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ELECTRIC ARC SURFACING OF WEAR-RESISTANT IRON- AND NICKEL-BASED ALLOYS ON COPPER

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ABSTRACT

The results of studying the formation of welded joint in electric arc surfacing on copper by the wires, providing a deposited metal based on iron and nickel, which according to the authors and publications in the technical literature, have a high resistance to different types of wear at elevated temperatures. The modes were selected and technologies of arc surfacing on a copper base by selected wires were developed, which provide a satisfactory formation of the deposited metal and its fusion with the base metal. According to the results of experiments on electric arc surfacing on copper, as well as the study of macro- and microstructure of deposited specimens, it was shown that the best results in terms of welding and technological properties are provided by the use of the nickel-based wire. The admissibility of individual defects that were found in the deposited metal and on the fusion line of the base and deposited metals during studies will be determined by the operating conditions of specific parts.

KEYWORDS: surfacing on copper, wear-resistant alloys, electric arc surfacing, copper, weldability, fusion zone

INTRODUCTION

Copper, having a high electrical and thermal conductivity, ductility and corrosion stability, is widely used in various industries in manufacture of molds, tuyeres, heat exchangers, pipelines, parts of chemical equipment, cable and electric contact products, etc. [1].

At the same time, a low wear resistance and heat resistance of copper leads to the fact that some copper parts, in particular, molds, tuyeres and other parts, which are operated in contact with molten metal, high-temperature gas flows and abrasives of different hardness, quickly come out of order and require replacement.

One of the possible ways of improving service properties of copper parts can be surfacing of layers with high wear resistant properties on their worn out surfaces.

Thermophysical properties of copper, iron and nickel [2]

Index	Copper	Iron	Nickel
Atomic mass	63.54	55.85	58.69
Melting point, °C	1083	1535	1453
CTE at 1 °C, 10^{-6}	17.06	12.15	13.6
Thermal conductivity, W/(m·K)	413	94	107
Specific heat capacity, J/(kg·K)	385	449	500
Specific resistance, Ohm·m,·10^{-8}	1.68	10.0	6.99
Density, kg/m^3	8930	7850	8900

However, during surfacing of wear resistant alloys of various systems of alloying on copper, in particular, based on iron and nickel, large difficulties arise due to the fact that the latter have a higher melting point and much lower electrical and thermal conductivity, as well as the coefficient of thermal expansion (CTE) than copper (Table).

The abovementioned differences in thermophysical properties can affect the weldability of iron- and nickel-based alloys with copper:

● high thermal conductivity of copper leads to high cooling rates and the need in using sources of welding heating with a high heat input or the use of preliminary and accompanying heating of copper parts, and sometimes both;

● a relatively low melting point of copper, which in arc surfacing of iron- and nickel-based alloys on copper can lead to a significant penetration of a copper base;

● a short time of welding pool staying in a liquid state due to a high thermal conductivity of copper limits the possibilities of its metallurgical treatment and requires the use of active deoxidizers;

● a high CTE of copper, which in surfacing of wear-resistant steels and alloys on copper parts can lead to high residual stresses and large deformations;

● high fluidity of copper, which in some cases can deteriorate the formation of deposited metal;

● light oxidability of copper in a molten state, which leads to the formation of low-melting eutectics, which reduce the resistance of copper to the formation of crystallization cracks [3].

Among these problems, arising in surfacing of wear-resistant iron- and nickel-based alloys on copper, the main ones are the lower melting point of copper and its higher thermal conductivity (see Table). As a result, during surfacing on copper, the welding pool quickly loses heat, which leads to a sharp decrease in its fluidity and, as a result, to a poor formation of deposited beads or even to the absence of their formation and fusion with the base metal.

Moreover, due to a high rate of crystallization of the welding pool, in the deposited metal the inclusions of copper may occur, which can reduce its service properties [3].

Aim of the research: Based on the abovementioned facts and available practical experience, to develop the technologies of electric arc surfacing of iron- and nickel-based layers, having high wear resistant properties at different types of wear at elevated temperatures, on a copper base.

MATERIALS AND PROCEDURES FOR CONDUCTING EXPERIMENTS ON ELECTRIC ARC SURFACING ON A COPPER BASE

Experiments on electric arc surfacing on a copper base by the wires that provide producing the deposited metal based on iron or nickel, having high wear resistant properties at elevated temperatures [4].

