INFLUENCE OF LOCAL HEAT TREATMENT AT EBW OF TITANIUM ALLOYS WITH SILICIDE STRENGTHENING ON MECHANICAL PROPERTIES OF WELD METAL

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Disadvantages of EBW of complex-alloyed titanium alloys include high rates of weld metal heating and cooling, leading to lowering of ductility properties. Research objective consisted in determination of the influence of preheating and local heat treatment by the electron beam on prevention of formation of defects in the form of cracks and improvement of ductility properties of welded joints of high-temperature titanium alloys. Research purpose was determination of preheating temperature to prevent the negative influence of high temperature gradient characteristic for EBW. In this case a smoother temperature gradient in welding is ensured that prevents cracking. After welding the joints were subjected to local annealing at the temperature of 900 °C for 10 min. All the welded joints were subjected to X-ray testing and metallographic examinations. It was revealed that varying the heating parameters at local heat treatment by the electron beam allows controlling the rate of phase and structural transformations in titanium alloys with silicide strengthening and, thus, changing the structure and, therefore, also the properties of welded joints that allows storing the welded structures for a long time before conducting total furnace treatment. The proposed approach can be used in manufacture of axial-flow compressors for gas turbine engines and power units. 6 Ref., 1 Table, 7 Figures.

Keywords: *electron beam welding, complex-alloyed titanium alloys, weld metal, local heat treatment, mechanical properties, prospects for application*

High-temperature titanium alloys are structural materials in manufacture of aircraft engine parts. Beginning from mid-1970s, EBW of parts from these alloys became widely accepted, allowing their narrow-gap joining with minimum distortion that is required in welding of axial-flow compressors. Disadvantages of EBW of high-temperature complex-alloyed titanium alloys include high rates of heating and cooling of weld metal and HAZ, leading to an abrupt lowering of ductility properties [1] that may cause defect formation in the form of transverse cracks at cooling after welding (Figure 1). Therefore, in welding of such structures it is rational to apply local heat treatment (LHT) directly in the chamber of EBW machine [2]. This technology allows prevention of cracking and improvement of ductility properties of welded joint metal for items of a small mass.

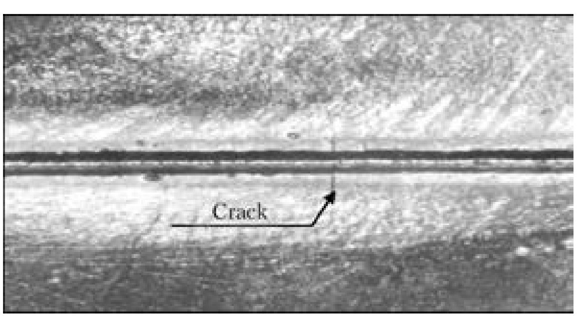

Figure 1. Appearance of EBW weld with a characteristic defect in the form of a crack

This work is a study of EB LHT influence on mechanical properties of weld metal in test titanium alloys with silicide strengthening of Ti–6.08Al–2.18Sn–3.88Zr–0.39Mo–1.14V–0.65Si (alloy 1) and Ti–5.5Al–3.02Sn–4.58Zr–0.1Mo–0.8Nb–0.59V–0.6Si (alloy 2) composition. Ingots were melted out in skull EB installation ISV-004 [3]. After rolling the produced alloys were annealed by the modes recommended for pseudo-α-alloys [4]. Experiments were conducted on flat samples of 150 × 70 × 13 mm size. EBW was performed in one pass with through-thickness penetration in UL 144 machine fitted with ELA 60/60 power unit. At LHT the width of the heated section was determined so that it covered the weld and HAZ. Figure 2 gives the appearance of a rectangular scan in the focused condition. At LHT beam current, focusing, impact duration and scanning frequency of the beam were selected from the

