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The Effect Of Modifiers On Alloy Properties In The Production Of Thin-Walled Castings From Copper Alloys

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Abstract: In this article, the effects of ligatures and modifiers on increasing the fluidity during the production of thin-walled castings from tin–copper alloys, as well as the effect of sodium tetraborate $Na_2B_4O_7$ in cleaning the alloy from slags, are studied. The advantages of the centrifugal casting method, the influence of additives, and the effect of the gypsum mold temperature on the thinness and thickness of casting walls and on the quality of jewelry products are analyzed. Based on the experimental results, a technology for improving fluidity is proposed.

Keywords: Copper, centrifugal method, casting, sodium tetraborate, fluidity, gypsum, jewelry product.

INTRODUCTION:

Copper–tin alloys are considered one of the oldest casting alloys. When tin is added to copper, the physical and technological properties of the alloy change. Tin–copper alloy is called bronze. When tin is added to copper, several intermetallic compounds are formed, namely the alpha phase, beta phase, and gamma phase. These phases increase the tensile strength and hardness of the alloy [1-3]. When tin is added in the range of 4% to 7%, a plastically deformable alloy is obtained. When the tin content is increased to 8%–12%, alloys suitable for casting are formed [4]. The most optimal mechanical properties are achieved when the tin content is between 4% and 12%. When the tin content exceeds 12%, the brittleness of the alloy increases. The addition of tin to copper reduces the melting temperature from 1080 °C to 850–950 °C [5]. This leads to a narrowing of the solidus–liquidus temperature range, which in turn reduces cracks and internal shrinkage in castings. At the same time, a decrease in electrical and thermal conductivity is observed. Therefore, bronze is not suitable as an electrical material but is more useful for mechanical components. In addition, since tin is lighter than copper, the density slightly decreases.

Fluidity also increases [6-8]. To further increase fluidity, aluminum can be added to the alloy. When aluminum is added, phases such as Cu_9Al_4, $CuAl_2$, Cu_2Sn, and Cu_6Sn_5 may form in the alloy. These phases can make the alloy harder, stronger, and less ductile. When aluminum is added to tin bronze, aluminum oxide (Al_2O_3) is formed, which creates a protective layer on the alloy surface, shielding it from air and moisture. When tin is added to copper, a darker reddish color is obtained. With the addition of aluminum, depending on its amount, the color changes from a golden hue to a lemon-like shade. The luster increases, and the alloy does not darken quickly. However, as the aluminum content increases, the brittleness of the casting also increases. It becomes more fragile under impact and more difficult to machine [9]. Therefore, to increase fluidity and achieve a golden color in jewelry products, the optimal aluminum content must be determined. When copper is melted, it has the ability to absorb oxygen from the air. This, in turn, leads to the formation of gas porosity in castings [10]. Since aluminum is a highly active metal, it reacts rapidly with oxygen in the air:

$$4Al+3O2\text{-}2Al_2O_3$$

As a result, aluminum oxide (Al_2O_3) forms on the surface of the alloy, creating a high-melting-point, hard, and sticky layer. Particles of this layer may be entrapped inside the casting [11]. Therefore, it is recommended to add fluxes to convert the oxide layer formed during oxidation into slag. As fluxes, boron-based fluxes, graphite fluxes, fluoride casting fluxes, and sodium tetraborate can be used. These convert aluminum oxide into slag. As a result, gas porosity is reduced, and defect-free castings can be obtained. After the molten metal, cleaned from slag, is poured into the investment mold using the centrifugal casting method, it is cooled for 10 minutes at room temperature and then quenched in a cold-water bath. If the mold is cooled immediately after pouring, internal stresses may develop in the castings during crystallization, leading to the formation of cold cracks.

