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SURFACE ENGINEERING

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COMPOSITION, STRUCTURE AND PROPERTIES OF BIMETALLIC MATERIALS PREPARED BY COPPER ALLOY SURFACING ON LOW-ALLOY HIGH-STRENGTH STEEL

S. A. Pichuzhkin,[1] A. A. Vainerman,[1] S. P. Chernobaev,[1] and A. V. Tsemenko[2]

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The quality, structure, chemical composition and mechanical properties of bimetallic materials prepared by argon-arc surfacing of copper alloys MNZhKT 5-1-0.2-0.2, Sv-MN18, Sv-MNZhMtsTK 40-1-1-0.3-0.1, MMts40, BrAZhNMts 8.5-4-5-1.5 and Monel NMZhMts 28-2.5-1.5 on high-strength low-alloy steel AB3 are investigated. It is shown that during surfacing copper alloys on steel, high-quality bimetal is provided without defects in the form of cracks, significant porosity, unmelted areas, or exfoliation.

Key words: bimetal, surfacing, copper alloy, high strength steel, intercrystalline penetration.

INTRODUCTION

Currently there is greater use in various branches of industry of objects made from low-alloy, high-strength steels with copper alloy surfacing. Copper alloys exhibit relatively good corrosion resistance in sea water, a satisfactory strength level under static and variable loading conditions, good antifriction properties, thermal and electrical conductivity, resistance to fouling by micro-organisms in sea water, providing the required set of properties for bimetal joints [1, 5, 13, 14, 17]. There is also extensive use of the bimetal structures not only for engineering but also for economic advantages.

Surfacing (welding) of copper on steels (with steels) has features that are noted in domestic and overseas research work [1 – 12, 15, 16]. As a result of surfacing copper alloys on steel in the melting area the two metals from a material differing considerably with respect to composition, structure, and properties of the original metals.

The aim of the present work is a study of the composition, structure, and properties of bimetal compounds obtained by argon-arc surfacing of various copper alloys on high-strength low-alloy steel type AB3.

METHODS OF STUDY

The bimetal joints studied are a plate of steel AB3 (09KhN3MD) 15 mm thick, surface with welding wires made from copper alloys. The average content of the main elements in welding used in the work are provide Table 1.

Bimetal was prepared by surfacing a coating on steel with welding wires (Table 1) by argon-arc melting with an infusible electrode with a current of 180 – 200 A using Faltig-400 AC/DC equipment. Surfacing using wire BrAZhNMts 8.5-4.5-1.5 was performed with an alternating current and in the rest of the cases with a direct polarity current.

Metallographic studies of the structure were conducted using an Axiovert 40 Mat and Axioobserver.A1m microscopes.

The chemical composition of a surface coating in different areas of bimetal was studied using a TESCAN VEGA II scanning electron microscope combined with an INCA X-Max-50 energy dispersion spectrometer.

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[1] Central Research Institute of Structural Materials "Prometey" Named by I. V. Gorynin of the National Research Center "Kurchatov Institute," (NITs Kurchatov Institute – TsNII KM 'Prometei'), St. Petersburg, Russia (e-mail: sergey1976111@yandex.ru).

[2] Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia.

TABLE 1. Average Content of Main Elements in Welding Wire

Welding wire grade	Element content, wt.%					T_m, °C
	Ni	Al	Fe	Mn	Cu	
BrAZhNMts 8.5-4-5-1.5	4.5	8.5	4.1	0.9	Base	1070
MNZhKT 5-1-0.2-0.2	5.1	–	1.2	0.4	Base	1120
Sv-MN18	17.0	–	1.0	1.0	Base	1190
MNZhMtsTK 40-1-1-0.3-0.1	41.0	–	1.1	1.2	Base	1230
NMZhMts 28-2.5-1.5	Base	–	2.3	1.5	29	1350
MMts40	–	1.3	–	40.2	Base	1000

Vickers hardness (*HV*) was measured with a load of 50 N in a Zwick/Roell ZHV hardness meter.

The bimetal layer strength for separation resistance was determined in an Instron 5585h instrument.