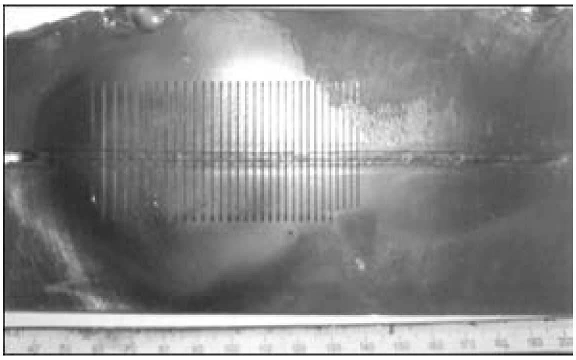

Figure 2. Appearance of rectangular scan used for LHT

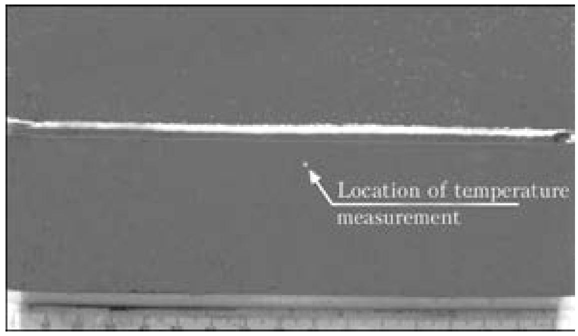

Figure 3. Location of thermocouple for temperature measurement at LHT

condition of ensuring temperature on the level of 750–950 °C in the treated section.

Temperature monitoring was performed using thermocouples fastened from the weld root side (Figure 3). Such a procedure is published in [5].

As was mentioned above, high heating and cooling rate, characteristic for EBW, is one of its disadvantages. In order to eliminate this negative influence, the impact of preheating on mechanical properties of the metal of welds of test titanium alloys 1 and 2 was studied. Such a method was not applied earlier in EBW of titanium alloys unlike subsequent LHT by the electron beam [6].

Preheating temperature was selected from the condition of ensuring a lowering of the level of welded sample deformations. We have tried out three preheating temperatures: 200, 300 and 400 °C, which ensured a smoother temperature gradient in welding. Mechanical testing of welded joints was conducted after each welding cycle with preheating. Test data are summarized in the Table. Conducted testing showed that the optimum preheating temperature of titanium alloys 1 and 2 is equal to 200 °C (Figure 4). Further increase of preheating temperatures to 300 and 400 °C leads to lowering of welded joint ductility (see the Table).

After welding of joints on titanium alloys 1 and 2, local annealing was performed at the temperature of 900 °C for 10 min (Figure 5). Welded joint macrostructure did not change after LHT. All the welded joints were subjected to X-ray testing and metallographic examination. No cracks were detected in welded joints, as LHT promoted relieving of welding stresses which are

Mechanical properties of weld metal of titanium with silicide strengthening*

Material	Preheating temperature for 5 min, °C	LHT temperature, °C, and duration, min	Yield point, MPa	Tensile strength, MPa	Impact toughness, J/cm^2	Notes
Alloy 1	–	–	1106.4	1208.2	9.05	Base metal
	Without HT	–	–	1309.7	–	Brittle fracture
	200	–	–	1187.6	5.40	–
	200	900, 10	810.5	1182.0	5.28	–
	300	–	–	1167.7	5.10	–
	300	900, 10	743.3	1088.9	4.97	–
	400	–	–	1192.0	3.88	–
	400	900, 10	789.8	1132.9	3.35	–
Alloy 2	–	–	1136.0	1273.6	10.4	Base metal
	Without HT	–	–	1190.6	–	Brittle fracture
	200	–	–	1140.1	4.91	–
	200	900, 10	1024.1	1042.9	4.40	–
	300	–	–	1167.8	3.28	–
	300	900, 10	1010.0	1167.8	3.16	–
	400	–	–	1040.8	3.13	–
	400	900, 10	1006.1	1168.0	3.48	–

*Average values after testing three samples are given.

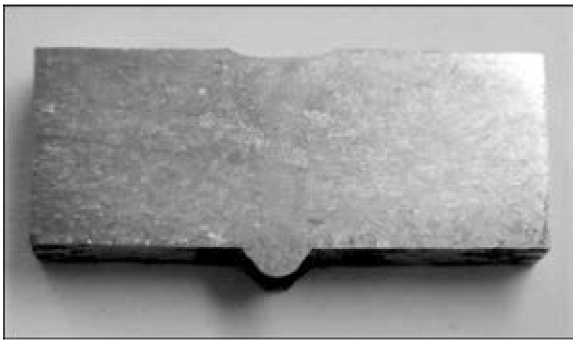

Figure 4. Macrosection of welded joint of alloy 1 made by EBW with 200 °C preheating

