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Analysis of welding methods for copper and copper alloys

M.M. Abdurakhmonov, M.Z. Abdullaev, J.N. Sadikov, S.S. Khudoyorov, N.S. Dunyashin, Z.D. Ermatov

Assistant, Department of Technological machines and equipment, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan
Senior lector, Department of Technological machines and equipment, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan
Associate Professor, Doctor of Philosophy in Technical Sciences (PhD), Department of Engineering technology, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan
Associate Professor, Doctor of Philosophy in Technical Sciences (PhD), Department of Technological machines and equipment, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan
Head of the Department, Professor, Doctor of Technical Sciences, Professor, Department of Technological machines and equipment, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan
Professor, Doctor of Technical Sciences, Department of Technological machines and equipment, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan

ABSTRACT: This article provides an analysis of methods for welding copper and copper alloys

KEY WORDS: copper, welding, brass, bronze, oxygen, hydrogen

I. INTRODUCTION

All main fusion and solid phase welding methods are applicable for copper and its alloys. Preparation for welding. Before welding, the metal and wire to be welded are thoroughly cleaned of oxides and contaminants to a metallic shine and degreased. Edge cleaning can be done mechanically (emery, metal brushes, etc.). The welding wire and the edges of the base metal are cleaned by etching in a solution consisting of 75cm3/l HNO3, 100 cm3/l H2SO4 и 1 cm3/l HCl, followed by washing in water and alkali, again in clean water and drying with hot air.

II. LITERATURE SURVEY

Due to the high thermal conductivity of copper (almost 6 times greater than that of steel), for fusion welding it is necessary to use heating sources with high thermal power, as well as increased heat input compared to steel. [1]

For example, arc welding is performed at increased currents with electrodes of large diameters. High thermal conductivity also leads to very significant cooling rates of the weld metal and heat-affected zone and a short residence time of the weld pool in the liquid state. This impairs the formation of the seam and causes difficulties during metallurgical processing of the bath. [2-3]

Good weld formation can be maintained by preheating, which ensures a more even distribution of heat in the weld pool. [4-5]

In addition to eliminating defects (undercuts, sagging, cracks, porosity), preliminary and concomitant heating of the base metal improves the conditions for crystallization of the weld, reduces internal stresses and eliminates the tendency of the weld metal to form cracks. [6]

III. METODOLOGY

Gas welding is predominantly performed with an oxy-acetylene flame. It is advisable to use acetylene substitutes (propane-butane mixture, etc.) when welding copper and brass of small thicknesses. The high thermal conductivity of

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copper necessitates the use of high-power flames, approximately 2 times higher than the power for welding low-carbon steel. For metal of small thicknesses (up to 3-4 mm), the flame power is selected at the rate of 150-175 l/h of acetylene per 1 mm of thickness, and for thicknesses up to 8-10 mm, the flame power increases to 175-225 l/h per 1 mm of thickness. For large thicknesses, it is recommended to use two or even three torches, and welding can be carried out with one torch, while the others are intended for heating. Welding should be carried out in only one layer at maximum speed to avoid grain growth and the formation of pores. When using two torches, the consumption of acetylene for heating is 150-200 l/h per 1 mm of thickness, and in a welding torch - 100 l/h per 1 mm of thickness. Copper and bronze are welded with a normal flame (β = 1,0—1,1). In order to reduce the loss of zinc, β=1,2—1,4 is taken for brass (the oxidizing flame binds hydrogen in H_2O, thereby reducing the dissolution of hydrogen in the liquid metal, which, in turn, leads to a decrease in the intensity of zinc evaporation).

The consumption of flammable gas - an acetylene substitute (v_g) - is determined from the equation

$v_g = (10 - 12)\psi_3 b\ 10^{-2}$, where ψ_3 is the acetylene replacement coefficient, $\psi_3 = v_3/v_a$ (v_3 and v_a are the costs of acetylene and acetylene substitute, l/h). When using substitute gases, oxygen consumption increases significantly (for example, with a propane-butane mixture, β can reach 3,5).

The use of an additive made from ordinary copper wire when gas welding copper does not give positive results: the seams, especially on thick metal, turn out to be porous and prone to cracking. Acetylene combustion products do not provide complete isolation of the weld pool from the atmosphere, and the seam is enriched with dissolved copper oxide. Therefore, the weld pool needs to be deoxidized.