The wires of these types were selected for research based on the following considerations and with taking into account the requirements for the abovementioned service properties of copper parts [4–6]:

- semi-heat- and heat-resistant steels, complex-alloyed with chromium, molybdenum, nickel, etc.;
- high-chromium cast iron (alloys of the type sormite);
- nickel-based alloys.

The flux-cored wires, providing producing of the deposited metal of the type of semi-heat- and heat-resistant steels of the alloying system Fe–C–Cr–Mo–V are widely used to strengthen the parts of metallurgical equipment, operating in the conditions of cyclic heat changes, high dynamic loads in combination with friction of metal against metal without or with the abrasive interlayer. Steels with a high content of tungsten have the highest hardness and heat resistance at high temperatures, however, thermal stability and impact toughness of such steels is relatively low [4]. Replacement of tungsten by molybdenum (full or partial) reduces the heat resistance of steel, but significantly increases its thermal stability. In surfacing, the steels of this class are prone to crack formation, for this reason, surfacing is conducted with a preliminary and sometimes with an accompanying heating. Hereinafter in the article, the flux-cored wire of this type used in the investigations, for brevity is called the wire No. 1.

The flux-cored wires or strips that provide producing the deposited metal of the type of high-chromium cast iron with carbon and chromium content of up to 5 and 30 %, respectively, are used for surfacing parts, operating in intensive abrasive or gas-abrasive wear at high temperatures (up to 1000 °C). For surfacing of these materials, different methods can be used, but surfacing technology is associated with considerable difficulties because of their high tendency to crack formation [4]. Further, the flux-cored wire of this type for brevity is called the wire No. 2.

The wires that provide producing the deposited metal on a nickel base, have high heat resistance, good resistance to thermal fatigue, high resistance to different types of corrosion and little prone to crack formation in surfacing. One of the most common grades of alloys of this type is the alloys of the Inconel alloying systems of the type Ni–Cr–Mo–Nb [4]. According to numerous studies [5–8, etc.], the use of nickel-based materials allows producing metal with better indices on weldability, corrosion and wear resistance. Further, the flux-cored wire of this type for brevity is called the wire No. 3.

With the use of the wires that provide producing the deposited metal of the types mentioned above, the experiments on practicing the technology and technique of arc surfacing on plane billets of M1 copper with the sizes (8–10)×100×100 mm were carried out.

Satisfactory results in electric arc surfacing on copper plates by the flux-cored wire No. 1 of 1.6 mm diameter under the flux AN-26P, which provides producing the deposited metal of the type of semi-heat-resistant tool steel 25Kh5FMS were achieved on the following modes: current — 280–300 A; voltage — 28–30 V; deposition rate — 15 m/h; bead overlapping — 15–20 %. However, the external inspection indicated that in surfacing on the mentioned modes, beads are produced very narrow. An increase in voltage to 32 V significantly improved the formation of deposited beads.

In arc surfacing on a copper plate by the self-shielding flux-cored wire No. 2 of 1.6 mm diameter, which provides producing the deposited metal of the type of high-chromium cast iron 400Kh25GSM, the following mode was selected, in which the process of surfacing was satisfactory, and the formation was quite well — 200–250 A, voltage — 24–26 V, deposition rate — 12–18 m/h; bead overlapping — 45–50 %.

The experiments were carried out on arc surfacing on copper in inert gas by the solid wire No. 3 of 1.6 mm diameter which provides producing the deposited metal of the type Inconel N65Kh25M11B4.

