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INFLUENCE OF ARC SURFACING MODES ON INTERGRANULAR PENETRATION OF HIGH-TIN BRONZE INTO STEEL

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The paper gives the results of studying the influence of the parameters of the submerged-arc surfacing process of steel with flux-cored wire of PPBrOF10-1 grade and with coated electrodes ANBO-2, providing deposited metal of the composition, corresponding to cast bronze of BrO10F1L grade, on formation of intercriystalline penetrations of bronze into steel. It is shown that formation of intercrystalline penetrations is the most significantly influenced by values of current and deposition rate. Based on metallographic examinations, it is found that absence of intercrystalline penetrations of bronze into steel is achieved at limitation of efficient heat input of the arc surfacing process both with flux-cored wire and with coated electrodes to the value of 450 kJ/m. 8 Ref., 2 Tables, 2 Figures.

Keywords: *high-tin bronze, coated electrodes, flux-cored wire, arc surfacing, intercrystalline penetrations*

The high-tin bronzes find a wide application in friction units operating under particularly severe conditions at high loads [1, 2]. Thus, for example, tin-phosphorous bronze BrO10F1L is applied in the power engineering for manufacture of bearing bushings and pistons of critical purpose. This is largely contributed by the favorable combination of its mechanical and antifriction properties, which is due to a specific structure consisting of α-solid solution, eutectoid ($\alpha + \delta$), and copper phosphides [1, 2]. With the aim of saving the scarce and expensive bronze, as well as improving the structural strength of parts, the use of steel-bronze bimetal is challenging. In many cases, this problem can be solved by applying the arc methods. The limiting factor for arc surfacing of high-tin bronzes is the absence of electrode materials (wires, strips), which provide the necessary chemical composition of deposited metal. In connection with the need in producing bimetal steel + high-tin bronze, at the E.O. Paton Electric Welding Institute the flux-cored wire of grade PPBrOF10-1 (recommended for automatic surfacing) and coated electrodes of grade ANBO-2 [3, 4] were developed. These materials were developed taking into account the requirements to provide producing of the deposited metal, corresponding by the composition to the cast bronze of grade BrO10F1L.

As is known, among all the copper alloys the tin bronzes are most prone to the formation of intercrystalline penetrations (ICP) of bronze into steel (during depostion on steel and welding of bronze with steel), which lead to a decrease in the impact strength, ductility, strength of bimetallic joints of bronze with steels at dynamic and cyclic loads [5–7]. Figure 1 shows the characteristic form of this defect during deposition of high-tin phosphorous bronzes on steel.

As a result of metallographic examinations, it was established that ICP of high-tin bronze into steel along the entire length have a cast structure and form a tight metallic joint with steel. The penetrations begin at the fusion line of copper alloy-steel and penetrate into steel along the grain boundaries. They pass along several grain boundaries, have different width and length. One and the same penetration as to its length can have areas with the same or variable width; the boundaries

Figure 1. Microstructure (×50) of metal of fusion zone of high-tin bronze and steel with ICP of bronze into steel

Table 1. Influence of modes of surfacing using flux-cored wire PPBrOF10-1 under flux and efficient heat input on tendency to formation ICP of bronze into steel

Number of specimen	Surfacing modes	Efficient heat input, kJ/m	Bead sizes, mm			ICP	
			Width	Height	Penetration depth	Section I	Section II
Current, A							
1	200–220	447.2	14.5–15.5	4.5–5.0	≤ 0.2	Absent	Absent
2	300–320	602.4	20–20.5	5.0–5.5	1.5–2.5	2	Absent
3	380–400	777.6	24–25	5.3–55	1.5–2.5	1	2
Voltage, V							
4	25–26	430.9	14.5–15	5.5–6.0	1.0;1.5	Absent	Absent
5	30–31	518.4	16.5–17	5.0–5.5	0.5;1.0	Same	2
6	35–36	602.6	19.5–20	5.0–5.2	2.5;1.5	2	Absent
V_d, m/h							
7	10	842.4	20–21	5.0–55	≤ 0.5	3	2
8	14	602.4	19.5–20	5.0–5.2	2.5–1.5	2	Absent
9	18	369.4	18–18.5	4.0–4.5	≤ 0.5	Absent	Same

of one and the same penetration at separate areas can be parallel, but can also pass at an angle to each other.

The mechanism of ICP of copper alloy into steel during arc surfacing was rather well studied in the works [5–8]. At the same time, there are comparatively few works devoted to the study of technological measures for preventing ICP. Most often for these purposes, it is recommended to apply deposition of a sublayer of materials not prone to ICP formation (alloys with a high-nickel content, such as monel, etc.).

The data given in the literature on the effect of surfacing and heat input modes on formation and development of ICP bear a recommendatory nature, and in most cases refer to the processes of surfacing in shielding gases.

The data on the effect of modes of surfacing under flux and using coated electrodes of any copper alloys on ICP are absent. Therefore, to evaluate the effect of submerged-arc surfacing modes on ICP using the developed flux-cored wire PPBrOF10-1 and coated electrodes of grade ANBO-2, a complex of investigations was performed. In each experiment, one process parameter was changed, while others remained constant. The flux-cored wire of 3 mm diameter, flux of grade AN-60 and coated electrodes of 3 and 4 mm diameters were used.