Deoxidation during gas welding of copper is achieved in two ways: by introducing deoxidizers into the filler metal and by using fluxes that dissolve copper oxide. For welding copper up to 10 mm thick, it is recommended to use copper filler wire containing up to 0,2% P, and for copper of greater thickness - an additional 0,15-0,30% Si. An excess of deoxidizing agents in the weld metal is undesirable, since a large amount of phosphorus and silicon leads to a decrease in the important properties of copper: thermal conductivity and electrical conductivity.

The process of deoxidation of the weld metal when phosphorus is introduced into the weld pool proceeds according to the reaction $5Cu_2O+2P \leftrightarrow P_2O_5+10Cu$. The introduced phosphorus increases the fluidity of copper and this makes it easier for impurities and slag to float to the surface of the bath.

When welding copper alloys containing active deoxidizers (aluminum, silicon, manganese), you can use an additive of the same composition as the base metal. For example, for welding brass - a filler metal that helps reduce zinc losses - silicon brass type LK 62-0,5 (62 % Cu, 0,3—0,7 % Si, the rest Zn). To dissolve and remove oxides when welding copper, fluxes based on borax and boric acid with the addition of sodium and potassium salts are used.

Carbon arc welding is used to a limited extent, mainly for products that do not experience significant loads. It is advisable to use carbon electrodes with a copper thickness of up to 15 mm. For large thicknesses, the best results are obtained with graphite electrodes. Welding is performed with electrodes sharpened to a cone 1/3 of the length of the electrode, using direct current of straight polarity.

The welding process is carried out with a long arc to avoid the harmful effects of released carbon monoxide (CO) on the weld pool. For the same purpose, and also in connection with the possibility of cooling the bath, the additive is not immersed in the bath, but is kept at an angle of approximately 30° to the product at a distance of 5-6 mm from the surface of the bath. The carbon electrode is held at an angle of 75-90° to the workpiece being welded. The arc voltage is determined from the expression Ud= 18+1,8ld

For a carbon electrode with a diameter of 12–18 mm and an arc length of 16–18 mm, it is recommended to increase the found values by 10–15%. On average, the operating voltage during welding is 40-50 V. Using wire containing deoxidizing agents such as phosphorus, manganese, silicon (for example, type BrKMts3-1) as a filler metal, welding is performed without additional protective measures.

Flux for welding copper with a carbon arc is applied to the filler wire or poured into the groove. Depending on the thickness of the metal, the following preparation of edges is recommended: beading of edges for metal with a thickness of 1-2 mm; butt joint without cutting edges 5-10 mm thick; V-shaped butt joint (bevel angle 70°, blunting 3 mm) - for metal of large thicknesses. Carbon electrode welding is performed using the “right” and “left” methods. The “right” method is more productive, since more heat is concentrated on the base metal, which makes it possible to weld butt joints made of thick metal without cutting the edges.

Welding is carried out mainly in the lower position or with a slight inclination of the parts being welded on graphite pads with grooves. In some cases, steel pads can also be used. To improve the quality of the seams, it is recommended to forge them after welding using the modes used in gas welding. In the case of using an additive from BrKMts3-1, welded copper joints have the following mechanical properties: $\sigma_в$ = 274,7 MPa; α= 180°.

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Automatic submerged arc welding with a carbon electrode is performed at direct current of direct polarity using standard fluxes used for welding steel: AN-348A, OSTS-45, etc. The carbon (or graphite) electrode is sharpened in the form of a flat blade, and the filler (made of brass or tombak) to deoxidize the weld metal, zinc is placed in the joint. Welding is carried out with a submerged arc. The initial section of the butt joint is preheated by closing the electrode to the product. Graphite pads are used.

The mechanical properties of the weld metal on M1 copper with a thickness of 5 mm are as follows: $\sigma_в$ = 176,6 – 182,5 MPa; δ = 25-33%. Roller rolling slightly increases the strength of the seam. Electric arc welding with coated electrodes is performed using direct current of reverse polarity.

