METALLURGICAL PECULIARITIES OF PLASMA-ARC WELDING OF CHROME-BRONZE

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Arc welding of parts from chrome-bronze is related with weld metal susceptibility to hot cracking. Given are the results of investigations on finding the measures for prevention of formation of hot microcracks in metal of chrome-bronze BrKh08 welds of large thickness performed by plasma-arc welding. It is shown that the main reason of defect formation in the weld metal is entry of air oxygen in plasma arc that results in intensive oxidation of chromium in a weld pool and transfer of weld metal to zone of maximum brittleness of Cu–Cr alloys. Considering that one slag coverage is not enough for large volume of liquid metal pool formed in plasma-arc welding over the flux layer using powerful modes (I_w = 1000–1400 A, U_a = 48–55 V) in order to obtain quality weld, additional alloying of weld metal by chromium and small additions of titanium being efficient deoxidizer is concluded to be reasonable. Special filler wire of PPBrKhT 12-2 grade was developed for this purpose. Its application in combination with selected flux allowed successfully solving the task of industrial manufacture of moulds for metallurgical electro-furnaces. 9 Ref., 5 Figures.

Keywords: *chrome-bronze, plasma-arc welding, solidification, structure, cracks*

Obtaining of quality welds in manufacture of large-size welded structures from chrome-bronze BrKh08, such as moulds of electrometallurgic furnaces, requires providing of initial thermal conditions for metal heating up in order to form weld pool. Limited power capacity of simple arc welding does not allow compensating a heat transfer into metal being welded and, as rule, requires application of preliminary and concurrent heating. This disadvantage was removed in development [1–3] of process of plasma-arc welding of copper and chrome-bronze which allows providing significant specific heat input into welded joint and regulating power and gas-dynamic parameters of plasma jet in a wide range.

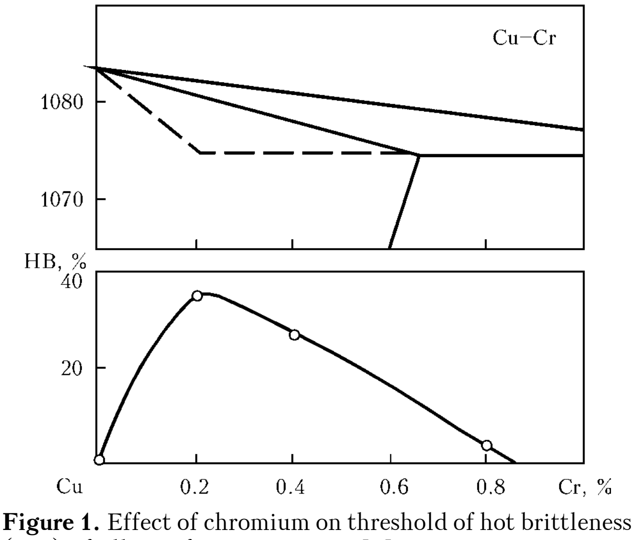

Figure 1. Effect of chromium on threshold of hot brittleness (HB) of alloys of Cu–Cr system [4]

Plasma gas is tangentially entered in plasmatron for plasma jet stabilizing that promotes vortex condition of gas flow and entering of certain amount of air in arc zone. This, in turn, results in liquid metal oxidation, due to which chromium being present in a base metal (BM) (0.8–1.2 %) burns out in the weld pool up to 0.1–0.2 %, and weld metal enters in the zone of maximum brittleness (Figure 1). Hot microcracks (Figure 2) are initiated in the formed weld metal. They are not detected by X-ray penetrant fluid and dye penetrant methods of testing, but develop and

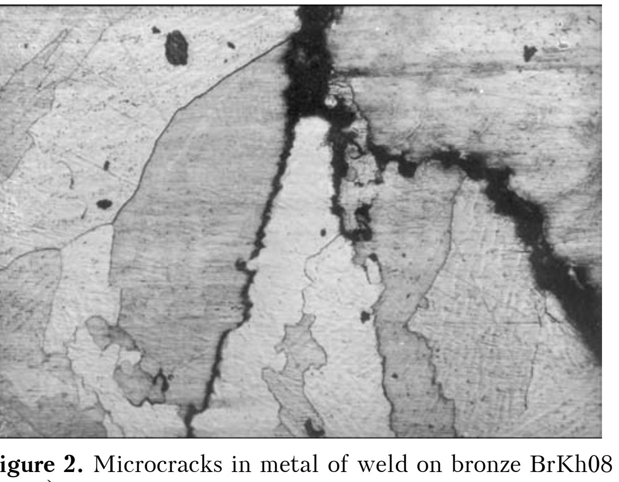

Figure 2. Microcracks in metal of weld on bronze BrKh08 (×300)

appear in further technological operations accompanied by deformations and heating of part.