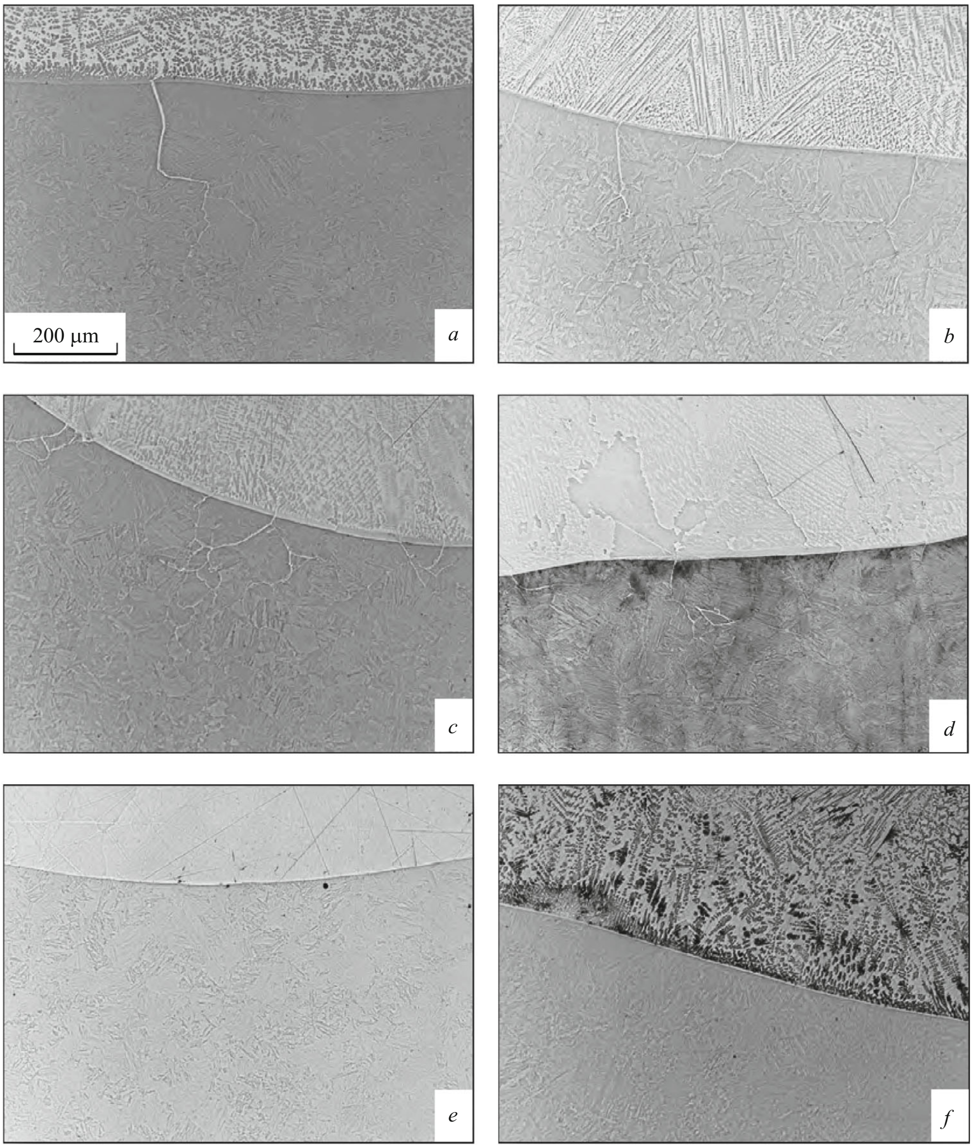

Fig. 1. Microstructure of compounds obtained by surfacing steel from different welding wires: *a*) BrAZhNMts 8.5-4.5-1.5; *b*) MNZhKT 5-1-0.2-0.2; *c*) Sv-MN18; *d*) Sv-MNZhMtsTK 40-1-1-0.3-01; *e*) NMZhMts 28-2.5-1.5; *f*) MNts40.