When multilayer welding of copper with a thickness of more than 10–12 mm (3–6 layers), electrodes with a diameter of 6–8 mm are used at a welding current of up to 500 A. Copper with a thickness of up to 4 mm is welded without cutting edges; up to 100 mm - with one-sided cutting at an edge bevel angle of up to 60-70°, blunting 1,5-3 mm. For larger thicknesses, X-shaped cutting is recommended. Welding is carried out with a short arc without transverse vibrations of the electrode. Better seam formation is ensured by the reciprocating movement of the electrode. Lengthening the arc impairs the formation of the seam and the mechanical properties of welded joints, and increases spattering. When welding butt joints, metal (steel or copper) or asbestos gaskets are used. Welding is carried out in a lower or slightly inclined position (uphill). When manually welding copper with coated electrodes, edge heating is necessary starting from a thickness of 4 mm. The heating temperature increases with the thickness of the edges being welded and the dimensions of the product. When the thickness of the welded edges is 5-8 mm, the metal is heated to 200-300° C, with a thickness of 24 mm - to 750-800° C. The welding speed is taken as high as possible. It increases with increasing preheating temperature and decreases with increasing metal thickness.

Satisfactory mechanical properties of the joints are ensured when welding with «K-100» electrodes with an M1 copper rod. In this case, the weld metal has δ = 18–20%; a_n = 588,6 – 784,8 kJ/m^3. Sufficiently high mechanical properties of the seam and welded joint on copper can also be obtained by using electrodes with rods made of BrKMts3-1 bronze with 3T coating.

Forging seams on copper without heating increases the strength of the metal of the seams with a slight decrease in ductility. Special high-performance electrodes of the ANC-1 brand ensure welding without heating for metal up to 15 mm thick or with low heating for metal of large thicknesses.

Butt joints on copper 20 mm thick are made without cutting edges using one- or two-sided seams, on graphite backings. Recommended modes: I_{sv} = 85-100 A; U=45-50 V. A necessary condition for obtaining high-quality seams is the use of direct current sources - welding rectifiers or converters with an open circuit voltage U_{xx} < 70 V.

The thermal conductivity and electrical conductivity of welds when welding copper with coated electrodes is significantly reduced in comparison with similar parameters of the base metal. During the melting of an electrode coated with “Komsomolets-100”, 0,2–0,25% Si, 0,5–0,6% Mn, and 1,1–1,2% Fe pass into the weld. The electrical conductivity of such an alloyed weld is only 20% of the electrical conductivity of M1 copper. The electrical conductivity of the weld decreases to approximately the same extent when welding with electrodes with rods made of BrKMts3-1 bronze.

Automatic submerged arc welding with a consumable electrode is performed using conventional welding machines using direct current of reverse polarity. Welding under ZhM-1 type ceramic flux can be performed using alternating current. For copper with a thickness of 4-10 mm, welding using standard fused fluxes (AN-26S; AN-20S; AN-348A and OSTS-45) does not cause difficulties. For metal of large thicknesses, it is necessary to use special dry granulation fluxes, for example, ANM-13.

The main advantage of automatic copper submerged arc welding is the ability to obtain stable high mechanical properties of joints without preheating. Therefore, when manufacturing large-sized welded structures from thick copper, the technological process is quite simple and practically does not differ from welding steel products.

Welding is usually performed in one pass with complete fusion of the joining edges. It is recommended to use cold-worked electrode wire made of oxygen-free copper MB or technical copper grade M1 (with an oxygen content of less than 0.01%). In this case, if the welds must have high thermophysical properties, in order to increase the strength of the joints, welding of copper and bronze (for example, brand BrKh08) is performed with bronze wires (BrKhT0,6-0,5; BrKh0,7; BrKMtsZ-1; BrOTs4- 3, etc.).

Metal up to 20-25 mm thick is welded with one electrode with a diameter of 4-5 mm without cutting the edges. For larger metal thicknesses, a U-shaped groove (blunting 5-8 mm) and a split electrode (the distance between the axes of the electrode wires located across the seam is about 20 mm) from wires with a diameter of 5 mm when welding with one electrode with a diameter of 6 mm are recommended.

