

Getting Aluminum Bronze Castings with SHS-Cast

¹Zinnur T. Zagretdinov, ²Nikolay N. Safronov, ³Lenar R. Kharisov
¹⁻³Kazan Federal University
 Email:ln271@mail.ru

Received: 23rd July 2019, Accepted: 10th August 2019, Published: 31st August 2019

Abstract

Aluminum bronzes are used in the automotive, aviation and instrument-making, machine-tool and defense, oil and chemical industries due to the high mechanical and anti-friction properties. The corrosion resistance of the alloy makes it possible to use aluminum bronze parts in seawater, so they are widely used in shipbuilding, and the excellent anti-friction properties of the alloy allow it to be used instead of tin bronzes, cheapening the cost of parts and their weight. The high cost of raw materials and electricity, multi-process technology and the complexity of the equipment design causes the high cost of the resulting alloy. A technology is proposed for obtaining bronzes from machine-building enterprises waste by means of self-propagating high-temperature synthesis, which occurs without external heat supply, without complicated machines and units and combines melting and pouring of the casting in one process. It is proposed to use copper scale, blacksmith, and aluminum chips as the starting materials. The technological process is based on a synergistic complex of casting and metallurgical factors affecting the melt in the stages of its melt preparation and crystallization in a mold. The resource-saving and waste-free process is implemented using the process of self-propagating high-temperature synthesis.

Keywords

Copper Alloys; Bronze; Scale; Copper Oxide.

Introduction

The bronze CuAl9Fe3 refers to tinless aluminum bronze, the chemical composition of which is regulated by GOST 18175-78.

The main alloying elements in the CuAl9Fe3 brand bronze are aluminum, whose content can reach up to 10%, and iron - up to 4%. In the alloy the presence of a small amount of impurities are allowed [1].

The chemical composition of bronze CuAl9Fe3								
Al	Fe	Sn	Si	Pb	P	Zn	Mn	Cu
8-10	2-4	0,1	0,1	0,01	0,01	1,0	0,5	remain

Aluminum is introduced into the composition of copper to improve the properties of the resulting alloy, so that bronze becomes corrosion-resistant, has high mechanical and anti-friction properties, which allows it to be used instead of scarce tin bronzes. Aluminum bronzes are much cheaper than tin bronzes, and parts of them are noticeably lighter, moreover, the operational properties of the alloy are higher [2].

Bronze	Pores, %	σ , MPa	δ , %	HB, MPa	Coefficient friction with lubricant	Permissible operating mode (load \times speed) PV, MPa \times m/s
Tinless	20-30	150-200	5-7	800-1000	0,01-0,03	2-5
Tin	20-30	130-150	3-5	400-700	0,02-0,04	1,5-2,5

The addition of iron to aluminum bronze increases the strength properties of bronze, slightly reducing the ductility.

Billets and semi-finished products made of aluminum bronze are used in the automotive, aviation and instrument-making, machine-tool and defense, oil and chemical industries, due to their high mechanical and antifriction properties. The corrosion resistance of the alloy makes it possible to use aluminum bronze parts in seawater, so they are widely used in shipbuilding, and the excellent anti-friction properties of the alloy allow it to be used instead of tin bronzes, cheapening the cost of parts and their weight. For example, aluminum bronze shows itself well in the friction units of various technological equipment for the petrochemical industry [3].

The CuAl9Fe3 brand bronze has proven to be an excellent material for plain bearings (fig.1), which will work at high speeds and with high shock loads. Circles and hollow billets of aluminum bronze are used for bearings. It is also made of b the CuAl9Fe3 brand bronze: forgings, extruded pipes, tubular blanks and rods; nuts for pressure screws, gears, bushings and valve seats for the aviation industry; fittings and antifriction parts.



Figure 1. Typical Products from CuAl9Fe3

Problem Statement

Copper alloys, which include tin and tin-free bronze and brass, are smelted mainly in electric arc and induction furnaces and less often in fiery, liquid-fueled furnaces. Crucible furnaces are sometimes used with small production volumes.

Since almost all the elements included in the composition of copper alloys are easily oxidized, the smelting process is carried out forcefully, and measures are taken to protect the alloys from the surface (with protective or coating fluxes), and some easily oxidized elements are used in the form of master alloys [4].

The charge materials for copper alloys can be fresh (pure) metals, secondary alloys, recycled alloy, as well as various master alloys supplied by industry or homemade. Phosphorous copper in the form of tiles, which before use is divided into small pieces, is used for the deoxidation of alloys. The use of master alloys are due to the fact that individual refractory components of the alloy have a higher melting point than the permissible overheating of the alloy. The melting points of master alloys and the metal to which they are seated should be close, and at the same time master alloys should have a high content of the refractory element [5].

