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Effect of Modifying and Alloying Elements on the Structure and Properties of Surfaced Layers Made of High-Tin Bronze

Abstract: The article discusses the effect of some modifying and alloying elements on the structural, mechanical and operational properties of high-tin bronze used for the submerged arc surfacing of steels. The research-related tests enabled the determination of optimum contents of the above-named elements ensuring the improvement of mechanical and operational properties through changes in the shape and structural constituent dimensions of the metal subjected to surfacing. In addition, the research revealed the favourable effect of a nickel addition (up to 2%) on the reduction of high-tin bronze penetration, on grain boundaries, in the steel base.

Keywords: high-tin bronze, submerged arc surfacing, penetration of bronze into steel base

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Introduction

Presently, high-tin bronze BrO10F1L is used as a wear-resistant material applied in the production of machinery, i.e. when making critical elements operated under significant loads in friction nodes of machinery. The popularity of the above-named bronze is connected with the favourable combination of its mechanical and antifriction properties related to its specific structure including solid solution α, eutectoid (α+δ) and copper phosphides [1÷3]. The application of bimetallic products is promising as it ensures the rational use of expensive copper and increases the structural strength of products. The obtainment of a bimetal using welding technology is often based on gas-shielded surfacing [4÷6], also using submerged arc [7]. In the production of large-sized bimetallic products, the most effective method involves submerged arc surfacing [7]. A factor impeding the use of arc-based surfacing methods (including submerged arc surfacing) is the lack of welding filler metals having chemical compositions corresponding to casting bronzes as the making of wires and strips of high-tin bronzes is impossible because of their low plasticity. The E.O. Paton Electric Welding Institute developed flux-cored wire grade PP BrOF 10-1 enabling the obtainment of a weld deposit having the chemical composition corresponding to that of casting bronze BrO10F1L. Tests have revealed that metals surfaced using the above-named wire are more resistant to wear than those surfaced using casting bronze BrO10F1L [8]. However, the use of the above-named newly developed wire grade leads to the slightly greater wear of a counter element (hardened steel 45), which, during explosion, could lead to

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the faster unsuitability of a combined part, e.g. a pin shaft in a bearing node. It should also be mentioned that the submerged arc surfacing of steel using high-tin bronze was accompanied by, characteristic of copper alloys, bronze penetration into steel on grain boundaries in the fusion zone (Fig. 1). The above-named disadvantages decrease the operating ability of bimetallic products exposed to thermal and dynamic loads of a changeable sign [9, 10].

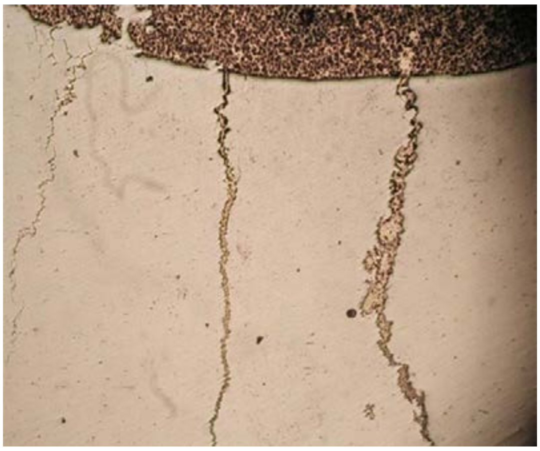


Fig. 1. Penetration of high-tin bronze into steel on grain boundaries; mag. x150

The work aimed to identify the effective methods enabling the improvement of the mechanical and operational properties of bronze-surfaced layers as well as the determination of factors reducing the penetration of bronze in the steel base on grain boundaries.

Tests and Results

One of the most rational methods enabling the improvement of operating properties is the process of modification widely used in foundry engineering. In accordance with the data presented in publication [11], the greatest refinement of a structure and the improvement of mechanical properties of tin bronzes is obtained by providing alloys with both boron and zirconium. It is also known that nickel refines grains and improves the mechanical properties of tin-phosphorus bronzes [2]. Copper alloys containing nickel are less prone to penetrate into the base on grain boundaries [12, 13]. The modification of the bronze composition involved the providing of the flux-cored wire composition with boron, zirconium and nickel (both separately and jointly).