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Since copper has extremely low electrical resistance, the rate of melting of copper wire does not depend on the amount of electrode stickout. The melting coefficient of the electrode wire is about 20 g/Ah. For alloyed wires, the melting rate increases with increasing electrode extension.
To hold the liquid metal of the weld pool and form the back side of the weld on copper, graphite pads are used (for metal thicknesses of up to 10-12 mm and welds of short length) or flux pads. Short seams on thin copper can be welded using a flux pad without additionally pressing the flux to the inside of the edges during welding. For assemblies made of copper of large thickness, regardless of the length of the seam, flux pressure is required, usually achieved pneumatically. The quality of connections when welding copper with submerged arcs is largely determined by the preparation for welding. Since copper is very prone to oxidation and is susceptible to the influence of hydrogen, in order to avoid the occurrence of defects (cracks, pores), the edges and electrode wire must be thoroughly cleaned to a metallic shine, and welding materials (flux, graphite blocks) must be calcined before welding.
To excite the arc during submerged arc welding, the wire is short-circuited to the workpiece through small, fat-free copper shavings or a spring wound from copper wire with a diameter of 0,5-0,8 mm. Edge tacking before welding is performed under submerged arc with the moving mechanism turned off; The tack pitch is 300-400 mm.
The beginning and end of the seam are brought out onto technological copper strips welded to the product. It is allowed to use attached graphite strips, the thickness of which must be equal to the thickness of the metal being welded. In order to prevent cracks from occurring in the seam, the gap between the strip and the end of the product should not exceed 1 mm. Subject to the technological process of assembly and submerged arc welding of products, it is possible to obtain high-quality welded joints from metal 30-40 mm thick.
Using an oxygen-free fluoride flux, for example, ANM-1, welds are obtained that do not differ in thermal conductivity and electrical conductivity from the base metal. The mechanical properties of the weld metal welded with copper electrode wire on commercial copper are somewhat lower than those of the base metal. The use of bronze wires increases the strength and ductility of the seams.
They weld bronze (aluminum, chromium, lead, etc.) well using an automatic submerged arc. Welding of bronze, like copper, is performed with direct current with reverse polarity. To improve the formation of the seam and eliminate defects of “bruising” of the seam surface, the height of the flux layer is limited. For the same purpose, it is recommended to use coarse granulation flux (2,3-3,0 mm). The mechanical properties of seams welded on aluminum bronzes under submerged arc are quite satisfactory. Welded joints made of chromium bronze are not inferior in strength to the base metal.
Welding in shielded gases of copper and its alloys is carried out with non-consumable and consumable electrodes. A non-consumable tungsten electrode is used to weld copper up to 4-6 mm thick in argon without preheating, and in helium and nitrogen - up to 6-8 mm thick. A consumable electrode can be used to weld thicker metal without heating: in argon - up to 6-8 mm, in helium and nitrogen - up to 10-12 mm.
The need to use preliminary and, for large thicknesses, accompanying heating is a serious difficulty when welding copper in a shielding gas environment. Helium and nitrogen provide higher efficiency of the welding process compared to argon, so they deserve preference.
However, argon, being the most universal protective gas, is widely used for copper (grades 1 and 2 according to GOST 10157-73). It is advisable to use gas mixtures (for example, the following volumetric content: 70-80% Ar, 20-30% N_2) to save argon and increase welding productivity.
Welding with a tungsten electrode is carried out using direct current of straight polarity. Copper up to 5-6 mm thick can be welded without cutting edges. For metal of large thicknesses, a V- or X-shaped groove with an opening angle of 60-70° is used.
Welding techniques in different protective environments differ mainly in the need to maintain arcs of different lengths. For argon and helium, the arc length should be as short as possible (usually about 3 mm). The arc in nitrogen is much longer (about 12 mm). Therefore, depending on the environment in which copper welding is performed, the static characteristics of the arcs differ sharply - the dependence of the arc voltage on the value of the welding current. At a given welding current, the arc voltage, and therefore its power and heat input, are highest in nitrogen (3-4 times higher than in argon). In helium these figures are approximately 2 times higher than in argon. When welding in nitrogen, seams are more prone to pore formation, especially with small sizes of the weld pool and an increased cooling rate. This is explained by the fact that in nitrogen the metal of the weld pool tends to decrease its fluidity. The consumption of protective gas, depending largely on its thermophysical properties and density, is on average as follows: argon - 8-10 l/min, helium - 10-20 l/min or more, nitrogen - 15-20 l/min. Gas mixtures are rarely used for copper welding. To increase welding speed, a mixture of argon with nitrogen or helium is recommended, where the volumetric content of nitrogen or helium is 30%. When welding, graphite pads or water-cooled copper plates are used. Welding in an argon environment