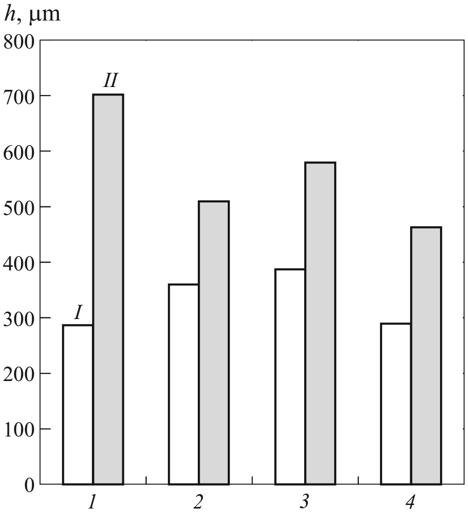

Fig. 2. Depth of copper alloy intercrystalline penetration into steel after surfacing with welding wires (*h*): BrAZhNMts 8.5-4.5-1.5 (*1*); SV-MNZhMtsTK 40-1-1-0.3-01 (*2*); MNZhKT 5-1-0.2-0.2 (*3*); Sv-MN18 (*4*): *I*) average penetration depth; *II*) maximum penetration depth.

RESULTS AND DISCUSSION

External examination using a × 5 magnifier of a metal layer surface with different copper alloys shows absence within it of any defects in the form of cracks, pore chains, and delamination. A study of microsections cut from bimetal also showed absence within it of unacceptable defects (unmelted area, cracks, and pores).

A typical feature of the process of joining copper alloys with steels by welding or surfacing is intercrystalline penetration of copper alloy into steel. As a result of surfacing on steel over grain boundaries there is formation of copper alloy penetration, entering from the surfacing boundary and extended from 0.01 up to 15 mm or more, depending on steel and copper alloy compositions, welding and surfacing methods, and regimes [1, 3, 11, 16]. An unfavorable effect is noted in [1, 10, 11] for penetration of copper alloy into steel to a depth of more than 1 mm on joint mechanical properties.

During a study of bimetal microsections obtained using wires BrAZhNMts 8.5-4.5-1.5, MNZhKT 5-1-0.2-0.2, Sv-MNZhMtsTK 40-1-1-0.3-01, and Sv-MN18, intercrystalline penetration of copper alloys into steel was observed (Fig. 1). In electron microscope images in a back-scattered electron regime at magnification up to × 6500 it is clearly seen that the fusion boundary of intercrystalline penetration of copper alloy into steel is dense without discontinuities.

The depth of intercrystalline penetration of copper alloy into steel is shown in Fig. 2. The least average value of penetration depth was obtained on steel during surfacing with BrAZhNMts 8.5-4.5-1.5 and Sv-MNZhMtsTK 40-1-1-0.3-01 alloys upon it. The maximum depth of intercrystalline penetration was recorded on steel after surfacing it with wire of alloy BrAZhNMts 8.5-4.5-1.5.

Since the depth of intercrystalline penetration of surfaced copper alloy on steel AB3 was less than 1 mm, then presence of penetration did not reduce the reliability and operating capacity of a structure.

No intercrystalline penetration was revealed in bimetal prepared with wires NMZhMts 28-2.5-1.5 and MMts40 (Fig. 1*e* and *f*).

Local analysis of the chemical composition of surfacing metal in areas with a size of 200 × 300 μm showed that during surfacing as a result of steel melting there is transfer of its elements into the surfacing metal (Table 2). The iron content is from 16 to 32% within the central part, and up to 52% close to the surfacing fusion boundary.