Estimation of susceptibility to crack formation of Cu–Cr alloys with different chromium content performed on procedure, described in work [5], using specimens of «fishbone» type, showed that the metal with chromium content in 0.5–1.0 % limits (Figure 3) has the minimum susceptibility to crack formation.

It is known that margin of technological strength in welding (resistance to hot crack formation) depends on relationship of three characteristics, i.e. brittlement temperature range (BTR), strain capability in this interval, and intensity of increment of plasto-elastic deformation with temperature reduction (rate of strain).

BTR value is determined by chemical composition of alloy, dendritic segregation, dimension and size of crystallites, rates of cooling and strain. Approximately, it can be evaluated on constitutional diagram considering solidification nonuniformity and effect of impurities. Ductility of alloy in BTR depends on ratio of volumes of solid and liquid phases, sizes and shape of crystallites, character of liquid phase distribution, chemical and corresponding structural microinhomogeniety and strain rate.

Strain rate is determined by thermal coefficient of linear expansion, rigidity of welded joint, character of temperature distribution (determining the level of strain concentration) as well as forming of parts being welded.

Analysis of cracks, formed in plasma-arc welding of copper and chrome-bronze, showed that they are intercrystalline with oxidized surface and have solidification character. Investigations performed at the E.O. Paton Electric Welding Institute showed that solidification cracks were induced by presence of detrimental impurities (bismuth, tellurium, sulfur, oxygen etc.) [5, 6]. Negative effect of these impurities is conditioned by their general physical-chemical properties, i.e. limited solubility in copper, formation of fusible eutectics, surface activity in relation to copper. Therefore, mechanism of influence of detrimental impurities on susceptibility to formation of solidification cracks is related with effect of adsorption decrease of ductility and strength (mechanism of liquid-metal brittleness) [7].

Rapid increase of concentration of detrimental impurities took place at last stages in solidification of single-phase alloy and work on crack nucleation is reduced due to their surface activity. In solidification of binary-phase alloy, liquid is still remaining at the last stage and no enrichment with detrimental impurities takes place. Therefore, copper is necessary to be alloyed by elements promoting formation of binary-phase alloy, for example, chromium in specific concentrations, in order to increase resistance to formation of solidification crack.

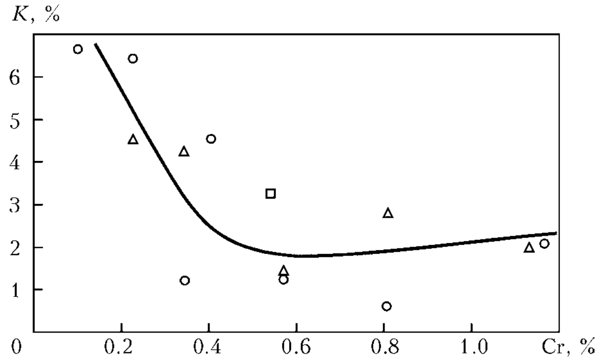

Figure 3. Dependence of technological strength of chrome-bronze on chromium content

Chromium has limited solubility in copper in solid solution (chromium solubility achieves 0.65 % at 1072 °C temperature of eutectic) and being one of the elements insignificantly reducing electric- and heat conduction of copper [8]. Therefore, compensation of waste of chromium and additional alloying of weld metal in such a way that chromium content in it being at the level of BM is necessary in plasma-arc welding of chrome-bronze for prevention of formation of solidification cracks. It also to be noted that chromium is efficient conditioning agent (Figure 4), that reduces enrichment of grain boundaries with detrimental impurities.