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is usually carried out from right to left with the electrode tilted towards the workpiece at an angle forward of 80-90°; The angle of inclination of the filler wire is 10-15°, the extension of the non-consumable electrode is 5-7 mm.

Welding of copper with a non-consumable electrode is carried out using filler metal from deoxidized copper, copper-nickel alloy MNZHKT5-1-0,2-0,2, bronze BrKMtsZ-1, BrOTs4-3.

The common technology of argon arc welding of copper using filler wires MNZHKT5-1-0,2-0,2 and Br.KMnZ-1, which make it possible to obtain welds of satisfactory quality, in some cases do not provide the thermophysical properties of the weld metal and the operational reliability of the welded joints.

The electrical conductivity of the seams is 80-95% of the electrical conductivity of the base metal. The best welding properties of oxygen-containing copper are achieved when helium is used as a protective medium. The bend angle of welded joints is 180°; σ_d=190-210 MPa. The most common defects in copper welds are porosity and hot cracks. The formation of cracks during the crystallization of welds is associated with the presence of residual impurities in the base metal, such as bismuth, oxygen, lead, sulfur, selenium, tellurium, and phosphorus.

Based on the nature of their influence on crack formation, impurities can be divided into three groups.

1. Impurities that increase the tendency to form and propagate cracks during welding—bismuth, tellurium, selenium, phosphorus, lead. These impurities, except phosphorus, have a harmful effect on the weldability of copper at their concentrations in thousandths and ten thousandths of a percent.

The influence of phosphorus is manifested when its content in copper is more than 0,01%. Bismuth and tellurium have the greatest influence. Lead begins to have a significant effect only at high welding speeds (more than 14 m/h), and when it is introduced into copper deoxidized with phosphorus, it even reduces the tendency to form and propagate cracks.

2. Impurities that, depending on the concentration, have a variable effect on the formation and propagation of cracks. At low concentrations (up to 0,01%), they increase the tendency to form and propagate cracks, and at high concentrations they reduce it. Such impurities are oxygen, sulfur, cadmium.

3. An impurity that has virtually no effect on the formation of cracks is arsenic. Based on the nature of their influence on the formation of crystallization cracks, alloying additives (with a content of up to 0,6%) can be divided into the following groups: elements that reduce the tendency of seams to form and propagate cracks - chromium, niobium, yttrium, and to a lesser extent - titanium, manganese, vanadium, silicon; elements that have virtually no effect on the formation of cracks, but reduce the tendency for their propagation - iron, nickel, cobalt, aluminum, zinc; elements that have a variable effect on the formation of cracks depending on their concentration and welding speed - boron, zirconium, magnesium.

This effect of alloying additives is associated with their influence on the nature of crystallization and different deoxidizing abilities in relation to copper.

Complex-alloyed copper-nickel and manganese-copper alloys, aluminum and tin bronzes are also characterized by an increased tendency to form hot cracks. When welding copper-based alloys, hot cracks may form both in the weld metal and in the heat-affected zone. Hot cracks in weld metal are usually caused by a wide effective crystallization range of the alloys. The main reason for the formation of such cracks can be considered the low plastic properties of these alloys at elevated temperatures, due to the presence of a ductility failure, which is observed in most copper-based alloys. The temperature limits and minimum plasticity in this range are different for different alloys.

The larger the range of loss of ductility, the more it is shifted to the region of low temperatures and the less ductility in this range, the higher the tendency of the alloy to form cracks. Manganese-copper alloys have the greatest tendency to hot cracks in the weld metal, and aluminum bronze alloys have the least tendency.

Copper-nickel alloys are susceptible to the formation of cracks in the HAZ, and the most resistant to the formation of such cracks are aluminum-nickel and manganese-aluminum bronzes.