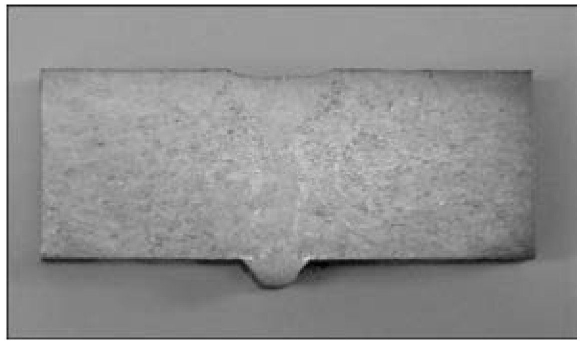

Figure 5. Macrosection of welded joint of alloy 1 made by EBW with 200 °C preheating and post-weld LHT

the main cause for cracking. As was noted in [2], varying the heating parameters at LHT by the electron beam allows not only eliminating welding stresses, but also controlling the rate of running of phase and structural transformations in titanium alloys and, thus, favorably changing the structure and properties of welded joints and ensuring complete absence of defects in them.

Technology of welding with post-weld LHT allows prevention of welded joint cracking up to performance of general furnace treatment.

Studied alloy 1 belongs to the group of pseudo-α-alloys of titanium, and has the coefficient of β-phase stabilization K_β = 0.1. In as-rolled condition the alloy has a plate-like structure (Figure 6, *a*), in which silicide particles are located relatively uniformly within primary β-grains both along the boundaries, and in the volume of α′-plates. Annealing stimulates the diffusion processes, the result of which is silicide concentration along the boundaries of α-plates (Figure 6, *b*).

Microstructures of a welded joint of alloy 1 are shown in Figure 7. Weld metal consists of aimed in the heat removal direction primary β-grains with plate-like α′-phase in the grain volume. In the weld upper part, the grains grow with 45° inclination to weld axis (Figure 7, *a*),

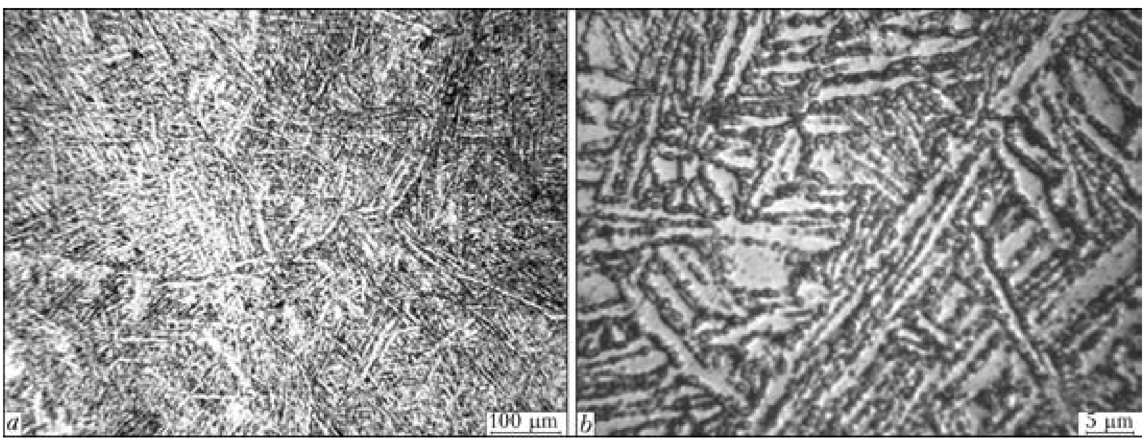

Figure 6. Microstructures of base metal of alloy 1

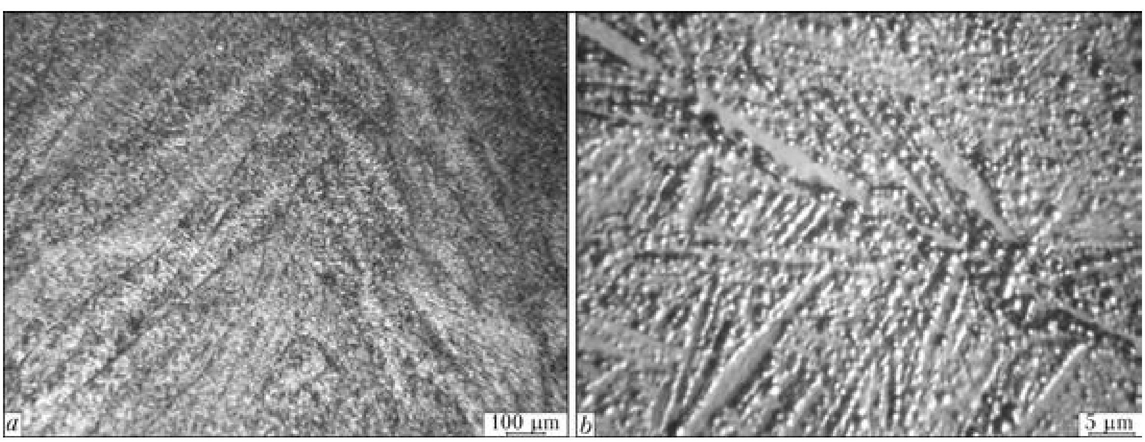

Figure 7. Microstructures of weld metal of alloy 1 after EBW with preheating at 200 C and post-weld LHT

