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Analysis of Technologies for Melting Copper Alloys

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Abstract: This article analyzes modern technologies for melting copper alloys and evaluates their efficiency. Copper and its alloys are among the important structural materials widely used in mechanical engineering, electrical engineering, metallurgy, and other industrial sectors. Therefore, the proper technological organization of the melting process directly affects the chemical composition, microstructure, and mechanical properties of the material. The obtained results show that melting technology in induction furnaces is one of the most effective methods in terms of energy efficiency and maintaining the stability of the metal composition. The research results contribute to optimizing the melting process of copper alloys, obtaining high-quality castings, and improving the technological efficiency of metallurgical production.

Keywords: Casting, alloy, melting process, furnace, bronze, brass, ligature.

Introduction: Bronze is usually melted in independent electric arc furnaces or flame furnaces, while brasses are melted in crucible induction furnaces as well as channel furnaces. The melting process of copper-based alloys is considered one of the important technological stages in the metallurgical industry [1-5]. During this process, many factors affecting the chemical composition of the alloy, the purity of the metal, and the quality of the casting are carefully controlled.

Copper alloys, including bronze and brass, are widely used in mechanical engineering, electrical engineering, shipbuilding, and other industrial sectors. Therefore, the correct selection of melting technology and the application of optimal technological regimes are of great importance for obtaining high-quality metal. During the melting process, special attention must be paid to preventing metal oxidation, the loss of alloying elements, and the formation of harmful impurities [6-8].

In modern metallurgy, electric arc furnaces, induction furnaces, and flame furnaces are widely used for melting copper alloys, each having its own technological advantages. This article analyzes the technologies for melting bronze and brass alloys, their efficiency, and their impact on the quality of the metal [9,10].

METHODS

Primary materials, returned metal, scrap metal, and cast alloys (brasses and bronzes) are used as charge materials [11]. To adjust the chemical composition of the alloy to the required standard, primary pure metals or master alloys (ligatures) are used (Table 1).

Table 1. Composition of master alloys used in copper alloy melting.

Master alloy	Mass percentage, %	Melting point, °C.
Cu–Mn alloy	73 Cu, 27 Mn	860
Cu–Be alloy	85-95 Cu, 5-15 Be	900
Cu–Si alloy	84 Cu, 16 Si	800
Cu–Sn alloy	50 Cu, 50 Ni	780
Cu–Ni alloy	67-85 Cu, 15-33 Ni	1050-1080
Al-Cu–Ni alloy	50 Al, 40 Cu, 10 Ni	670

Master alloys (ligatures) can be prepared in any type of furnace; however, the use of induction furnaces is preferable because they ensure effective mixing of the melt and minimize the loss of valuable non-ferrous metals. The technology for producing copper–aluminum master alloys can be described as follows.

Approximately two-thirds of the calculated amount of aluminum is charged into the furnace, melted, and overheated to a temperature of 800–1000 °C [12]. After that, copper preheated to 150–200 °C is added portion by portion. The alloy is thoroughly mixed, and after all the copper has melted, the remaining amount of aluminum is introduced. The melt is stirred again and held at 720–750 °C, after which it is refined using dehydrated zinc chloride or manganese chloride. The prepared master alloy at a temperature of 670–700 °C is then poured into a cast-iron mold (ingot mold) preheated to 150–200 °C.

Brasses are melted in almost all types of furnaces except arc and vacuum furnaces, since in these two furnaces zinc tends to burn off significantly [13]. The prepared charge is loaded into a cleaned and preheated furnace. If melting is carried out using the primary components of the charge, first a dried flux (for example, borax in an amount of 0.25% of the metal mass) and pure copper are charged. After the copper melts, it is overheated to 1130–1150 °C and deoxidized with phosphorous copper in an amount of 0.3–0.4% of the melt mass.

The alloy is thoroughly mixed, and under the slag layer a copper–silicon master alloy (15–20% Si) preheated to 200–250 °C is added according to the calculated amount. Slagging of the master alloy pieces must be avoided. After the master alloy has completely melted, heated zinc and then lead are introduced. While continuously stirring the melt with a graphite rod, its temperature is brought to 1050–1100 °C. After that, a sample is taken.

The readiness of the alloy is evaluated based on the fracture surface of the cast sample. A fine-grained fracture and the absence of liquation bulges on the surface of the sample indicate that the alloy is of high quality and ready for casting into molds. If a high degree of gas saturation in the alloy is detected, it is degassed. Degassing is carried out either by introducing nitrogen into the melt or by refining through overheating. The melting of complex multicomponent brasses differs in that, before introducing alloying components such as aluminum, the brass is first deoxidized with phosphorous copper. To remove non-metallic inclusions, the alloys are refined with manganese chloride or filtered through granular filters.