Welding of copper with a consumable electrode in a shielding gas environment is carried out using direct current of reverse polarity. It is used for copper with a thickness of at least 6-8 mm. V- and X-shaped cuts are recommended. The productivity of welding copper with a consumable electrode is approximately 2-3 times higher than when welding with a non-consumable electrode.

However, with a consumable electrode, it is difficult to ensure process stability and obtain pore-free seams. Thus, at a welding current density above 300 A/mm^2 in argon and 110 A/mm^2 in nitrogen, a porous weld is formed. For each protective environment and welding mode, the optimal wire diameter is selected. The best properties of the weld metal when welding copper with a consumable electrode in an inert gas environment are ensured by the use of wire alloyed with 0,22% Mg, 0,22% Li, 0,2% Cr. It has better welding and technological properties compared to foreign and domestic wires intended for welding copper in an inert gas environment, in particular, it has higher resistance to the formation of pores and cracks, ensures stable arc burning and jet transfer of electrode metal, and higher electrical conductivity seams.

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The arc length when welding copper with a consumable electrode is one of the most important characteristics of the process, since not only the loss of electrode metal, its saturation with hydrogen and oxidation, but also the effective efficiency of the arc depend on it. When welding copper with straight polarity current, the arc length depends on both the composition of the shielding gas and the composition of the electrode wire. Satisfactory formation of seams when welding with wires of different chemical compositions can be obtained with an arc length of 4-5 mm.

When welding copper with a consumable electrode, the best results are achieved under conditions of jet transfer of the electrode metal on a current of reverse polarity in argon, as well as on a current of direct polarity in both inert and active gases when using electrodes.

The best results when welding with a consumable electrode are obtained by jet transfer of the electrode metal, which is observed when welding with a current of reverse polarity in argon, as well as with a current of direct polarity in both inert and active gases when using electrodes with surface-activating coatings.

Argon arc welding of copper using flux-pastes allows you to increase the penetration ability of the arc. Flux pastes developed for copper welding (ANM-15A, etc.) are intended for metal of a certain thickness, and their welding and technological properties are manifested in a relatively small range of modes.

The effect of using paste fluxes is assessed by the area of metal penetration. The penetration ability of fluxes depends on their chemical composition and heat input during welding. An increase in heat input sharply reduces the effect of using fluxes. Therefore, the optimal composition of the flux-paste is variable; it depends on both the current and the welding speed. Fluxes can be used in manual argon arc welding by applying directly to the joint or in automatic welding with a non-consumable electrode in the form of filler wire fillers.

Plasma welding has a number of advantages when connecting elements made of copper and its alloys of large thickness; the possibility of large heat inputs into welded edges, welding of butt joints without cutting edges, minimal amount of mechanical processing before and after welding. A mixture of argon and helium (volume fraction of He 80-85%) is used as a plasma-forming gas. To protect the weld pool from interaction with the atmosphere and ensure good formation of the seam, welding is performed over a layer of flux (for example, AN-26S). A special flux-cored wire of the PPBrKhT-12-2 brand is used, which makes it possible to deoxidize and delegate the weld metal. This eliminates the tendency of the seam to form crystallization cracks and increases the deformability of welded joints.

Welding of metal up to 50-60 mm thick is performed without cutting edges in one pass. For larger thicknesses, double-sided welding is used. When welding copper, the current and gas flow should be increased by 10-15°C. When plasma welding of copper, direct-acting plasma torches are used, designed for long-term operation under forced conditions, and special power sources.

Electron beam welding is very effective in the manufacture of electric vacuum devices. Thus, when welding especially pure MB copper, high physical and mechanical properties of welded joints are ensured while maintaining the original purity of the metal in the weld and the heat-affected zone.

In EBW of copper, difficulties arise due to the intense evaporation of the metal in a vacuum when overheated above the melting point, as well as its high thermal conductivity. A high concentration of power when welding thin-sheet copper leads to a weakening of the weld cross-section due to loss of metal during evaporation, and when welding thick metal, it leads to intense spattering and unsatisfactory formation of the weld.

