Sand cast bronzes and gunmetals

Introduction

Bronzes and more specifically gunmetals are common alloys used for pressure-tight castings such as valves and pumps. Gunmetal is also used for bearings where loads and speeds are moderate. The main elements of these alloys are copper, tin, zinc and lead. Gunmetals have improved corrosion resistance due to the tin and good fluidity for casting aided by the zinc. Lead is added to improve the machinability.

Gunmetals are the favoured alloys for sand casting. In order to get good castings, it is essential to be aware of the key steps of the process, which are metal treatment, feeding and filtration. Moreover simulation of the castings is essential to design moulds "right first time".

Typical alloy compositions of bronzes and gunmetal are given in Table 1 together with recommended pouring temperatures for various casting section thicknesses.

Melt treatment

Bronze and gunmetal alloys can be melted in crucible, reverberatory or induction furnaces. However, with any of these, hydrogen can be a problem, giving rise to porosity. This may be derived from the products of combustion of the furnace gases, from water vapour in the atmosphere, from water in refractories and from scrap metal. Hydrogen is less soluble in bronze than in pure copper, however, it can cause severe porosity, especially if the alloy cools fairly slowly as in sand casting.

Steam reaction

The steam reaction corresponds to the reaction between cuprous oxide (resulting from a reaction between copper and the atmosphere or copper and water vapour), which is soluble in the molten metal, and hydrogen. Indeed during cooling hydrogen can react with the cuprous oxide present to form copper and water vapour ("steam"). This water vapour will remain trapped in the metal as a severe form of porosity.

For this reason, it is often advisable to both degas and deoxidise gunmetal melts before casting. The technique used is the oxidation-deoxidation process.

Oxidation-deoxidation process

During melting, an oxidising atmosphere provides a barrier against hydrogen pick-up. This is achieved by the use of CUPREX* fluxes (CUPREX 1 tablets or RAFFINATOR 91 powder flux). The CUPREX fluxes are placed in the bottom of the hot crucible (1% of the charge weight) followed by the charge. It is recommended to melt and bring to pouring temperature as rapidly as possible. Whilst melting proceeds, CUPREX flux evolves oxidising gases, which bubble up through the melt and preclude hydrogen. The flux cover protects the melt from further hydrogen absorption.

If the charge materials contain scrap, which is oily or dirty, a larger quantity of hydrogen will find its way into the melt. Thus extra degassing will be necessary. Also in the case of special castings required to support relatively high internal pressure or to be specially sound and free from porosity, the melt is degassed with LOGAS* 50 briquettes or alternatively with a rotary degassing unit (FDU*). Finally, just prior to pouring, the flux layer is skimmed off and surplus oxygen removed by plunging DEOXIDISING TUBES DS into the melt in order to get an adequate deoxidation and to maximise fluidity.

It is necessary to check the correct pouring temperature, skim and cast without delay, taking care to prevent slag entering the mould cavity. Positive slag control can be achieved with the slag coagulant SLAX* 20.

Molten bronze and gunmetal alloys should never be held in the furnace for prolonged periods, the moulds must be prepared in advance to receive the metal as soon as its melting and fluxing treatment is completed.

Cu-Sn-Zn-Pb	< 15 mm	15-40 mm	> 40 mm
83/3/9/5	1180°C	1140°C	1100°C
85/5/5/5	1200°C	1150°C	1120°C
86/7/5/2	1200°C	1160°C	1120°C
88/10/2	1200°C	1170°C	1130°C

Table 1 Typical alloy compositions with recommended pouring temperatures

Aluminium removal

Aluminium is a common and very deleterious impurity in gunmetal and bronzes. As little as 0.01 % is enough to cause leakage of pressure tight castings, as aluminium oxide films and stringers become trapped in the solidifying casting. ELIMINAL* 8 can be used to remove aluminium from the molten alloy.