and in the grain middle they intergrow at an angle of about 180°. After welding silicide particles are localized both along the boundaries of primary β-grains, and in α-plate volume. After annealing silicide particles are mainly located on α-plate boundaries (Figure 7, *b*).

It should be noted that microstructures of welded joints of alloys 1 and 2 are similar, irrespective of the difference in their composition. In addition, these two alloys have approximately the same silicon content.

Thus, conducted investigations showed that EBW of titanium alloys with silicide strengthening with preheating and post-weld LHT prevents cracking of welded joints during cooling after welding and provides satisfactory ductility properties. Proposed procedure ensures sound formation of welded joints before performance of the corresponding furnace treatment.

1. Gurevich, S.M., Zamkov, V.N., Blashchuk, V.E. et al. (1986) *Metallurgy and technology of welding of titanium and its alloys*. Kiev: Naukova Dumka.
2. Lyasotskaya, V.S. (2003) *Heat treatment of titanium alloy welded joints*. Moscow: Ekomet.
3. Levitsky, N.I., Matviets, E.A., Lapshuk, T.V. et al. (2012) Production of multicomponent titanium alloys by the method of electron beam skull melting. *Metall i Litio Ukrainy*, **4**, 6–9.
4. Iliin, A.A., Kolachev, B.A., Polkin, I.S. (2009) *Titanium alloys. Composition, structure, properties*: Refer. Book. Moscow: VILS–MATI.
5. Lysenkov, Yu.T., Vlasov, G.A., Ovchinnikov, V.V. (1980) Improvement of properties of VT20 alloy welded joints by local electron beam heat treatment. *Svarochn. Proizvodstvo*, **4**, 7–8.
6. Lyasotskaya, V.S., Lysenkov, Yu.T., Biryukov, I.M. et al. (1981) Improvement of properties of VT20 alloy welded joints by local electron beam heat treatment. *Ibid*., **11**, 19–20.

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NEWS

Technology of Ultrasonic Welding of Products of Polystyrene

The most effective method of joining products of polystyrene is the ultrasonic welding (USW). The given process allows producing the quality joint during fractions of seconds, eliminating here the process of adhesion or mechanical assembly of parts and structures of polystyrene.

At the E.O. Paton Electric Welding Institute a large scientific and industrial experience has been gained on USW of products made of polystyrene. The developed technologies are easily adapted to a definite type of polymer, shape or geometry of product and envisage:

- optimizing of main parameters of USW conditions;
- selection of method of introducing the ultrasonic oscillations (welding in near and far field);
- calculation and recommendation for selection of type of edge preparation, their geometry and sizes;
- recommendations for selection of type of filling materials and dyes, their concentration with account for their light and weather stability, spreading capacity and weldability of polymer by an ultrasound;
- selection of sequence of operations in a working cycle and method of dosing of mechanical energy being exerted, providing the preset quality of welded joints;
- selection of waveguide-tool, its design, manufacture and final optimizing.

The developed technologies provide strength of welded joints, close to the strength of parent metal, high efficiency of process, its ecology.

USW technology can be applied for manufacture of products and structures of polystyrene and copolymers of styrene and methyl methacrylate, which are used in auto-, avia- and machine building, light, food and chemical industry, radio electronics, medicine, agriculture.

The developed technological processes of USW provide:

- high quality of welded joints, reduction in labor intensity of operations and saving the energy consumption by a possibility of using the new criteria of dosing the input energy and automation of the welding process;
- decrease in cost of purchase, i.e. the cost of technology is 2–5 times lower than the cost of foreign analogs;
- elimination of processes of adhesion by dichloroethane, toluene, butyl acetate and other substances, harmful for the human organism.

Efficiency: up to 60 welds per minute.

This development has been implemented at a number of enterprises of Ukraine and Russia.