In casting, the fluidity of the molten metal is of great importance. Copper alloys are widely used in the jewelry industry. They possess high strength, corrosion resistance, and good technological properties. In the production of jewelry by casting methods, the fluidity of copper alloys plays a crucial role. However, since the fluidity of copper alloys is significantly lower than that of gold and silver, defects often appear in castings. Therefore, conducting research to increase the fluidity of copper alloys and developing new alloy technologies is considered an urgent task.

METHODS

For the study, an alloy consisting of 91% copper, 8% tin, and 1% aluminum as an additional ligature was used. Under laboratory conditions, copper was melted in an induction furnace with a graphite crucible at a temperature of 1150 °C until it reached a molten state, after which tin was added and mixed at a lower temperature. Then aluminum was added in amounts of 0.5%, 1%, and 1.5%, and the alloys were prepared.

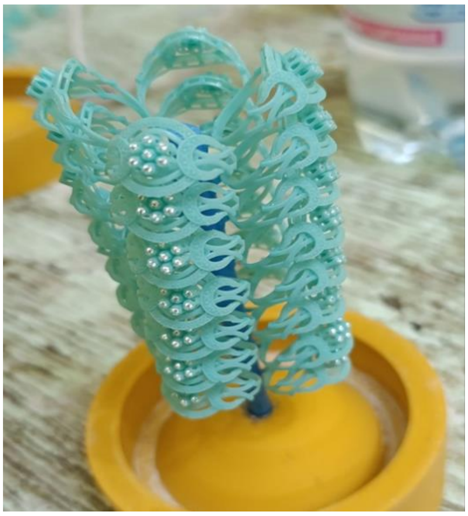

Fig.1. Molds.

To clean the alloy from slag, borax was sprinkled onto the surface of the melt. After slag removal, in order to determine fluidity, each alloy was cast in a spiral shape, and the spiral length was measured. Using metallographic methods, the hardness, strength, and overall quality of the alloy were examined.

Wax models of jewelry items were arranged in a tree-like configuration inside a cylindrical flask (Figure 1), after which a special heat-resistant gypsum-based investment was poured over them. Water at a temperature of 20–22 °C was mixed with gypsum in a ratio of 39:100 using a mixer for 1 minute, and the resulting gypsum slurry was poured into the flask. Then, air was removed from the gypsum using a vacuum device. The gypsum investment was dried at room temperature for one hour.

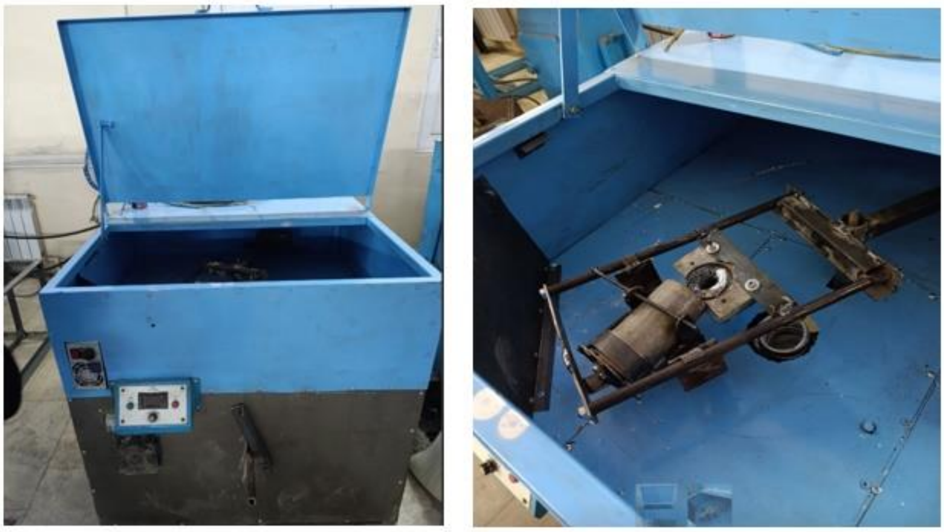

Fig. 2. View of a centrifugal casting machine.