Induction furnaces with steel core and without core are most often used for smelting copper alloys. An induction furnace with a steel core, a schematic section of which is shown in Fig.2, is a transformer, the primary winding of which is a copper coil mounted on a core of electrical steel plates with a thickness of 0.35-0.5 mm. The secondary winding is a ring of liquid alloy located in the melting channel. Alternating current of industrial frequency, passing through the primary winding, creates around it a magnetic flux, closed through the magnetic steel core of the transformer, and induces a current in the alloy, which is in the annular channels. The channel-filling alloy communicates with the bath of the liquid alloy and gives it heat due to the circulation created by the temperature difference of the alloy along the height of the furnace [6].

The peculiarity of melting in induction furnaces is that the liquid alloy that fills the channels must remain in the furnace

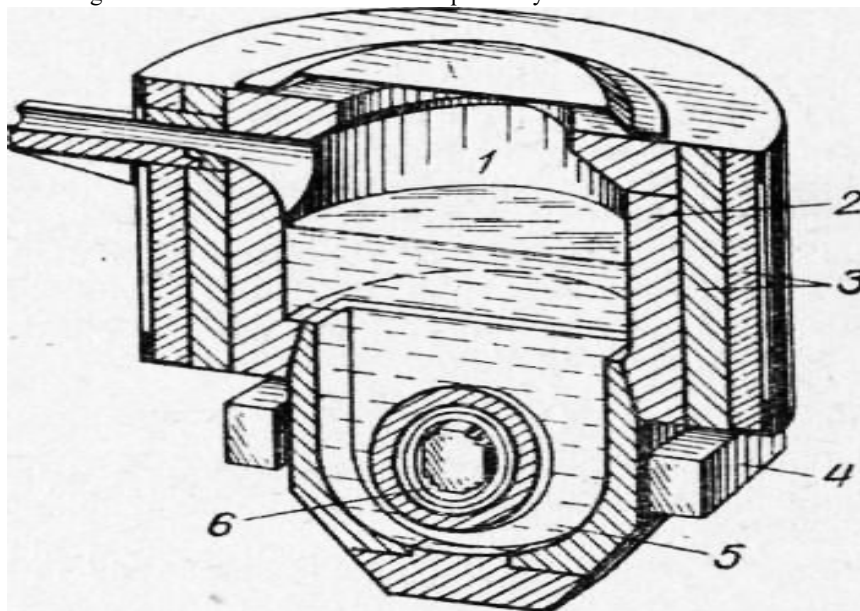


Figure 2. The Diagram of an Induction Furnace with a Steel Core:

1: A Camera; 2: Lining; 3: Thermal Insulation; 4: Primary Winding; 5: A Melting Channel; 6: A Magnetic Core.

even after the melting is released to form a closed electric circuit during the subsequent melting. In this regard, in the induction furnaces the transition to the melting of a new alloy is difficult. In this case, it is necessary to drain the entire alloy from the channels and make one or two washing melts of the non-critical alloy.

After filling the annular channels and the “swamp” (a layer of liquid alloy 30-50 mm thick, located above the channels) with a liquid alloy and the furnace is heated, a preheated mixture is loaded: first copper, and after its melting, circulating and secondary alloys. When the entire charge is melted, deoxidation is carried out, slag is removed from the surface and easily oxidized elements are introduced. When draining the finished alloy, it is necessary to leave it in the channels and above them in a layer of 30-50 mm.

In the traditional smelting of copper alloys, the charge usually includes red electrolytic copper, which is melted and deoxidized with phosphorous copper before the rest of the charge components are charged into the furnace. Copper smelting should occur very quickly under a layer of well dried and calcined charcoal. The furnace before loading the copper must be well heated. The quality of deoxidation is checked by the technological sample: the filled and cooled bar at bending should not cause cracks in the place of bending. Due to the fact that copper alloys have a tendency to gas absorption and oxidation, it is necessary to maintain a small height of the jet when pouring molds, not to interrupt it and not to allow splashing of the alloy. Casting is done through the toe of hand and crane buckets, similar to those used in casting iron [7].

