL, Japan) and system for energy-dispersed microanalyzer INCA Energy-350 (Oxford Instruments, Great Britain). Experiments were carried out at accelerating voltage of 20 kV, 200- – 10000-fold magnification, element analysis was made in the range from boron to uranium.

Data of X-ray spectral analysis prove the uniform nature of distribution of elements (nitrogen, oxygen, aluminium, iron) in the structure of base metal, hardened with nitrogen of up to 0.1 %, and weld metal, made by EBW (Figure 5). At clearly revealed relief of the structure (Figure 5, I, II, *a*) the chemical non-homogeneity by main elements is not observed. Results of examinations confirm also that at content of up to 0.1 % of nitrogen in titanium the hard inclusions of titanium nitride are absent.

In conclusion, it is necessary to outline the urgency of the carried out works for the updating the technological processes of producing the commercial titanium [13] and increase of its strength characteristics by a regulated adding of admixtures, in particular, the interstitial elements. To produce the full-strength joint of the sheet commercial titanium 35 mm thick, hardened by nitrogen of up to 0.1 % in the ASR process, the application of EBW is effective. At such concentration of nitrogen the hard inclusions of titanium nitride are absent in all the zones of welded joint. The uniform distribution of nitrogen, aluminium, titanium, iron, oxygen, formation of homogeneous microstructure and rather uniform distribution of hardness and microhardness are noted. It is also important that such hardened commercial titanium can find the wide application in industry and medicine.

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