Metal – mould reaction

Molten metal cast into either green sand or a dry sand mould is immediately exposed to a steam atmosphere with which it will react. In most cases the metal oxide forms a tough and relatively impermeable skin thus stopping further reaction quite effectively. With certain alloys, however, or if the oxide skin is affected by other factors (such as the presence or absence of deoxidants, impurities, etc.) protection is not provided and further reaction can take place. Metal/mould reaction will therefore be most likely to occur in alloys that are inadequately or excessively deoxidised particularly where phosphorus or magnesium are the deoxidants used.

The water vapour formed when the molten metal enters the mould, having given up its oxygen to form an oxide skin, releases a quantity of hydrogen. Such hydrogen is very active and can enter into solution in the molten metal unless the oxide skin formed on it is very strong and protective.

With leaded or lead free gunmetal containing zinc, a phosphorus content of 0.03% or above is enough to cause the reaction. A residual phosphorus content 0.06% to 0.08% is usually sufficient to produce an appreciable effect. For gunmetal alloys and bronzes a severe reaction can be prevented by coating the moulds and cores with MOLDCOTE*, MOLCO* or TENO* coatings.

Running and feeding

Methods best suited to long freezing-range alloys should be used, with unpressurised or slightly pressurised systems based on ratios such as 1:4:6 or 1:4:4. This type of sprue/runner/ingate system can provide a useful source of feed metal to the casting as long as the gate remains unfrozen. Where additional feed is required, generous feeders must be placed on the heavier sections, as is usual for long freezing-range alloys. KALMIN* S feeder sleeves are particularly suitable for bronzes and gunmetals. Due to the usage of a high proportion of light refractory raw materials, a density of 0.45g/cc is achieved, ensuring highly insulating properties. KALMIN S feeder sleeves extend the solidification times by a factor of 2.0-2.2 compared to natural sand feeders of the same size. From these results, Modulus Extension Factors (MEF) of 1.4-1.5 have been calculated. Though KALMIN S feeder sleeves can give more than 33% of their feeder volume to the solidifying casting, it is recommended that a maximum of one-third of the feed metal volume should be fed into the casting so that the residual feeder modulus is adequate in relation to the casting modulus at the end of solidification. For this reason, it is recommended to consider modulus as well as solidification shrinkage in order to determine the correct feeder. FOSECO provides tables allowing KALMIN S feeders to be selected with the desired modulus, volume (capacity) and dimensions.

Filtration

The widespread use of ceramic foam filters has introduced a new dimension into the running and gating of castings. Filters have several important effects:

- They effectively trap dross and oxide films
- They control metal flow
- They reduce turbulence

The use of ceramic filters allows the traditional gating rules to be modified while still achieving quality castings. Ceramic foam filters have a distinct advantage over the extruded type in that there is no separation of the initial metal stream, hence the possibility of reoxidation at the filter face is reduced. The provision of a ceramic foam filter immediately after the base of the sprue changes the flow patterns markedly.

The filter requires a certain amount of pressure and time to prime, so the flow of metal is temporarily arrested on encountering the filter, this allows the sprue to backfill excluding air from the incoming metal. Metal exits the filter in a single turbulence-free stream at low velocity, hence the runner fills gently and the gates operate as designed. The casting then fills without the entrainment of air and oxide films. The beneficial effect of filters is their ability to eliminate turbulence, although they also filter any gross dross inclusions which may be carried over from the melting unit. Bronze and gunmetal alloys especially benefit greatly from filtration in the mould. Because of the higher temperature compared to aluminium-based alloys, SEDEX* ceramic foam filters are recommended for copper-based alloys instead of SIVEX* FC filters, which are usually used for Aluminium alloys.

Simulation

A number of software packages are now available which model the flow of metals into dies or moulds and allow the filling and the solidification of the casting to be simulated. Computer modelling is being increasingly used for the design of dies and moulds in order to reduce the lead time required for making new castings.

Predictive fluid flow software, MAGMASOFT® being one of the best known, uses physics-based modelling to allow mould filling to be studied and its effects on casting soundness to be assessed. Ideally such modelling should enable the onset of turbulence during mould filling to be predicted and the effect of gating systems on the temperature distribution within the casting to be studied.