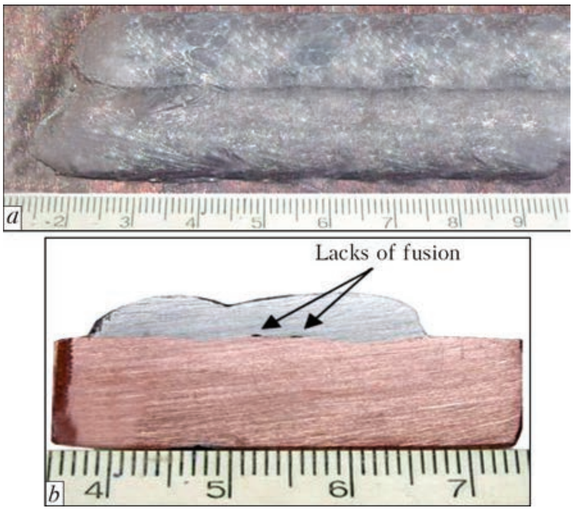

Figure 1. Appearance of beads deposited on the specimen of M1 copper by the flux-cored wire No. 1 (type of deposited metal 25Kh5FMS) (*a*) and macrosection of their cross-section (*b*)

Figure 2. Microstructure (×200) of copper used as a base metal

Surfacing was performed by single beads without and with bead overlapping by 40–50 %. The surfacing mode, which provides a good formation of deposited beads, is the following: current — 190–200 A; voltage — 25–26 V; deposition rate — 15–18 m/h; shielding gas consumption — 15 l/min.

While practicing the technology of surfacing by three wires to prevent crack formation in deposited beads, a preliminary heating of deposited specimens was used.

RESULTS OF EXPERIMENTS AND THEIR DISCUSSION

The appearance of the beads deposited on a copper plate by the flux-cored wire No. 1 on the abovementioned modes is shown in Figure 1, *a*, and the macrosection of their cross-section is in Figure 1, *b*. A fairly high quality of fusion of steel 25Kh5FMS with a copper base is observed, although the presence of small lacks of fusion, located along the fusion line, is noted. The hardness of the deposited metal is *HRC* 46–50.

The microstructure of the specimen, deposited by the flux-cored wire No. 1 was investigated. A copper base near the fusion line has a coarse-grained structure (Figure 2), the hardness of a copper base is *HV*1 — 822 MPa. The fusion line in the specimen has a wavy shape (Figure 3, *a*), along the boundaries, lacks of fusion in the base and deposited metals (Figure 3, *b*) and single pores with a diameter of 70–150 μm (Figure 3, *c*) were detected. The hardness of the base metal (copper) at a distance ≈ 150 μm from the fusion line is