Studies have shown that depending on the grade of material the average iron content in surfacing metal is different with the same surfacing technology (Table 2) a different de-

TABLE 2. Surfacing Metal Chemical Composition

Welding wire grade	Test area	Element content, wt.%								Average Fe content in surfacing metal, wt.%
		Cu	Fe	Al	Ni	Si	Mn	Cr	Ti	
MNZhMtsTK 40-1-1-0.3-0.1	*1*	36.1	32.9	–	28.6	0.4	1.00	0.36	0.44	32.9
	2	24.2	52.1	–	21.5	0.41	0.78	0.61	0.29	
Sv-MN18	*1*	60.1	24.4	–	13.6	0.19	1.03	0.32	0.24	24.4
	2	58.0	28.2	–	12.1	0.22	1.00	0.19	0.24	
BrAZhNMts 8.5-4-5-1.5	*1*	70.7	16.2	7.0	4.8	0.17	1.19	–	–	16.2
	2	60.4	27.9	6.0	4.1	0.20	0.90	0.30		
MMts40	*1*	50.6	13.1	1.2	1.8	0.18	33.0	–	–	13.1
MNZhKT 5-1-0.2-0.2	*1*	70.4	22.6	–	5.7	0.40	0.60	–	–	22.6
NMZhMts 28-2.5-1.5	*1*	18.0	29.8	–	45.3	–	1.48	–	–	29.8
	2	16.2	40.0	–	41.5	0.26	1.18	0.42	–	

Note. Zone *1* is surfacing metal in center of surface, zone *2* is surfacing metal at a distance of 20 – 40 μm from melting boundary with steel.

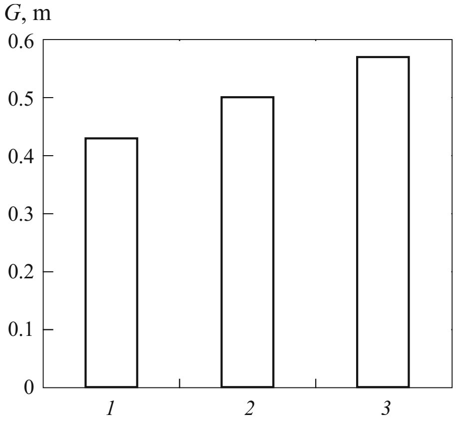

Fig. 3. Fluidity (*G*) at 1453 K of alloys Sv-MN18 (*1*), MMts40 (*2*), and BrAZhNMts 8.5-4.5-1.5 (*3*).

gree of steel melting, and consequently iron content with identical regimes and surfacing technology may be explained by the different melting temperature of copper alloys (Table 1) and their fluidity (Fig. 3). Coper-nickel alloys exhibit considerably lower fluidity than aluminum bronzes and copper-manganese alloys, and also a higher melting temperature. With an increase in nickel content in copper-nickel alloys their fluidity decreases. In view of this aluminum bronzes and copper-manganese alloy during surfacing start to melt a little sooner than copper-nickel alloy on steel, and due to greater fluidity they spread well over a steel surface. This provides the possibility of introducing the welding process so the welding arc burns between the liquid metal copper alloy and a tungsten electrode. This makes it possible to reduce the degree of steel melting and consequently the iron content within surfacing metal.

Metallographic studies of microsections showed that within a metal surfaced with wires of alloys BrAZhNMts 8.5-4.5-1.5, MNZhKT 5-1-0.2-0.2, Sv-MNZhMtsTK 40-1-1-0.3-01, MNts40, and Sv-MN18 on steel there is formation of a new phase absent in the original materials. Structural components of the phase crystallize in the form of individual precipitates over the surfacing metal cross section and then the interlayer at the steel boundary (Fig. 1). The greatest amount (with respect to area) of precipitates is observed in the area of surfacing metal variable composition at the steel boundary (Fig. 1). The dimensions of individual precipitates varies from 1 – 2 to 10 – 15 μm or more. The shape of precipitates is also different, i.e., globular, dendritic, and starred. Layers located either along the whole joint melt boundary with steel or in the form of individual areas have variable thickness from several microns to 0.5 mm.

No new phases are detected in metal surface with alloy wire NMZhMts 28-2.5-1.5.

It has been established that precipitates of phases in surface metal and the interlayer in the fusion zone detected by metallographic studies have an iron base and contain elements of both the copper alloy and steel (Table 3).

It should be noted that precipitates of phases based on iron within surfacing metal compared with the crystallization interlayer have a higher content of copper, aluminum, manganese, titanium and a reduced content of iron and chromium. This is connected with the small dimensions and contact with the matrix of surfacing metal based on copper over the whole boundary.

