Improvement of quality of a gravity die casting made from aluminum bronze by application of numerical simulation

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Abstract

The paper describes the possibility of improving the quality of gravity die cast connectors for overhead power transmission lines. The castings were made from aluminum bronze, grade CuAl9Fe1Ni1. A MAGMASoft computer programme was used for simulation of the process of die filling and casting solidification to avoid defects, like shrinkage depression and gas porosities. The results of the simulation have finally led to redesigning of the metal feeding and cooling system and to reduced level of defects in castings.

Key words: Gravity die casting, Aluminum bronze, Numerical simulation

1. Introduction

Aluminum bronzes are copper alloys with aluminum playing the role of a main alloying element. Aluminum bronzes are divided into simple alloys (Al-Cu alloys) and complex alloys, containing alloying additions, like Fe, Ni, Mn, introduced as individual elements or in combination.

In terms of structure, aluminum bronzes are divided into mono-phase alloys α and two-phase alloys α+β. The division mainly depends on the cooling rate and refers to alloys containing 7,5-8,5% Al. Other types of structural constitution include: α + (α+β) for 8,5-11% Al and γ2 when the aluminum content is above 11% Al. The (α+β) eutectic is present in a lamellar form [1].

To improve the mechanical and technological properties of Cu-Al alloys, the additions of some alloying elements are introduced to their composition; these are mainly the additives of iron, nickel and manganese, occasionally also of silicon.

Iron in an amount of up to 2% dissolves in the α-Cu phase. The precipitating phase of FeAl3 forms additional nuclei of crystallisation, which refine the structure and raise the mechanical properties, i.e. the tensile strength, hardness and proof stress.

The most valuable alloying addition is nickel, since its presence increases the melting point and extends the range of solidification. Moreover, nickel has a very beneficial effect on nearly all of the properties, raising the mechanical strength, thermal and electric conductivity, resistance to high temperatures and to chemical corrosion.

The two above mentioned alloying additions occurring jointly in aluminum bronzes promote the formation of phases rich in Fe and Ni (e.g. FeAl11, NiAl3, FeNiAl6), which have a very beneficial effect on alloy properties. A very well-known representative of this family of alloys is the CuAl9Fe1Ni1 alloy according to DIN 17656.

The technology of casting Cu-Al bronzes is quite complicated, mainly because of a large casting contraction (2-2,5%) due to the narrow range of solidification temperatures, the tendency to solidification in layers and formation of scattered...
shrinkage depression. At the same time, the presence of alloying elements highly active in respect of oxygen makes these alloys prone to the formation of slag inclusions. All these factors account for the fact that making castings from alloys included in this family requires profound knowledge of the problems related with alloy characteristics and strict observance of the technological regime during melting, treatment of molten metal, and gravity pouring of the metal into permanent moulds - dies.

2. Technical and technological guidelines

Using casting documentation in the form of a drawing and the results of analysis, allowing also for the production volume of castings, the following guidelines were developed and adopted:
- type of alloy cast – CuAl9Fe1Ni1,
- casting process – gravity die casting,
- die parting plane – vertical,
- die opening and locking system – movement in horizontal axis,
- number of cavities – 2,
- material for die – hot-work steel, grade WCL,
- heating or cooling system during pouring – gas heating, air or water cooling,
- average overall dimensions of die – (LxHxW) (445 x 280 x 95) mm;
- ejectors stroke length – 20 mm,
- system of metal feeding to die cavity – central gate with bottom side feeding to casting,
- overflows – in upper part of casting parallel to its lengthwise axis.

Following the developed guidelines, a computer drawing of the casting was designed, allowing for the relatively large casting contraction of the alloy (2-2,5 %), due mainly to a very narrow range of the solidification temperatures. When the computer drawing was ready, a technological concept of making the casting was developed and casting position in the die was established, as shown in Figure 1.

3. Simulation of the casting process

To perform correct simulation of the die filling process and casting solidification, it was necessary to provide the following input data:
- drawing of die design (3D) and of the gating and feeding system (risers);
- alloy properties (from the library of database);
- casting weight: 2,260 kg;
- pouring time: 2-3 s;
- pouring temperature: 1150±20 ºC;
- die temperature: 220-250 ºC;
- type of release-parting agent: based on boron nitride;
- thermophysical parameters for determination of heat exchange rate between casting and die.

Using the above input data and the technological concept depicted in Figure 1, a simulation of the die cavity filling process was made; the results are shown in Figure 2.

The technique of feeding metal to the die cavity as shown in Figure 2 results in overheating of the lower part of casting which, because of its configuration, cannot be filled directly from the feeder. The results of the simulation shown in Figure 3 indicate that the lack of directional solidification and higher temperature in the lower part of casting (Fig.3.a) are the cause of occurrence of shrinkage depression on the casting surface and increase the level of porosity defects (Fig.3.b).
To eliminate overheating in lower part of the die, a modification was introduced to the concept of casting pouring, shifting the ingates location to the upper part of casting, as shown in Figure 4. The corresponding results of simulation are shown in Figure 5.

From the results of the simulation it follows that the applied solution improved the directional solidification of casting and reduced the severity of shrinkage depressions. Nevertheless, the redesigned metal feeding system did not allow full elimination of the defects from castings. The next stage in redesigning work included water cooling system introduced to obtain a uniform temperature distribution in the solidifying casting. The technique of die cooling is shown in Figure 6; the results of simulation are shown in Figure 7.

From Figure 7 it follows that due to this solution it was possible to considerably reduce the shrinkage depression in lower part of the casting and eliminate porosity in the feeder neck. Total
elimination of porosity from casting was obtained during technological tests through application of an insulating coating on the riser neck.

4. SUMMARY

Casting defects, like shrinkage depressions and gaseous porosities, are one of the most serious problems in casting production. The problem is particularly important when castings are made from aluminum bronzes, which - due to their specific characteristics - are very prone to formation of these defects during casting solidification process.

One of the tools to assist the foundrymen in solving of this problem and to reduce the number of quite expensive tests is computer simulation of the die filling process and casting solidification. The main aim of this simulation is optimizing of the mould design and process conditions not only to make the defects appear in some local places, but also to reduce their severity or eliminate them completely from casting.

The example described in this article of making castings in CuAl9Fe1Ni1 aluminum bronze shows how, through mould redesigning, the computer simulation enables elimination of casting defects.

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Fig. 7. Simulation of filling process - a) solidification, b) porosity