EFFECTIVENESS OF APPLICATION OF NEW CONSUMABLES IN WELDING AND SURFACING OF COPPER AND ITS ALLOYS (Review)

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Results of investigations on development of high-efficient electrode and filler materials for welding and surfacing of copper and alloys on its base are considered. It is shown that increased requirements to quality of welded joints and deposited metal can be satisfied, primarily due to development of reliable welding consumables: electrode and filler wires, fluxes (fused and activating flux-pastes), as well as special coated electrodes. Arc welding and surfacing processes improved on their base provide the required level of thermophysical properties of welded joints, high strength and tightness of welds, reliable service durability in friction assemblies and corrosion media, etc. Effectiveness of new welding consumables is confirmed by their practical application in manufacture of welded crucible moulds of electrometallurgical furnaces, welding busbars, electrode holders, enlargement of hot-rolled coils for their further rolling, making various bimetal items by surfacing, etc. 10 Ref., 5 Tables.

Keywords: *arc welding and surfacing, copper and its alloys, electrode and filler wires, fluxes, coated electrodes, welded joints, thermophysical properties, quality*

Owing to unique combination of physico-chemical properties: electric and heat conductivity, corrosion resistance, high level of mechanical and antifriction properties, heat and cavitation resistance, adaptability to fabrication, copper and alloys on its base are widely used in various industries. There is, probably, not a single industry, where copper and its low- and complex-alloys (bronzes, brasses) are not used. Therefore, a highly urgent task is development and continuous improvement of technologies of welding and surfacing these metals and, primarily, development of high-efficient welding and surfacing materials.

Systematic studies in this area began at PWI as far back as in the 1950–1960s of the previous century (V.V. Podgaetsky, D.M. Rabkin, Yu.M. Korenyuk, etc.). The most effective were studies, made in the 1970–1980s, when a group and then Laboratory of Welding and Surfacing of Copper and Its Alloys was set up within the new Department of Physico-Metallurgical Processes of Welding Refractory and Reactive Non-Ferrous Metals (Department Head was Prof. S.M. Gurevich) [1].

This review provides generalization of the results of investigations on development of reliable welding consumables and manufacturing technologies, allowing for increased requirements to quality of welded joints and deposited metal: ensuring the required level of electric conductivity, high strength and tightness (including vacuum) of welds, ensuring operating reliability in friction assemblies and corrosion environments, etc.

The most significant of them are developments in the field of arc welding and surfacing processes.

Welding and surfacing wires. Solid and flux-cored wires are used as electrode materials for mechanized processes of welding and surfacing of copper and its alloys.

In keeping with GOST 16130–90, industry manufactures a number of wires for welding copper and its low-alloyed structural alloys of chromium copper type: M1; M1r; MSr1; MN-ZhKT5-1-0.2-0.2; BrKh0.7; BrKMts3-1; BrOTs4-3. For bronze welding and surfacing, in view of the difficulty of drawing doped alloys, the wire range is narrow: BrKMts3-1; BrAMts9-2; BrAZhMts10-3-1.5; BrOTs4-3; BrOF6.5-0.15. Wires from some high-strength aluminium bronzes (BrAZhNMts, BrMtsAZhN type) are made by special specifications.

It is characteristic that the above wires for welding copper, while having satisfactory welding-technological properties in submerged-arc welding, in MIG/MAG process, as well as ensuring composite welds, as a rule do not meet the requirements on thermophysical properties of welded joints. Heat and electric conductivity do not exceed 20–30 % of those for welded copper (except for welds, made by submerged arc with copper wire). However, in submerged-arc welding with increase of welded copper thickness

Table 1. Composition of new welding wires, wt.%

Alloy grade	Li	B	Mg	Cr	Si	Al	Total impurities, not more than
ML0.2	0.1–0.3	–	–	–	–	–	0.03
MBMg	–	0.1–0.3	0.1–0.3	–	–	–	0.03
MLBMg	0.05–0.2	0.05–0.3	0.05–0.2	–	–	–	0.03
MLAKB	0.05–0.2	0.05–0.3	–	–	0.1–0.25	0.1–0.25	0.03
MLKhMg	0.1–0.25	–	0.1–0.4	0.15–0.4	–	–	0.03

(>15–20 mm) copper welding wire does not ensure the required tightness of welds or required ductility of welded joints. Better results in this case are achieved at application of special welding wire BrKhT0.6-0.5, developed at PWI. Simultaneous alloying of welds with chromium and titanium improves the metal mechanical properties, particularly at high temperatures, and increases metal resistance to porosity. The same principle of additional alloying of weld metal with chromium and titanium was the basis for development of special filler flux-cored wire PP-BrKhT12-2, designed for plasma-arc welding of copper and chromium copper. This flux-cored filler wire is used with success in manufacture of welded moulds of crucibles of electrometallurgical furnaces in OJSC «Sibelektroterm» (Novosibirsk, RF) [2, 3].