Experimental Procedures

The high cost of raw materials and electricity, multi-process technology and the complexity of the equipment design causes the high cost of the resulting alloy. The technology is proposed for producing the CuAl9Fe3 alloy from waste of engineering enterprises by means of self-propagating high-temperature synthesis (SHS), which occurs without external heat supply, without complicated machines and units and combines melting and pouring of the casting in one process [8]. SHS is an exothermic chemical process of the type of combustion that occurs in the autowave mode in mixtures of powders and leads to the formation of useful condensed products, materials and articles. SHS is a mode of exothermic reaction, in which heat is localized in a narrow layer and transferred from layer to layer by heat transfer. The advantage of SHS technology lies in the principle itself - the use of the released heat of chemical reactions instead of heating a substance from an external source, therefore, SHS processes successfully compete with traditional energy-intensive technologies. The powder mixture (charge) is placed in the reactor and in the gaseous medium a local process initiation (ignition) is carried out. Then spontaneous propagation of the combustion wave occurs, covering the entire mixture, completion of the reaction and cooling of the synthesized product.

The advantages of the SHS method:

1. Low power consumption. Some energy is needed in the SHS method for heating the igniter coil and igniting the original powder. Further the synthesis process is carried out due to its own internal heat release as a result of a strong exothermic synthesis reaction, i.e. due to self-heating. Energy is not consumed from outside here, but rather is released inside. So then, after the synthesis, it has to be diverted outside, cooling the red-hot products of the synthesis.
2. The SHS method is characterized by simple and compact equipment. To implement the SHS process, there is no need for long-term high-temperature external heating, in bulky furnaces with heating, thermal protection and thermal control systems. Self-heating of the powder at SHS allows the process to be carried out in simple small-sized reactors, and not in furnaces.
3. The SHS method is characterized by high performance. As a result of self-heating during combustion, very high temperatures are reached, significantly exceeding the heating temperatures in powder metallurgy processes, therefore, the synthesis reaction rate is much higher. On the initial mass of the powder the wave of synthesis runs in the form of a combustion wave with a speed from several mm /sec to dozens cm /sec. The duration of the synthesis in the SHS reactor takes from several seconds to several minutes, while in furnace synthesis these time takes from several dozens of minutes to several hours.
4. The SHS method is distinguished by high purity of products and environmental safety. This is also associated with very high synthesis temperatures as compared to furnace synthesis. At such high temperatures harmful impurities are decomposed and evaporated from the product, ensuring its increased purity and environmental safety of the SHS process.
5. The SHS method gives a wide range of materials: powders, porous materials, non-porous compact, cast, composite, surfacings and coatings. This is achieved by changing the composition of the initial powders and the conditions of their combustion. Changing them, first of all, the combustion temperature and pressure, we can get the most different synthesis products in a very different form. As a result, the SHS method has great flexibility, allowing you to get the most diverse products on almost the same equipment.

In this paper, the starting materials are copper scale, and aluminum dross, iron oxide in ratio – 0,72:0,05:0,23 (fig.3).

Copper scale is a fragile black-gray colored mass consisting of copper oxides. Its composition is variable just like iron