RESULTS

After that, the wax was melted out in a muffle furnace at 150 °C, and according to the instructions indicated on the gypsum packaging, the flask was heated up to 730 °C. Once the temperature reached 730 °C, the flask was fired at this temperature for two hours. Then, depending on the wall thickness and volume of the jewelry items inside the flask, the flask temperature was adjusted.

If the wall thickness of the jewelry items (decorative part) was thicker than 1 mm, and the shank part (finger base) had a width of 4 mm and a thickness greater than 1 mm, the flask temperature was reduced to 550 °C over one hour. The alloy, heated to 1050 °C, was then cast using the centrifugal casting method at a rotational speed of 350 rpm (Figure 2).

To calculate the charge for the alloy, the wax models arranged in a tree-like structure are weighed on a scale, and the resulting weight is multiplied by 10. The purpose of this is to prevent excessive metal loss. If the flask temperature exceeds 550 °C, metal shrinkage occurs in the jewelry items during crystallization (Figure 3, a.). Gas porosity (gas cavities) may also appear, which leads to defects in the castings. By optimizing the temperatures of the flask and the alloy, it is possible to obtain defect-free jewelry castings using the centrifugal casting method (Figure 3, b.).

a) b)

Fig. 3. Samples. a- with casting defects, b-without casting defects.

If the wall thickness and volume are lower than the above-mentioned values, casting is carried out at a flask temperature of 590 °C and an alloy temperature of 1150 °C. If the temperature is too low, the metal cools rapidly, resulting in incomplete filling of the mold walls (misrun). As a result, the castings become defective. After the molten metal is poured into the flask, it is cooled for 10 minutes at room temperature and then quenched in a water bath, after which the castings are removed from the flask. However, some jewelry items can be cast together with gemstones. Flasks intended for casting with stones must be cooled slowly at room temperature. The jewelry items are then separated from the sprue, placed in a tumbling drum, and rotated for three hours to remove gypsum residues from the castings. After that, the castings are polished in a mixture of nitric acid and sulfuric acid (in a 9:1 ratio) and rinsed with clean water. Following mechanical finishing, the jewelry items are visually inspected, and their quality is determined. The experiments showed that as the aluminum content in the alloy increased, the fluidity also increased. However, a change in the alloy color was also observed. When 1% aluminum was added to the alloy, the fluidity increased by 16–18%, and the alloy color became close to a golden shade. When the aluminum content was increased to 1.5%, the alloy color turned yellow, resembling a lemon hue. Using the centrifugal casting method, fluidity was further improved, making it possible to obtain defect-free castings. The density of the castings also increased. Aluminum reacted with oxygen present in the alloy, preventing the formation of gas pores. As a result, a fine-grained structure formed in the alloys, leading to improved hardness, strength, and overall quality. To prevent the formation of shrinkage in the castings, the temperature of the mold (flask) investment (gypsum) was adjusted to approximately 550–590 °C, depending on the wall thickness and volume of the castings.

The addition of aluminum to the alloy reduced the formation of gas porosity, increased fluidity, and made it possible to obtain defect-free castings. It was determined that, when cast using the centrifugal casting method, the density and microstructure of the alloy components were significantly improved.

CONCLUSIONS

1. Fluidity is influenced by the alloy temperature, composition, mold (flask) investment (gypsum) temperature, and the rotational speed of the centrifugal casting method.

2. The most optimal parameters are recommended as a temperature of 1150 °C and a rotational speed of 350 rpm.

3. Adding 1% aluminum to a tin–copper alloy increases fluidity, ensures defect-free casting, and gives the alloy a golden-like color, while also improving hardness, density, and strength.

4. The optimal temperature of the mold (flask) investment (gypsum) is recommended to be in the range of 550–590 °C, depending on the wall thickness and volume of the jewelry items.

5. Based on the obtained results, recommendations were developed to improve the casting technology for producing thin-walled jewelry items from tin bronze alloys.

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