Wires from MNZhKT and BrKMts alloys are used for welding copper in shielding gas atmosphere. As was already noted, thermophysical properties of welds are quite low here. OK Autrod 19.12 wire recommended by ESAB company for these purpose, by our data does not ensure the required electric conductivity of joints, either. Owing to joint investigations of PWI and «Giprotsvetmetobrabotka» (now Company «Institute of Procesing of Non-Ferrous Metals», Moscow), compositions of effective welding consumables for welding copper and its low alloys have been developed (Table 1) [4–6].

Wires from ML0.2 and MBMg alloys, recommended as filler materials for nonconsumable electrode welding, provide tight, well-formed welds with high electric conductivity (more than 90 % of that of copper) and have mechanical properties on the level of those of base metal. Filler wire from ML0.2 alloy is applied with success for argon-arc welding of buses from oxygen-containing copper, and wire from MBMg alloy — for enlargement of hot-rolled copper coils by argon-arc welding for their further rolling and rolled stock application without cutting out welds at the user's facility. Wires from MLBMg, MLAKB and MLKhMg alloys were developed as all-purpose ones, and can be applied for welding copper and its low alloys both by consumable and nonconsumable electrodes, providing increased energy efficiency of the arc, high quality and electric conductivity of welded joints. Alongside application of inert gases (argon, helium and their mixtures) wire from MLBMg alloy guarantees high quality of welds and also welding in nitrogen atmosphere. Manufacture of new welding wires has been mastered in Moscow Experimental Plant of Quality Alloys.

In view of certain complexity of manufacturing these wires (melting in vacuum furnaces, rod pressing, rolling, annealing of billets and drawing), a more accessible filler material for TIG process is flux-cored wire of PP-AN-M1 grade, developed by PWI [3]. Doping flux-cored wire composition with effective deoxidizers ensures the required quality and thermophysical properties of welded joints in helium-arc welding of thick-walled elements of various electrical engineering products (motors, busbars, etc.).

An important objective of welding fabrication also is expansion of application of surfacing technologies with the objective of both restoring the worn parts, and manufacturing bimetal products. Pursuing investigations in the field of surfacing with antifriction copper alloys (aluminium and tin bronzes), PWI developed a number of grades of bronze flux-cored wires (Table 2), which, as a rule, provide a comparatively simple solution of the problem of ensuring the required composition of deposited metal [7, 8].

Developed wires and technologies of mechanized surfacing have been introduced with success in manufacture of bimetal bushings, thrust bearings and other components of friction assembles of heavy-duty mechanisms (ore mining and processing equipment, critical fittings, bearing bushings of electric motors, etc.) [1].

Coated electrodes. Comparatively small volumes of welded products from copper and its alloys can be manufactured by coated-electrode manual welding. Known electrodes of «Komsomolets-100» grade, mainly applied for this pur-

Table 2. Composition and properties of metal deposited with flux-cored wires, wt.%

Wire grade	Cu	Al	Fe*	Mn	Ni	Sn	Zn	Pb	P
PP-BrANMts	Base	7.5–10	2–4	1–2	1–2	–	–	–	
PP-BrMtsAN	Same	7.5–9		9–11	1–2	–	–	–	–
PP-BrOF	»	–	≤1	–	–	9–10	–	–	0.4–0.8
PP-BrOTs	»	–		–	–	9–10	1.5–3	–	–
PP-BrOTsS	»	–		–	–	5–6.5	5–6.5	2–4	–
PP-BrOS	»	–		–	–	7.5–9	–	18–21	–

*Iron content in steel surfacing.

Table 3. Properties of the metal of welds and welded joints made with coated electrodes

Electrode grade	Mechanical properties			ΣCr, Si, Al, Mn, Fe in weld metal, wt.%	Weld electrical conductivity, % of that for copper	Deposition rate*, g/min
	Weld metal	Welded joint				
	σ_t, MPa	δ, %	α, deg			
ANTs-1	210–240	20–25	130–180	≤1.1	40–70	110–150
ANTs/OZM-2	180–220	25–35	160–180	≤0.8	50–80	85–125
ANTs-3M	230–260	30–33	180	≤1.4	40–60	110–150
«Komsomolets-100»	250	10	–	≤6.0	20–25	40–50

*Data on deposition rate are given for 3 mm electrodes.