Tests aimed to identify the effect of additions on the mechanical properties of bronze involved the double-layer surfacing of steel St3 (300 × 150 × 20 mm). The research-related under-flux two-electrode mechanised surfacing involved the use of a flux-cored wire having a diameter of 3.0 and flux AN-60, previously developed for surfacing the steels using bronze Bros8-21 [7]. The surfacing technological conditions included current restricted within the range of 220÷240 A, arc voltage restricted within the range of 34÷36 V and a welding rate of 10 m/h. The distance between electrodes (i.e. between wire axes) amounted to 6.0 mm. The surfaced metal was sampled for specimens for mechanical tests in accordance with the Gost 1497-84 standard *Metals. Methods of tension tests*. To identify wear resistance in accordance with methodology [4] developed at the E.O. Paton Electric Welding Institute, specimens were cut out so that the height of bronze (surfaced on the steel) would amount to 3 mm (in each case). Table 1 presents the chemical composition of surfaced layers obtained using experimental flux-cored wires.

Table 1. Chemical composition of the weld deposits of the test flux-cored wires

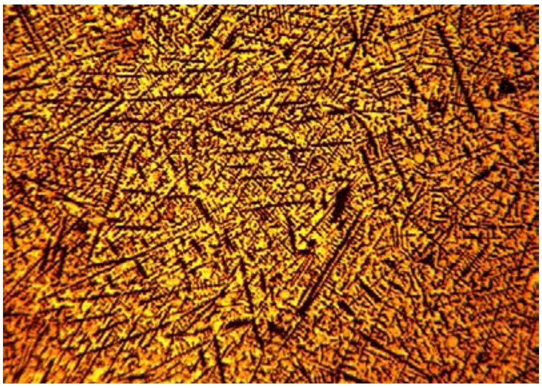
Flux-cored wire	Weld deposit chemical composition, %						
	Sn	P	Fe	Ni	B	Zr	Cu
PP no. 23	10.1	0.56	2.9	-	-	-	Rest
PP no. 24	9.8	0.65	2.7	-	0.08	0.09	
PP no. 25	10.4	0.52	2.8	1.5	-	-	
PP no. 33	9.9	0.48	2.8	1.6	0.07	0.08	

When making the overlay welds it was observed that when the content of boron amounted to over 0.1%, the bronze used for surfacing contained gas pores and the formation of the surfaced layer worsened. A nickel content of over

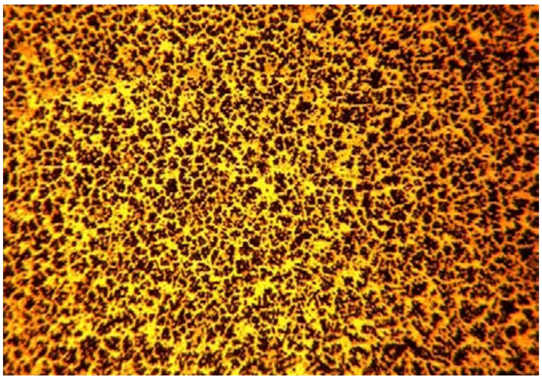
3% visibly deteriorated the separation of slag. The most favourable results were obtained during surfacing performed using wire PP no. 33.

The metallographic tests revealed that the maximum refinement of the structural constituents of the bronze was related to the joint application of boron and zirconium in the wire composition. The effective modifying influence of boron with zirconium could be attributed to the formation of zirconium borides (ZrB_2) as well as to the compounding of zirconium diboride with iron, some amount of which was present in the metal being surfaced. The modifiers of the first type have a melting point of approximately 3000°C and are additional crystallisation nuclei, thus affecting the structure of the metal being surfaced (Fig. 2).

As can be seen in Figure 2, in the overlay welds made using the flux-cored wire containing modifiers, the eutectoid constituent, composed of an α-solid solution and electron phase $Cu_{31}Sn_8$, transformed from the dendritic (acicular-like) form into more globular.



PP no. 23



PP no. 33

Fig. 2. Microstructure of the high-tin bronze surfaced using wires PP no. 23 and PP no. 33; mag. x50

The nickel additions nearly did not trigger the change of the eutectic constituent structure and the alloy in its entirety. A slight increase in dendrites in the cross-section and a decrease in the dendrites in the longitudinal section were observed. According to the authors, the lack of the greater effect resulting from the addition of nickel could be attributed to the high crystallisation rate of the alloy as it is known [2] that during slow cooling (in the presence of nickel) a new phase is formed in the tin bronze composition. In terms of the chemical composition, the above-named newly-formed phase corresponds to intermetallic compound Ni_4Sn precipitating in the form of globular bright-blue inclusions possibly constituting new crystallisation nuclei. It was noticed that the use of the modifiers was responsible for some refinement of the constituent containing iron present in the form of separate globular inclusions in the bronze being surfaced. The inclusions was more uniformly arranged in the alloy matrix, which could positively affect the stability of results concerning mechanical properties.