If a certain value of the specific power in the heating spot is exceeded, it is usually not possible to obtain a good quality copper welded joint. For these reasons, for welding and its alloys, preference is given to the use of an oscillating beam. The content of impurities in it has a great influence on the EBW behavior of copper. An increase in the impurity content leads to a decrease in the penetration depth and the size of the HAZ. At the same time, recrystallization and grain growth are inhibited.

When welding copper of large thicknesses, electron-optical systems are used that ensure uniform current across the beam cross-section, or systems in which the maximum current density is shifted beyond a certain central region. Significant heat inputs are also required. For example, to obtain penetration to a depth of 15 mm at a welding speed of 50 m/h, a power of approximately 14 kW is required at u - 28 kV.

With EBW of copper and some of its alloys (for example, BrKhO,8 bronze), welds with a fine-grained structure and good mechanical properties are obtained, almost equivalent to the properties of the base metal.

Electroslag welding is successfully used for copper of large cross-sections. Due to the high thermal conductivity of copper, welding must be carried out at high heat input. For welding copper, the most suitable electrode is a large cross-section - a plate electrode (for short seams) or a plate-wire electrode - a melting nozzle (for long seams).

Considering that ESW excludes the possibility of introducing alloying elements through flux, the seam is alloyed using plate electrodes of the appropriate composition. For ESW of copper, special low-melting fluoride-based fluxes are used

(for example, type ANM-10), which ensure a stable process, heating and melting of edges to the required depth, good formation of seams and easy removal of slag crust from their surface.
In order to obtain maximum heat concentration and minimize heat losses, special graphite forming devices are used when welding copper workpieces. The width of the gap between the welded edges affects the stability of the process and the depth of their penetration. Reducing the gap leads to disruption of process stability due to short circuits of the plate electrode to the product, as well as to a decrease in the penetration depth.
If the gap is too large, welding productivity decreases and filler material consumption increases. Thus, when welding copper workpieces with a cross-section of 140x160 mm, a gap of 50-60 mm is taken, and the thickness of the plate electrode is 18 mm.

IV.CONCLUSION

The results of the studies made it possible to select the optimal copper welding method.

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AUTHOR'S BIOGRAPHY

	**Abdurahmonov Mansurjon Muridjon ugli**, Assistant, was born May 3, 1993 year in Tashkent city, Republic of Uzbekistan. He has more than 15 published scientific works in the form of articles, theses and tutorials. Currently works at the department of "Technological machines and equipment" in Tashkent State Technical University as an assistant teacher, Tashkent, Uzbekistan.
	**Abdullayev Muzaffar Zahidjonovich**, Senior lector was born in June 26, 1989th year in Tashkent city, Republic of Uzbekistan. He has more than 15 published scientific works in the form of articles, theses and tutorials. Currently works at the department of "Technological machines and equipment" in Tashkent State Technical University as an assistant teacher, Tashkent, Uzbekistan.
	**Sadikov Jaxongir Nasirdjanovich** , Associate Professor, Doctor of Philosophy in Technical Sciences (PhD), was born March 10, 1975 year in Tashkent city, Republic of Uzbekistan. Has more than 20 published scientific works in the form of articles, journals, theses and tutorials. Currently works as researcher at the department of "Technological machines and equipment" in Tashkent State Technical University

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	**Khudoyorov Sardor Sadullaevich**, Associate Professor, Doctor of Philosophy in Technical Sciences (PhD), was born March 7, 1989 year in Tashkent city, Republic of Uzbekistan. Has more than 50 published scientific works in the form of articles, journals, theses and tutorials. Currently works at the department of "Technological machines and equipment" in Tashkent State Technical University.
	**Dunyashin Nikolay Sergeyeevich** , Head of Department, Doctor of Science, Professor was born February 13, 1978 year in Tashkent city, Republic of Uzbekistan. Has more than 140 published scientific works in the form of articles, journals, theses and tutorials. Currently works at the department of "Technological machines and equipment" in Tashkent State Technical University.
	**Ermatov Ziyadulla Dosmatovich**, Doctor of Science, Professor was born in May 16, 1978th year in Tashkent city, Republic of Uzbekistan. He has more than 110 published scientific works in the form of articles, these and tutorials. Currently Professor of the department of "Technological machines and equipment" in Tashkent State Technical University, Tashkent, Uzbekistan.