Tin bronzes are melted using primary materials, recycled production materials, and bronze in the form of cast scrap. A large portion of the charge is loaded into a preheated furnace, and dried charcoal is spread over its surface. The melted copper is deoxidized with phosphorous copper (9–10% P) in an amount of 0.2% of the metal mass, after which the temperature of the melt is increased to 1100–1150 °C. Then the remaining components of the charge are added sequentially (zinc, tin, and lead), and the temperature of the alloy is raised to 1100–1200 °C. The alloy is then refined using manganese chloride or nitrogen, modified (for example, with a complex modifier containing 0.05% Zn, 0.06% B, and 0.2% Ti), a technological sample is taken, and the melt is transported for casting [14].

In the melting of tin bronzes, in addition to deoxidation with phosphorous copper, deoxidation with zinc is also applied at a rate of 500 g of phosphorous copper and 500 g of zinc per 100 kg of alloy. Deoxidation with phosphorous copper is carried out in two stages: first 250 g of phosphorous copper is added and the alloy is stirred (if melting is carried out using primary materials, this is done before adding tin), then 500 g of zinc is added, and before tapping the melt, the remaining 250 g of phosphorous copper is introduced.

Bronzes that do not contain tin, such as aluminum bronzes, are usually melted in electric arc furnaces or induction furnaces under accelerated conditions. Fuel-fired furnaces are used less frequently. Aluminum bronzes are extremely sensitive to overheating and have a high tendency to absorb gases; therefore, they are melted under a flux layer in an oxidizing atmosphere, while the alloy temperature should not exceed 1200 °C.

RESULTS AND DISCUSSION

When melting aluminum bronzes alloyed with nickel, manganese, or iron, copper is first melted and then deoxidized with phosphorous copper (0.05–0.1%). After that, aluminum or an Al–Cu master alloy (ligature) is added. Aluminum must be introduced before manganese and iron; otherwise, films may form that render the alloy unsuitable for casting. The alloy is then heated to a temperature of 1150–1200 °C and refined using manganese chloride or cryolite in an amount of 0.1–0.3% of the molten metal mass. To remove films, the melt is filtered through granular filters. In order to obtain a fine-grained structure, the metal is modified with vanadium, boron, tungsten, zirconium, or titanium in an amount of 0.05–0.015% of the molten metal mass, after which Cu–Ni, Cu–Mn, and Cu–Fe master alloys are added, and the alloy is again deoxidized with phosphorous copper.

The densities of the introduced copper and aluminum components differ significantly. Considering that this difference can promote zonal liquation, the melt must be thoroughly mixed. The melting operation is carried out under a flux. Aluminum bronzes tend to form fibrous non-metallic inclusion films; therefore, filtering the melt is recommended to remove them.The melting of lead bronzes (BrS30) presents certain difficulties [16]. The significant difference in the densities of the components increases the tendency of these alloys toward liquation. To reduce liquation, it is recommended to melt the alloy in induction furnaces, since in such furnaces the molten mass is well mixed. In addition, the bronze may be alloyed with nickel (2–2.5% of the mass) and cast into metal molds, which create conditions for rapid crystallization of the castings. The melting process of beryllium bronzes is similar to that of tin bronzes. However, it should be noted that beryllium is toxic and requires special safety precautions. Therefore, the alloy must be melted in isolated rooms equipped with efficient ventilation and air extraction systems. The melting of silicon bronzes is also similar to that of tin bronzes. To prevent hydrogen saturation of the alloy, the molten metal should not be heated above 1250–1300 °C. In the final stages of producing copper alloys, the application of modification treatments is considered appropriate.

CONCLUSIONS

The analysis of melting technologies for copper alloys, particularly bronze and brass, has shown that they significantly affect metal quality, the stability of chemical composition, and production efficiency. The type of furnace used in the melting process, the temperature regime, and technological conditions play an important role in the formation of the microstructure and mechanical properties of the alloy.

The analysis indicates that the melting process in induction furnaces is characterized by energy efficiency, improved metal purity, and reduced loss of alloying elements. Electric arc and flame furnaces, on the other hand, are effective for melting large volumes of metal.Thus, the correct selection of copper alloy melting technology is of great importance for obtaining high-quality castings, improving the physical and mechanical properties of the metal, and increasing the overall efficiency of metallurgical production. The results of this research provide a scientific basis for further improving copper alloy melting processes and for applying efficient technologies in industrial practice.

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