TABLE 3. Precipitated Phase Chemical Composition Based on Iron, Interlayers, and Joint Metal Matrix

Welding wire grade	Test area	Element content, wt.%							
		Cu	Fe	Al	Ni	Si	Mn	Cr	Ti
MNZhMtsTK 40-1-1-0.3-0.1	*1*	22.4 – 23.4	41.7 – 42.8	–	33.0 – 33.1	0.25 – 0.31	0.65 – 0.66	0.40 – 0.46	0.25 – 0.33
	2	12.3	67.6	–	18.1	0.3	0.5	0.78	0.2
	3	75.4 – 77.9	9.0 – 10.2	–	10.4 – 12.1	0.15, 0.16	1.8 – 2.1	0.10 – 0.15	0.10 – 0.11
Sv-MN18	*1*	22.4 – 22.8	53.0 – 54.0	–	21.7 – 22.1	0.3 – 0.4	0.50 – 0.65	0.4 – 0.5	0.17 – 0.32
	2	17.9 – 18.3	62.1 – 62.2	–	18.0 – 18.3	0.28 – 0.32	0.43 – 0.55	0.43 – 0.62	0.14 – 0.25
	3	78.8 – 87.0	5.6 – 10.7	–	4.7 – 9.0	0.09 – 0.25	1.4 – 2.3	–	–
BrAZhNMts 8.5-4-5-1.5	*1*	12.2 – 15.4	73.1 – 75.4	4.0 – 5.5	4.4 – 5.4	0.36 – 0.53	0.61 – 0.74	0.46 – 0.62	–
	2	12.4	78.2	3.7	3.8	0.3	0.7	0.68	–
	3	82.5 – 82.8	5.9 – 6.0	6.4 – 6.6	3.12	0.09 – 0.22	1.3 – 1.5	0.04 – 0.08	–
MMts40	*1* and *2*	14.6 – 16.4	44.1 – 45.3	1.1 – 1.3	1.7 – 1.76	0.2 – 0.4	35.1 – 36.3	0.5 – 0.7	–
	3	58.9 – 64.2	1.6 – 6.0	1.0 – 1.3	1.1 – 2.3	0.02 – 0.10	31.3 – 32.8	–	–
MNZhKT 5-1-0.2-0.2	*1*	14.8 – 21.5	66 – 76.1		7.7 – 10.2	0.35 – 0.60	0.2 – 0.3	0.50 – 0.72	–
	2	13.6 – 14.0	78.6 – 78.8		5.9	0.39 – 0.40	0.17 – 0.22	0.81 – 0.82	–
	3	90.6 – 91.6	5.1 – 5.9	–	2.1 – 2.5	0.11 – 0.19	0.7 – 0.8	–	–

Note. Zone *1* is precipitates in surfacing metal, zone *2* is interlayer in melting area, zone *3* is surfacing metal matrix (base of surfacing metal without precipitates and interlayers).

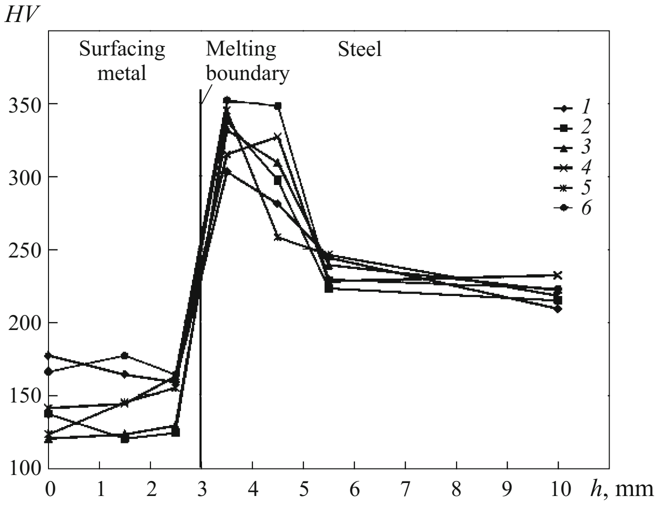

Fig. 4. Hardness distribution through bimetal of steel – welding wire of different alloys: *1*) BrAZhNMts 8.5-4.5-1.5; *2*) Sv-MN18; *3*) NMZhMts 28-2.5-1.5; *4*) Sv-MNZhMtsTK 40-1-0.3-01; *5*) MNZhKT 5-1-0.2-0.2; *6*) MMts40.