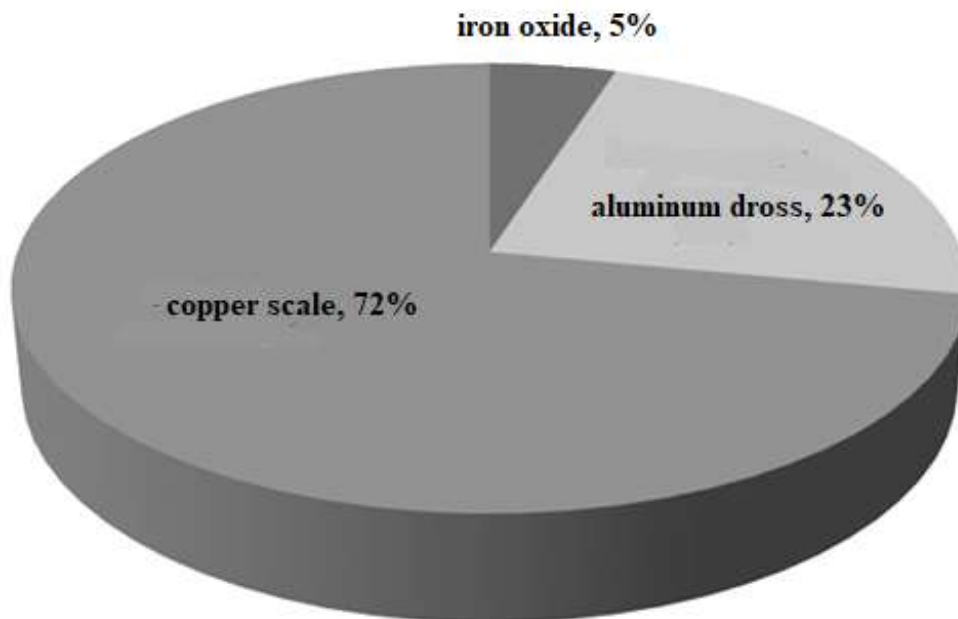


Figure 3. The Composition of the Charge of the SHS Process

oxide and may fluctuate depending on temperature and excess of oxygen when it is produced. Cu_2O is oxidized to CuO with red heat and with enough oxygen, therefore, under these conditions, copper scale mainly consists of CuO , and at temperatures above 1100°C , due to decomposition of CuO to Cu_2O and oxygen, Cu_2O prevails in copper scale. Copper scale is formed at enterprises producing cable products and is a waste of production.

Experimental Results and Discussion

The components of the charge were thoroughly mixed and placed in a graphite cylinder, which made a rotational movement so that the charge and the products of the process were exposed to centrifugal force. To create artificial gravity, we used the formula for selecting the rotation frequency (n , rev/min) of a graphite cylinder:

$$n = \frac{300\sqrt{k}}{r}, \quad (1)$$

where r – is the radius of rotation of the graphite cylinder.

Under conditions of artificial gravity and under the influence of centrifugal force, the formation and solidification of the liquid products of the SHS process with an overload equal to 200g is ensured, which guarantees the production of dense castings in the SHS process [9-12]. This circumstance promotes the complete separation of the liquid products of the SHS process and, as a consequence, the improvement of the quality of the synthesis products. The scheme of the experimental setup is shown in Figure 4.

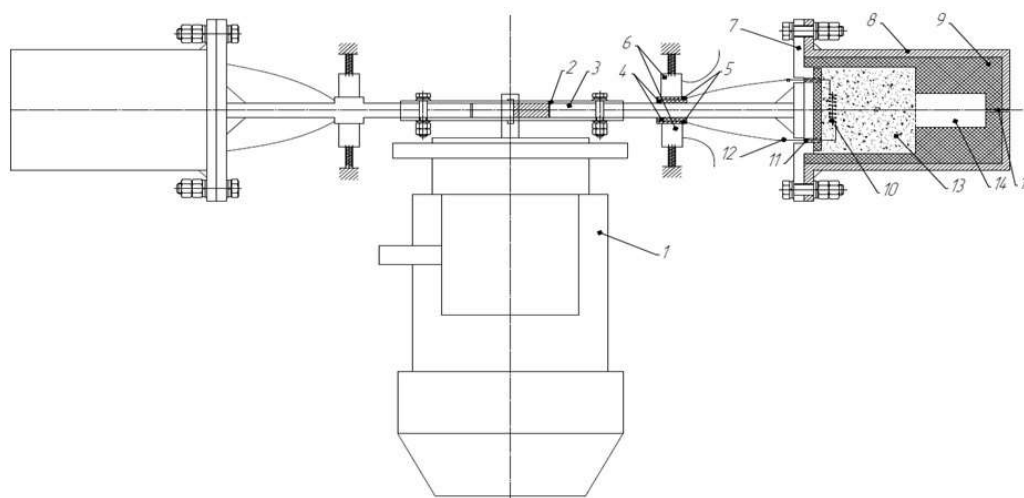


Figure 4. Diagram of the Experimental Setup.

1: An Asynchronous Motor; 2: A Supporting Disc; 3: A Bar; 4: A Dielectric Strip; 5: Current-Carrying Rings; 6: Current-Carrying Brushes; 7: A Reactor Cover; 8: A Reactor Shell; 9: A Graphite Form; 10: A Nichrome Spiral; 11: Ceramic Insulators; 12: Connecting Terminals; 13: Charge of the SHS Process; 14: A Cavity for Casting Formation; 15: A Ventilation Duct.

Conclusions

The advantages of the SHS process before the energy and material-intensive furnace method of melt preparation are: the use of fast-dissipating heat of chemical reactions, the amount of which is sufficient to heat, melt of the charge, division it into two liquid immiscible phases and overheating them; recycling of dispersed waste of engineering in a waste-free mode; the intensity of the thermal processes of converting the charge composition to a highly overheated state and cooling the liquid phases in a form with high thermal activity. These advantages of the SHS process create prerequisites for the synthesis of engineering parts, which are advantageously distinguished by the uniqueness of the obtained characteristics and low cost.

Acknowledgements

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

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