Special filler flux-cored wire PPBrKhT 12-2 [2] containing around 10–15 % Cr, which provides necessary additional alloying of the weld metal by chromium, was developed for compensation of chromium waste. Entering of 1.5–3.0 % Ti (efficient deoxidizing agent) in the wire promotes deoxidation of metal of weld pool, as well as reduction of chromium waste. Besides, as follows from results of investigation [9], microalloying of welds of chrome-bronze BrKh08 by 0.04–0.07 % Ti also increases their crack resis-

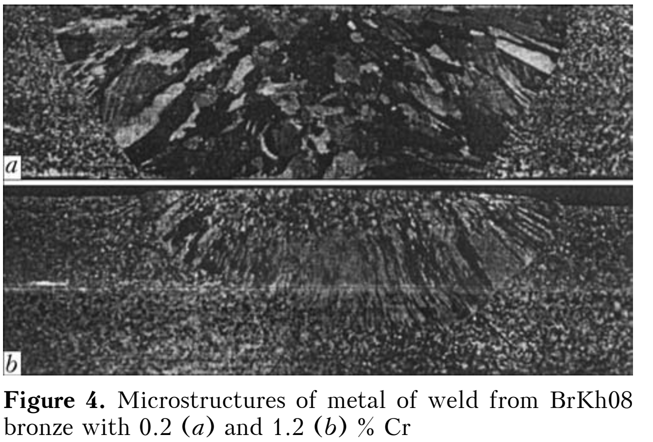

Figure 4. Microstructures of metal of weld from BrKh08 bronze with 0.2 (*a*) and 1.2 (*b*) % Cr

Figure 5. Mould for vacuum electric-arc melting titanium ingots of bronze BrKh08 40 mm thick

tance and rises strain capability of the welded joints.

The simplest method of feeding of filler wire in welding zone under manufacture conditions is its laying along the joint with further filling up by flux layer.

Considering that plasma-arc welding of copper and chrome-bronze of large thicknesses (up to 40–50 mm) is made on powerful modes (I_w = = 1000–1400 A, U_a = 48–55 V) and formed liquid metal pool has significant dimensions (more than 80 × 160 mm for 40 mm thickness metal), protection of such volume of molten metal from air influence is not simple task. Solving it by additional gas shield at the expense of plasmatron structure being already sufficiently complex is not easy. Besides, increase of consumption of inert gas for protection of molten metal from air results in its splashing from the pool. In this connection, plasma-arc welding is carried out over the flux layer, height of which makes 15–20 mm. Binary mixture of fluxes of AN-26 and AF-4A grades in 10:1 ratio was selected in experimental way, where addition of chloride flux slaking refractory oxide film Cr_2O_3 improves separability of slag crust.

Industrial technology of plasma-arc welding of chrome-bronze of large thicknesses, which was successfully mastered in manufacture of unique welded moulds of metallurgical electro-furnaces (Figure 5) was developed on the basis of investigations performed.

1. Ilyushenko, V.M., Sedov, V.E., Anoshin, V.A. (1977) Improvement of technology of plasma-arc welding of parts from copper and chrome-bronze. *Svarochn. Proizvodstvo*, **11**, 31–32.
2. Gurevich, S.M. (1981) *Reference book on welding non-ferrous metals*. Kiev: Naukova Dumka.
3. Novoseltsev, Yu.G. (2008) *Technological peculiarities of plasma welding of large dimension structures from copper and its alloys*. Krasnoyarsk: KGU.
4. Novikov, I.I. (1966) *Hot brittleness of non-ferrous metals and alloys*. Moscow: Nauka.
5. Ilyushenko, V.M., Anoshin, V.A., Bondarenko, A.N. et al. (1980) Study of effect of impurities and alloying elements on hot crack formation in copper welding. In: *Proc. of 1st All-Union Conf. on Relevant Problems of Welding of Non-Ferrous Metals*. Kiev: Naukova Dumka, 217–221.
6. Ilyushenko, V.M., Anoshin, V.A., Zherdev, A.M. et al. (1985) About effect of impurities on susceptibility to crack formation in copper welding. In: *Proc. of 2nd All-Union Conf. on Relevant Problems of Welding of Non-Ferrous Metals*. Kiev: Naukova Dumka, 335–337.
7. Glikman, E.E., Goryunov, Yu.V. (1978) Mechanism of liquid metal brittleness and other developments of Rehbinder effect in metallic systems. *Fiz.-Khimich. Mekhanika Materialov*, **4**, 20–30 .
8. Smiryagin, A.P. (1956) *Inductrial non-ferrous metals and alloys*. Moscow: Metallurgizdat.
9. Shipulin, A.P., Zobnina, G.K., Bosak, L.K. et al. (1974) Effect of titanium on weld metal plasticity in submerged arc welding of BrKh08 alloy. *Svarochn. Proizvodstvo*, **4**, 25–27.

Received 13.02.2013