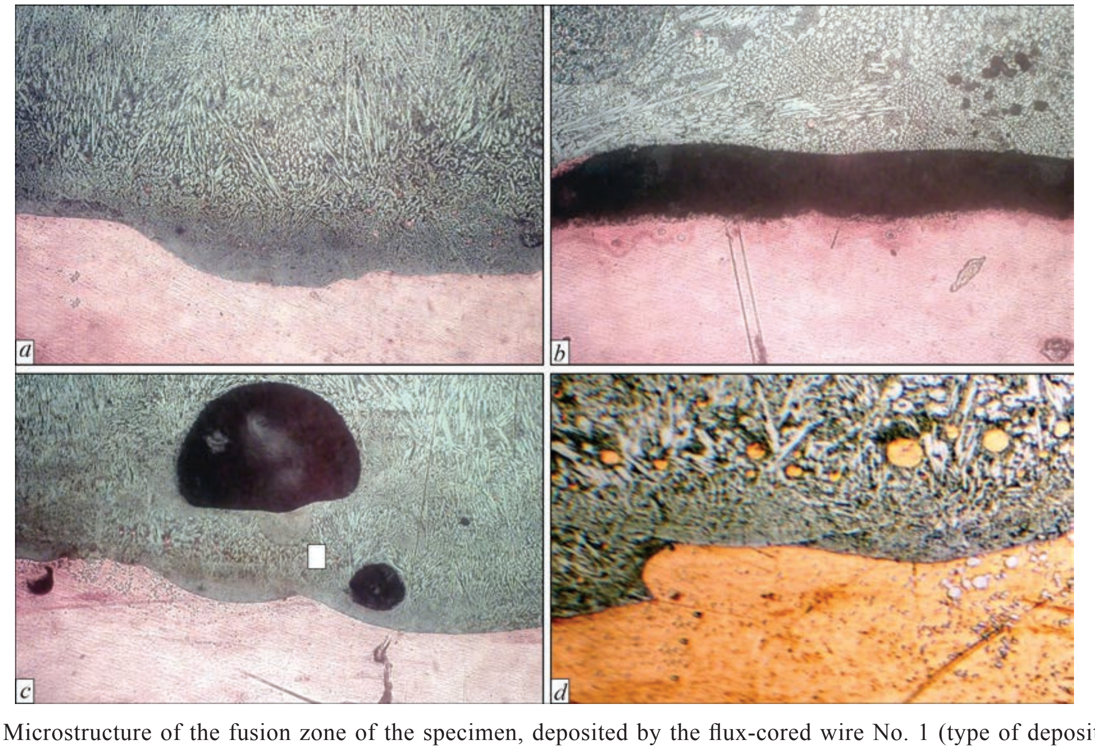

Figure 3. Microstructure of the fusion zone of the specimen, deposited by the flux-cored wire No. 1 (type of deposited metal 25Kh5FMS): *a* — in the fusion zone; *b* — lack of fusion area; *c* — pores in the fusion area; *d* — area of mutual diffusion steel-copper: *a*–*c* — ×200; e — ×320

at the level of the base metal *HV*1 — 840 MPa, and near the fusion line it is *HV*1 — 1050 MPa, which is caused by diffusion processes at the steel-copper interface.

In the deposited metal along the fusion line at a distance of 30–80 μm, an area with a dispersed structure is located, which has a hardness of 5420 MPa. In the volumes of the metal adjacent to it, precipitation of carbides in the form of plates and needles with a higher hardness *HV*1 — 6130 MPa is observed. In this area, also small inclusions of copper of a globular shape were also detected (Figure 3, *d*).

In the central part of the deposited metal, a significant coarsening of the structure occurs (Figure 4). In the solid solution based on iron, carbides of different morphology — hexagonal, laminar and lanceolate are precipitated, having a maximum size of 150 μm and the hardness *HV*1 — 10180–11870 MPa, as well as eutectic formations with the hardness *HV*1 6810–7240 MPa.

The deposited metal also contains inclusions of copper of a globular shape with the hardness *HV*1 — 1030–2540 MPa (Figure 4). In the direct vicinity of these inclusions, the hardness of deposited metal is reduced (*HV*1 — 6060 MPa) as compared to the hardness of matrix *HV*1 — 6810–7240 MPa.

The appearance of the copper specimen, deposited by the wire No. 2, is shown in Figure 5, *a*, and the macrosection of its cross-section is in Figure 5, *b*. A fairly high quality of fusion of the deposited metal of the type of high-chromium cast iron with a cop-

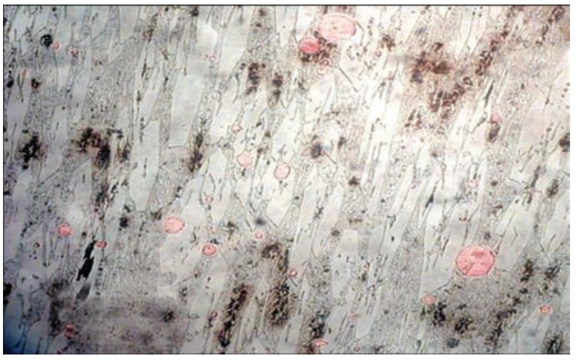

Figure 4. Microstructure (×200) of the central part of the metal, deposited by the flux-cored wire No. 1 (type of deposited metal 25Kh5FMS)

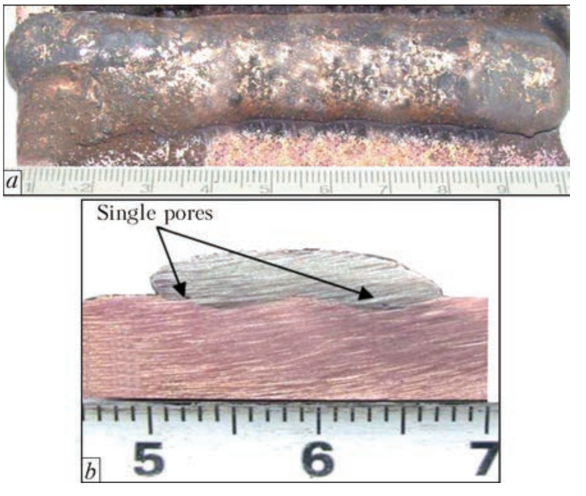

Figure 5. Appearance of beads, deposited on the specimen of M1 copper by the self-shielding flux-cored wire No.2 (type of deposited metal 400Kh25GSM) (*a*) and macrosection of their cross-section (*b*)