The first step in any flow modelling investigation is to obtain a 3D CAD model of the mould cavity and all of the boundary conditions such as alloy type, mould and core materials, coating used etc. The filling simulation indicates the direction of flow, the velocity and the temperature of metal at any point and any given time during the filling sequence.

This type of analysis is used increasingly to identify and eliminate potential sources of defects such as hot spots, cold laps, misruns and oxide defects. Feed metal requirements are quantified and optimum pouring temperature proposed. Increasingly it will be possible to have dies and moulds designed "right first time".

The simulation of an existing feeding system, with two natural risers and two KALMIN S 7/10 K feeder sleeves shows two disadvantages: The two natural risers are ineffective in terms of yield, and due to the height of the natural risers the sprue cannot work effectively (figure 1).

Figure 2 shows the addition of a round SEDEX ceramic foam filter 50mm Ø x 22mm x 10 ppi and four KALMIN S 7/10 K feeder sleeves. The filter controls the metal flow rate by keeping the velocity low, leading to a reduction in turbulence and higher quality standards. Figure 2 shows the mould filling after 0.6 seconds.

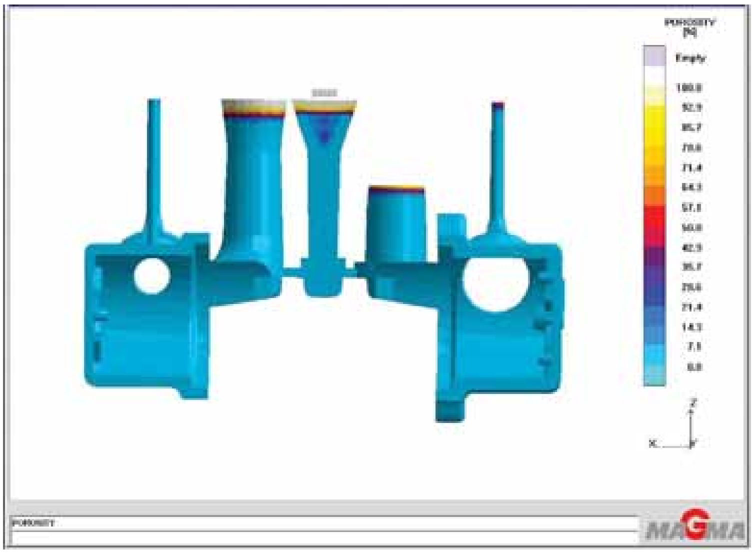

Figure 1 Simulation of a gunmetal casting (before feeding system optimization)

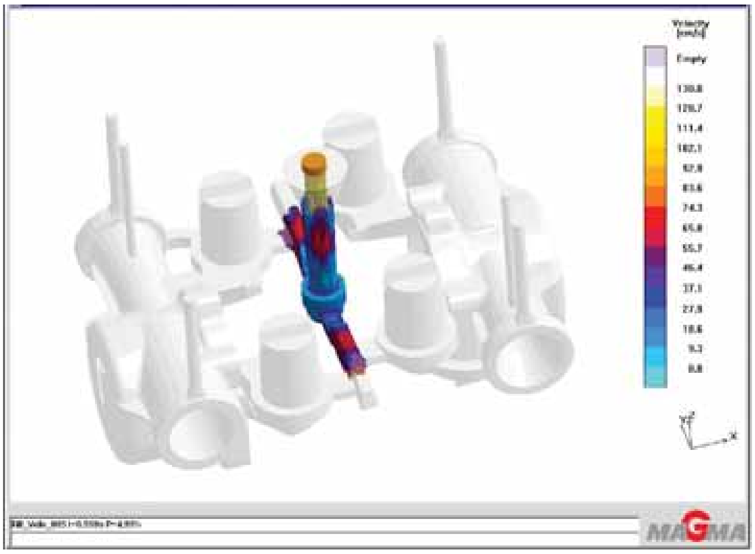

Figure 2 Simulation of a gunmetal casting (after feeding system optimization)

Figure 3 shows the smooth filling of the mould. The scale on the right hand side gives the velocity by colour, any figure below the critical velocity of 50 cm/s is shown in blue. Figure 3 shows the mould filling after 5.3 seconds.