The base of surfacing metal, i.e., copper alloy without precipitates and layers (subsequently the surfacing metal matrix) contains elements of copper both and also steel (Table 3).

The matrix of surfacing metal is a solid solution based on copper (Table 3). The iron content within this solid solution (5.1 – 10.7%) exceeds the solubility of iron in copper and its alloys (2.3% [1]). It may be proposed that under conditions of rapid cooling excess iron does not manage to separate within the total volume to values of iron solubility in copper alloy and it is retained in the form of a supersaturated solid solution in copper.

It should be noted that within the surfacing metal matrix the content of aluminum and nickel is lower than in the original welding wires (Table 1). This may be explained by the fact that aluminum and nickel and transferred during crystallization with subsequent matrix cooling into formation of structural components based on iron.

The chemical composition of metal of intercrystalline penetration is close to that of the joint metal matrix.

Results of studying hardness in surfaced bimetal specimens are given in Fig. 4. Studies have shown that within the heat-affected zone an increase in hardness by up to 30% is noted. No marked drops in hardness values are observed in surfacing metal.

TABLE 4. Strength of Surfacing Metal Joint with Steel

Welding wire grade	$\sigma_{r(1)}$, MPa	$\sigma_{r(2)}$, MPa
MNZhMtsTK 40-1-1-0.3-0.1	≥ 420	420 – 460
Sv-MN18	≥ 320	408 – 452
BrAZhNMts 8.5-4-5-1.5	≥ 590	587 – 636
MMts40	≥ 490	495 – 520
MNZhKT 5-1-0.2-0.2	≥ 250	311 – 320
NMZhMts 28-2.5-1.5	≥ 440	450 – 490

Separation tests showed that the strength of the joint between bimetal layers (steel and surfacing copper alloy) is not lower than the strength of the copper alloy surfacing metal (Table 4). An increase in values of strength for a joint is connected with the strengthening effect of phases based on iron [1].

Therefore, with argon-arc surfacing of copper alloys BrAZhNMts 8.5-4.5-1.5, MNZhKT 5-1-0.2-0.2, Sv-MNZhMtsTK 40-1-1-0.3-01, MNts40, Sv-MN18, and NMZhMts 28-2.5-1.5 on high-strength steel AB3 high quality bimetals joints are provided with strength properties at the level of copper alloy.

CONCLUSIONS

1. With a layer of bimetal surfaced with wires BrAZhNMts 8.5-4.5-1.5, MNZhKT 5-1-0.2-0.2, Sv-MNZhMtsTK 40-1-1-0.3-01, MNts40, and Sv-MN18 on steel AB3 there is formation of new structural components based in iron, absent from the original material, crystallizing in the form of inclusions of different form through the surfacing metal cross section and an interlayer in the melting zone, containing elements of both steel and copper alloy.
2. The surfacing metal matrix is significantly combined with the main alloying components, such as aluminum, nickel, manganese diffusing into a phase based on iron.
3. During surfacing copper alloys BrAZhNMts 8.5-4.5-1.5, MNZhKT 5-1-0.2-0.2, Sv-MNZhMtsTK 40-1-1-0.3-01 on high-strength steel AB3 into it there is formation of intercrystalline penetration of surfacing copper alloy to a depth of 700 μm. The maximum depth of penetration is recorded in steel by metal surfaced with wire BrAZhNMts 8.5-4.5-1.5. With surfacing wire NMZhMts 28-2.5-1.5 (Monel metal) and MNts40 intercrystalline penetration of the surfacing copper alloy into steel is not observed.
4. The strength properties of bimetal joints are at the level of the properties of the surfacing copper alloys.

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