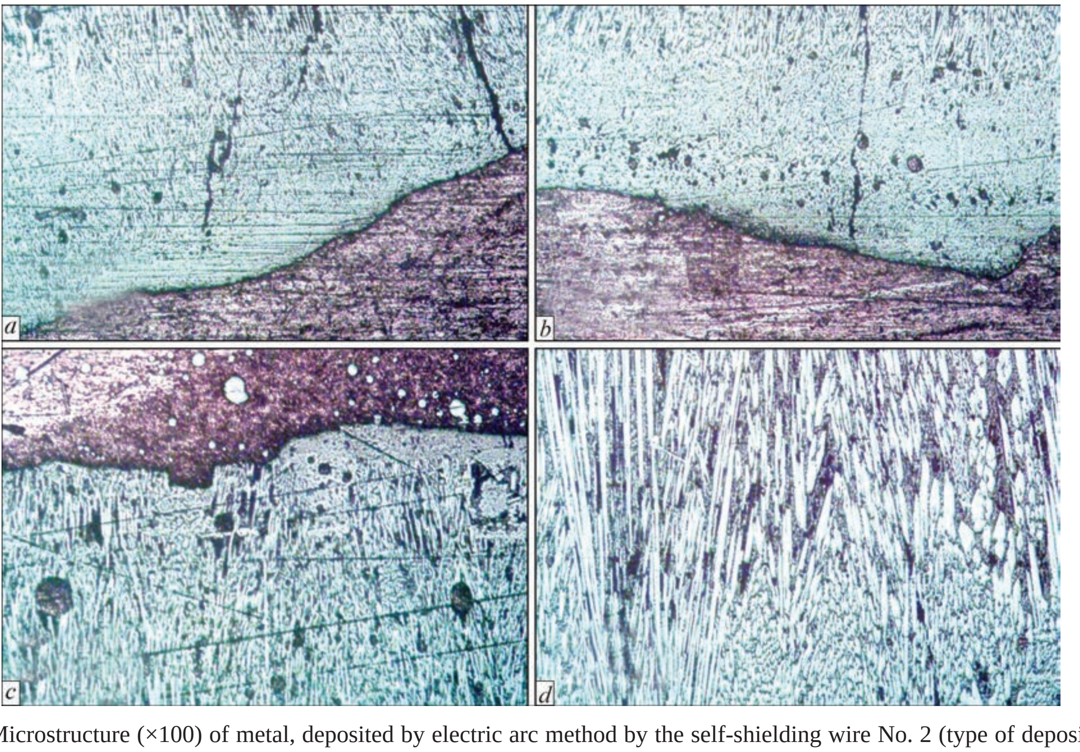

Figure 6. Microstructure (×100) of metal, deposited by electric arc method by the self-shielding wire No. 2 (type of deposited metal 400Kh25GSM): *a*, *b* — fusion line; *c* — upper edge of deposited layer with the interlayer of copper; *d* — center of the deposited layer

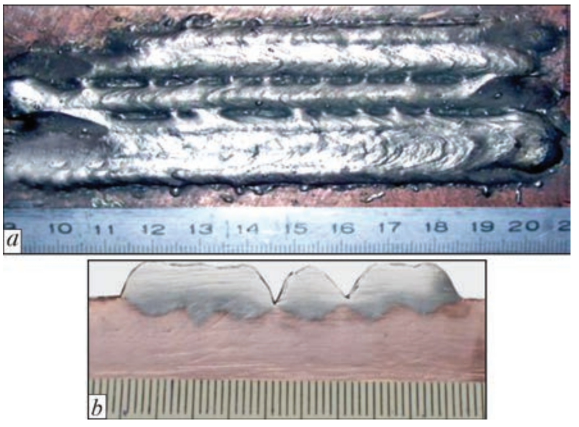

Figure 7. Appearance of beads, deposited on the specimen of M1 copper by the solid wire No. 3 (type of deposited metal N65Kh25M11B4) (*a*) and macrosection of their cross-section (*b*)

per base is observed, although the presence of single small pores located near the fusion line is noted. The hardness of deposited metal is *HRC* 56–60.