The efficient heat input was determined by the formula:

$$Q_{eff}\,0.24\frac{U_a I_w \eta_{eff}}{v_d},$$

where U_a is the voltage, V; I_w is the current, A; η_{eff} is the efficiency coefficient of the process of heating the product by a welding arc (for submerged arc welding

Table 2. Influence of modes of surfacing using coated electrodes ANBO-2 and efficient heat input on tendency to formation ICP of bronze into steel

Number of specimen	Surfacing current, A	Efficient heat input, kJ/m	Bead sizes, mm			ICP	
			Width	Height	Penetration depth	Section I	Section II
U_a = 23–25 V; v_d = 3 m/h							
1	60	331	5–7	1.5–2.5	≤ 0.1	Absent	Absent
2	80	442	7–9	2.5–2.8	≤ 0.2	Same	Same
3	100	553	10–12	2.8–3.2	≤ 0.25	»	1
4	120	663	11–14	3.2–3.5	0.5	2	1
5	160	885	15–18	3.4–3.7	1.0	2	3
U_a = 23–25 V; v_d = 4 m/h							
6	60	248	5–6	1.5–2	≤ 0.1	Absent	Absent
7	80	332	6–8	2–2.5	≤ 0.15	Same	Same
8	100	415	8–10	2.5–2.7	0.5	»	»
9	120	498	11–13	2.8–3.1	0.8	»	1
10	160	664	14–15	3–3.2	1.5	1	2
U_a = 23–25 V; v_d = 5 m/h							
11	60	200	4–5	1–2	≤ 0.1	Absent	Absent
12	80	265	5–6	2–2.2	≤ 0.2	Same	Same
13	100	331	7–8.5	2.2–2.5	0.5	»	»
14	120	398	9–11	2.5–2.8	1.5	»	»
15	160	531	10–13	2.8–3	2.0	2	»

η_{eff} = 0.8–0.95, for coated electrode, η_{eff} = 0.65–0.8); v_d is the rate of deposition, m/h.

The presence and nature of ICP were studied on etched sections of specimens taken from the cross-section of the bead (not less than two areas). The sizes of cross-section of the beads and the penetration depth of base metal were also fixed. The results of investigations are given in Table 1.

From the results presented in Table 1, it is seen that appearance of ICP is affected by all the parameters of surfacing process. However, the current value and the deposition rate have a greater influence than the arc voltage. Any effect of the penetration depth on ICP was not revealed. ICPs are also equally probable during penetration (up to 2.5 mm) and almost at its complete absence (≤ 0.5 mm) — deposited specimens 3 and 7. The heat input in these cases is approximately the same. It is also seen from Table 1 that there is a certain threshold value of the efficient heat input, below which the ICP formations are low probable. For the process of surfacing under flux using the flux-cored wire PPBrOF10-1, this value is 450 kJ/m.

During deposition on steel using coated electrodes, the value of the efficient heat input mainly depends on the value of current and deposition rate. The results of carried out investigations are given in Table 2.

The data presented in Table 2, indicate that the value of the efficient heat input of 450 kJ/m is a critical value, exceeding which the ICPs of bronze into steel in the deposited metal are present. Therefore, during deposition on steel (especially of the first layer), it is rationally to use coated electrodes of 3 mm diameter. In this case, a more stable process without the arc breaks and short circuits of the electrode on the steel plate is provided.

The microstructure of the metal in the fusion zone of high-tin bronze with steel deposited at the modes U_a = 23–25 V; v_d = 4 m/h; I_w = 80–100 A using electrode of grade ANBO-2 of 3 mm diameter is shown in Figure 2.

The metallographic examinations revealed no defects, including ICP of bronze into steel in the fusion zone.

As a result of carried out experimental works it was established that by limiting the efficient heat input of arc methods of deposition of high-tin bronze on steel below 450 kJ/m, it is possible to minimize the probability of formation and significant development of ICP using flux-cored wire PPBrOF10-1 and ANBO-2 coated electrodes as electrode materials.

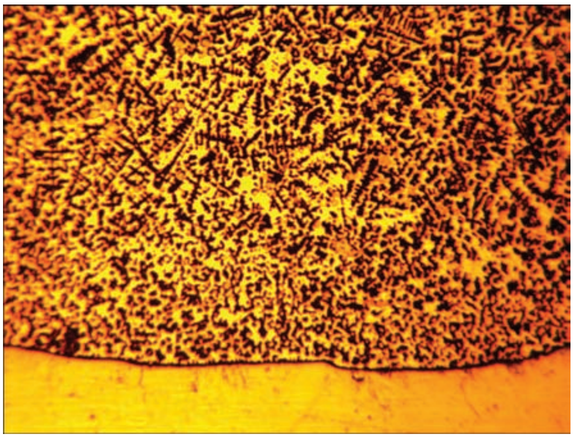

Figure 2. Microstructure (×50) of metal of fusion zone steel + high-tin bronze

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