The cut-through of the casting sprue shows no porosity and the casting is pressure tight. The replacement of the two natural risers (figure 4) by two further KALMIN S 7/10 K feeder sleeves brings a saving of approximately 5 Kg metal and therefore a higher yield. Moreover with the two further KALMIN S 7/10 K feeder sleeves, the sprue is able to supply more metal to the casting giving higher feeding effectiveness.

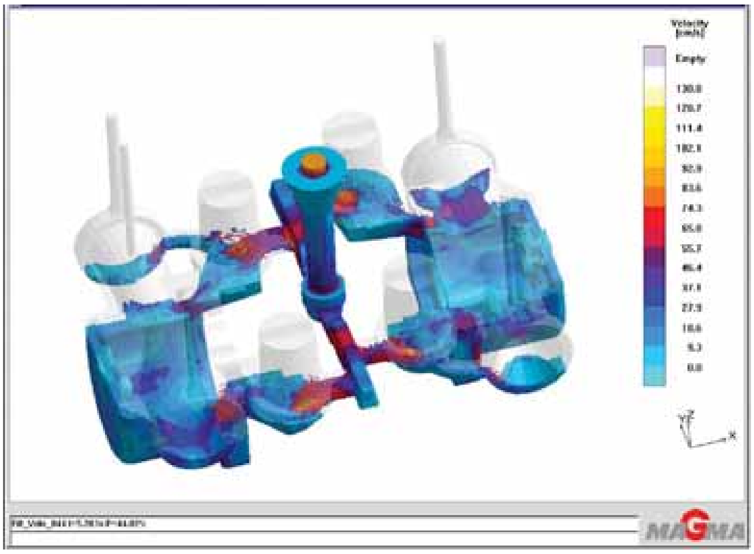

Figure 3 Simulation of a gunmetal casting (after feeding system optimization)

Conclusion

Copper-based alloys and particularly bronzes and gunmetals have been used for over a thousand years because of their corrosion resistance and their good combination of castability, machinability and strength. They are used for cold and hot vapour armatures, acid armatures, pumps and valves, and also for bearings where loads and speeds are moderate.

In order to get high quality castings, it is very important to pay particular attention to the different steps of the process and particularly to metal treatment, feeding and filtration. In addition, simulation of the castings is strongly recommended in order to obtain optimum filling and solidification and therefore improved quality.

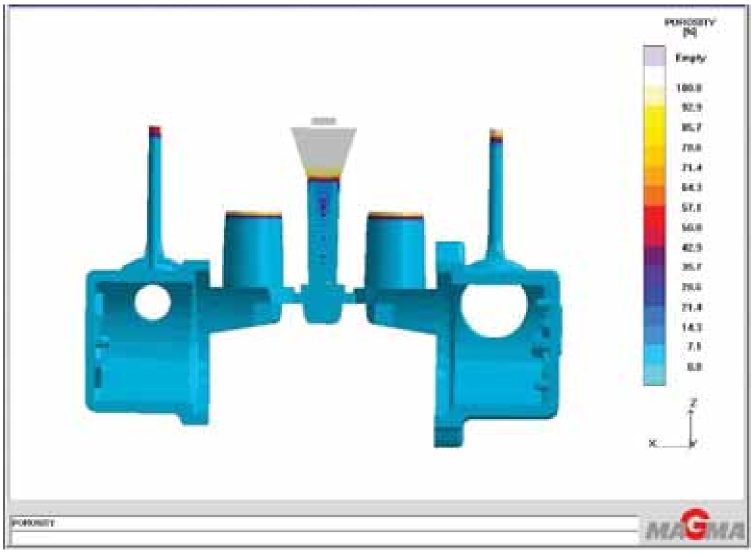

Figure 4 Simulation of a gunmetal casting (after feeding system optimization)