Table 4. Composition of metal deposited with bronze electrodes, wt.%

Electrode grade	Cu	Al	Mn	Fe	Si	Sn	P	Ni
ANBA-1	Base	7.0–8.0	1.5–2.0	≤3.0	≤0.5	–	–	–
ANBO-1	Same	–	0.5–1.0	≤2.0	–	5.0–7.0	0.15–0.25	0.3–0.8
ANBO-2	»	–	0.5–1.0	≤2.0	–	8.5–10.5	0.5–0.8	–

pose, were developed as far back as in the 1950s of the previous century and have essential drawbacks: over-alloyed weld metal, in particular by manganese and iron (up to 5–6 %), which abruptly lowers its heat and electric conductivity; low weld quality; high preheating and concurrent heating of items being welded. To eliminate these drawbacks PWI developed high-efficient electrodes of ANTs grade (ANTs-1, ANTs/OZM-2, ANTs-3M) (Table 3) [4]. An advantage of the new electrodes is the ability to perform copper welding without preheating or concurrent heating (for δ = 10–15 mm) or with low preheating (up to 200–400 °C) for thicker metal. This is achieved through application of forced welding modes and concentrated heat input, ensured at melting of thick-coated electrode. Efficiency of welding with new electrodes is 2–3 times higher compared to «Komsomolets-100». Electric and heat conductivity of welded joints is equal to 70–80 % of that for copper. Welding and repair of products with application of high-efficient electrodes of ANTs-3 grade has been mastered with success by a number of metallurgical plants of CIS countries in manufacture of crucibles, repair of moulds, bottom plates and electrode holders of various metallurgical furnaces and other products.

Considering that Ukraine has no manufacture of electrodes for welding and surfacing of bronzes (aluminium and tin), PWI performed a package of research on development of such electrodes of grades ANBA-1 for welding Al-bronzes, and ANBO-1, ANBO-2 — for welding Sn-bronzes (Table 4) [8, 9]. Standard wire of BrAMts9-2 grade was used as rods for electrodes of ANBA-1 grade, and for electrodes of ANBO-1 grade — copper wire M1T, for ANBO-2 grade — bronze wire BrOF6.5-0.4.

Developed electrodes for bronze welding and surfacing have good welding-technological properties, and by a number of indices (slag separability, resistance to pore formation) they are superior to foreign analogs. Test batches of developed electrodes are made at the PWI Science and Technology Complex.

Table 5. Activating fluxes for TIG welding of copper and its alloys

Flux grade	Flux system	Remark
AN-M15A	MgF_2–B	Welding of copper commercial grades
AN-M17A	MgF_2–Na_3AlF_6–B(P)	Welding of bronzes
AN-M19A	AlF_3–MgF_2	Microplasma welding of thin copper
AN-M21A	AlF_3–CaF_2–MgF_2	Nitrogen-arc welding of copper strips for subsequent rolling
AN-M23A	AlF_3–CaF_2–MgF_2–B	Welding of copper-nickel alloys
AN-M25A	Cu_2O–Sn	Welding of brasses

Fused welding fluxes and flux-pastes. The possibility of application for these purposes of a number of fused flux grades designed for steel welding was shown already in the first works on automatic submerged-arc welding of copper and its alloys. With increase of welded copper thickness (above 20 mm), however, standard fused fluxes, even with exact following of all technological recommendations (flux drying, scraping and degreasing of edges being welded, respective preparation of electrode wire, etc.) do not ensure the required weld tightness.

As shown by investigations, the most effective measure to prevent weld porosity in copper welding turned out to be application of low-silicon manganese flux manufactured by air-stream granulation with higher oxidation degree [3]. New flux of AN-M13 grade ensures producing vacuum-tight welds in manufacture of crucible moulds for VAM and ESM furnaces.

Owing to development of low-melting AN-M10 flux based on fluoride compounds of alkali-earth metals, electroslag welding of thick copper was performed with success for the first time in the word practice for fabrication of crucible bands of continuous casting machines and rolling rods from non-ferrous metals, as well as current conduits from thick-walled compact sections [2].

To improve weld quality and effectiveness of arc heat application, and, therefore, also efficiency of TIG welding of copper and its alloys, special flux-pastes based on halogenides of alkali and alkali-earth metals have been developed (Table 5).

Ability of making a metallurgical impact on weld pool with minimum weld alloying, which results in welded joints being close to base metal as to their thermophysical properties, should be regarded as one of the advantages of ATIG-process of copper welding. Application of flux-pastes enables considerable enhancement of technological capabilities of TIG welding: widening the range of thicknesses welded in one pass, and increasing welding speed [2, 10].

Thus, developed welding consumables and improved technological processes of welding and surfacing of copper and alloys on its base allowed an essential improvement of welded and surfaced product quality, reaching required level of service properties of welded joints and deposited metal, as well as ensuring further mastering of mechanized processes of welding and surfacing of these materials.

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Received 15.04.2014