The tests concerning the mechanical properties of the surfaced bronzes (Table 2) revealed that the yield point of the bronze without the modifiers was slightly higher than that of the casting bronze. In cases of bronzes with alloying additions, the yield point grew 1.5 times. The tensile strength was 1.2÷1.5 times higher than that of the casting bronze when the wire both without additions and with boron and zirconium was used. When the addition of nickel was used, the yield point and tensile strength increased by additional 10÷15%, which coincided with reference data concerning the casting bronze [1]. The relative elongation and area reduction were on the level of these indicators for the casting bronze. The hardness of the surfaced high-tin bronze was by 15÷30% higher than that of casting bronze BrO10F1L.

The strength of the joint of the surfaced layer (without modifiers) with the base was determined by the tension of the specimens sampled from the base material and the weld, perpendicularly to the plane of their contact. The yield point and tensile strength were the same as those of the casting bronze and amounted to 226 and 258 MPa respectively. To determine the wear resistance of the surfaced bronze and that of the casting bronze it was necessary to perform comparative laboratory tests, the results of which are presented in Table 2.

The most favourable wear-resistance indicators of the weld deposit accompanied the providing of the flux-cored wire composition with modifiers. The increase in resistance to wear was also favoured by the refinement of the constituent containing iron, the presence of the small amount of which along with copper phosphide Cu_3P and the phase δ of eutectoid constituted "resistance crystals". In accordance with the Charpy principle [15] (as a result of the successive arrangement of hard and soft alloy constituents), the above-named crystals improved the antifriction properties of the bronze. In such a manner, the resistance of the bronze surfaced using flux-cored wire no. 33 was 1.5÷2.0 times higher than that of casting bronze grade BrO10F1L, where the counter element wear was lower than in the contact with the casting bronze and the metal subjected to surfacing using the flux-cored wire without the modifiers (PP no. 23).

In spite of the visible effect of nickel on the structure of surfaced bronzes, its presence favourably decreased penetration on grain boundaries. In the authors' opinion, the above-named effect of nickel could be related to the fact that nickel belongs to the group of transition metals forming the continuous series of solid solutions with copper and, in accordance with the structure of the electron shells of nickel and copper atoms, should not lead to the adsorptive reduction of strength [16]; the nickel addition to the copper alloy increased the surface energy in direct proportion to its (nickel) content, which, in turn, decreased the possible strength reduction of the grain edge in the area of contact with the liquid copper alloy.

Conclusions

1. The experimental tests revealed that providing the flux-cored wire composition with the optimum amount of modifying agents (boron and zirconium) significantly refined the structure of the overlay weld metal, increasing the mechanical and antifriction mechanical properties of the overlay weld in comparison with those of the overlay weld made of casting bronze.

2. By triggering the Rehbinder effect and increasing the surface energy of the copper alloy in the contact area between iron and liquid bronze, the nickel addition of 1.0÷2.0% reduced

Table 2. Mechanical properties and the wear-resistance of compared materials

Material	Yield point, MPa	Tensile strength, MPa	Relative elongation, %	Relative area reduction, %	Hardness HB	Specimen wear, mm^3	Counter element wear, mg
BrO10F1L	140-200 170	200-350 275	3-10 7	3-10 7	80-120 100	0.66-0.89 0.72	1.2-1.45 1.3
PP no. 23 (without modifiers)	208-229 221	388-397 394	5-10 7	6-11 8	122-141 134	0.40-0.57 0.5	1.31-1.47 1.37
PP no. 24(B+Zr)	286-298 294	396-399 398	5-9 7	7-13 9	121-125 123	0.26-0.39 0.33	0.70-1.2 0.9
PP no. 25 (Ni)	300-349 325	413-465 432	6-13 8	7-14 11	121-129 127	0.46-0.50 0.47	1.02-1.32 1.1
PP no. 33 (Ni+ B+Zr)	316-323 320	458-488 472	7-15 12	7-13 10	125-129 127	0.31-0.42 0.35	0.65-0.98 0.85

the amount and extent of high-tin bronze penetration on steel grain boundaries.

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