The study of the microstructure of the specimen, deposited by the wire No. 2, showed that the fusion line in it is quite pronounced, moreover, in the deposited layer cracks are present, some of which go out to the surface (Figure 6, *a*, *b*). Cracks of this type, characteristic of deposited metal of the type of high-chromium cast irons and, for example, in surfacing of wear-resistant bimetallic sheets, are not a sign of rejection [4].

In the given specimen, the presence of interlayer of cast copper in the upper part of the deposited layer with inclusions of wear-resistant metal is noted (Figure 6, *c*). Crystallization of deposited metal has a directional character (Figure 6, *d*).

The appearance of the specimen, deposited by the wire No. 3, is shown in Figure 7, *a*, and the macrosection of its cross-section is in Figure 7, *b*. A good formation of deposited beads and a high quality of fusion of the deposited nickel-based metal with copper should be noted, which has no defects in the deposited metal and on the fusion line. The hardness of the deposited metal is *HB* 245.

The microstructure of the fusion zone and a central part of the metal, deposited by the wire No. 3, are shown in Figure 8, *a*, *b*.

The study of the microstructure of this specimen showed the absence of defects both in the deposited metal as well as near the fusion line. It was found that the structure of the deposited metal is quite homogeneous. The nature of the fusion line of the base and deposited metals has a pronounced wavy shape, which is clearly visible at large magnifications (Figure 8, *a*).

The microstructure in the center of the deposited layer is quite homogeneous, it does not contain defects in the form of pores, inclusions, cracks, etc. (Figure 8, *b*). It represents a solid solution of chromium, molybdenum, niobium and other alloying elements in nickel and has the appearance of a rather uniform mixture of coarse and fine grains, intersected by twin boundaries (Figure 8, *b*). The average grain size is in the range of 30–50 μm.

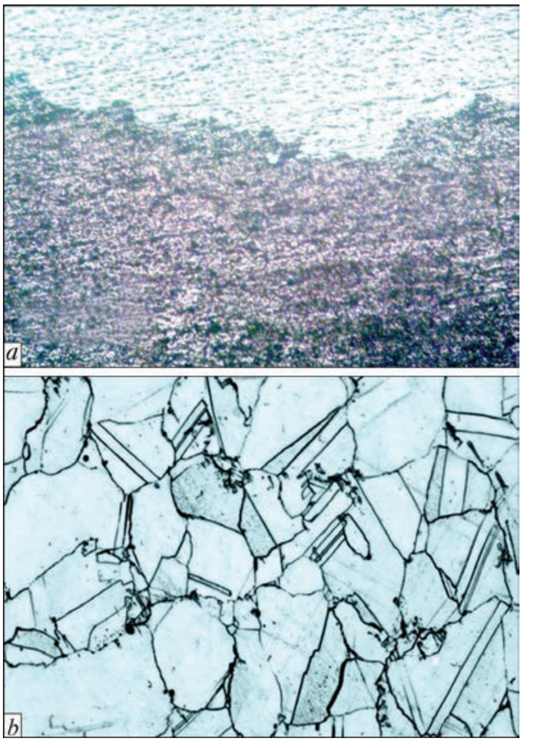

Figure 8. Microstructure of metal, deposited by the wire No. 3 (type of deposited metal N65Kh25M11B4): *a* — fusion line; *b* — central part of the metal of deposited layer. ×100 (*a*), ×320 (*b*)

CONCLUSIONS

1. According to the results of experiments on electric arc surfacing by three wires that provide producing a wear-resistant deposited metal based on iron and nickel, on M1 copper, the modes were selected and technologies of arc surfacing by these wires were developed, which provide a satisfactory formation of deposited metal and its fusion with the base metal. In this case, from the point of view of welding and technological properties, the best results are provided by the use of the nickel-based wire.

2. While using the flux-cored wires, that provide producing the iron-based deposited metal (semi-heat-resistant steel and high-chromium cast iron), some defects in the deposited metal and on the fusion line were detected, whose admissibility will be determined by the conditions of operation of specific parts. The latter also refers to the nickel-based wire.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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