Effect of protective release coatings on the basis of superdispersed zirconium oxide powder on the formation of gas defects in bronze casting

Nikita V. Martyushev¹, Nikolay A. Risto
Tomsk Polytechnic University, 30, Lenina av., Tomsk, 634050, Russia
E-mail: martjushev@tpu.ru, ris_to555@list.ru

Abstract. This paper investigates the use of nanopowders in the composition of foundry coatings when casting leaded tin bronzes. Influence of the composition of the applied protective coating on surface finish is studied. The effects of the coatings of the following compositions are compared: non-stick coating (a mixture of low-dispersed chromium oxide powder and heat-treated vegetable oil); non-stick lubricant ASPF-2/RgU on the basis of low-dispersed graphite powder and heat-treated vegetable oil; patent #2297300 (a mixture of superdispersed zirconium dioxide powder with industrial oil). It is demonstrated that application of foundry coatings containing superdispersed metal oxide powders with low thermal conductivity makes it possible to significantly reduce irregularities and eliminate gas porosity on the surface of tin-leaded bronze castings.

1. Introduction
Nowadays, a considerable number of leaded tin bronze castings are obtained by casting into steel or cast iron chill molds. Chill casting of such alloys is often accompanied with the formation of numerous gas defects on the surface. The presence of surface defects is considered to be unacceptable for most parts produced this way including piston rings, gaskets, plain bearings, etc. There exist a few methods to prevent the formation of such defects and to ensure enhanced quality of the casting surface.

There are several techniques to improve surface quality when casting into metal molds. These are casting into forcibly cooled molds [1], and casting into pre-heated molds [2]. However, these techniques are rather complicated in terms of their implementation and often fail to fully eliminate the casting defects which are formed on the surface.

The most prospective method for achieving a high-quality casting surface is application of foundry coatings. It allows us to virtually eliminate the burn-on due to the appearance of an additional medium that separates the melt from the mold. Furthermore, these protective release coatings for molds are characterized by low thermal conductivity, which prolongs the period when the melt is in the liquid state and, thus, allows more efficient removal of gas from the melt. Such foundry coatings often contain organic binders, which, when being burnt, emit gases by themselves leading to the formation of pinholes on the surface [3, 4]. In addition, the most widespread coatings used when casting copper alloys contain relatively coarse material particles as fillers (graphite, chromium oxide), which can result in coating’s layering.

¹ To whom any correspondence should be addressed.
Application of superdispersed powders as coating fillers is seen as a possible solution to the above mentioned problems [5, 6].

2. Materials and Methods
The researchers of the Department of Materials Science and Process Metallurgy of the Tomsk Polytechnic University investigated the effect of superdispersed powders used in the composition of a coating on castings’ surface characteristics. When performing several contracts and casting piston and gasket rings for high-pressure compressors, it became clear that it was necessary to reduce the number of the workpieces rejected due to gas defects. The materials for rings were multicomponent bronzes. The parts were produced by using the technique of horizontal centrifugal casting in steel and cast iron molds. Casting was performed both with and without protective coating for comparison purposes. Prior to pouring, coatings of the following compositions were applied to molds preheated to a temperature of ~200-250°C:

- non-stick coating (a mixture of low-dispersed chromium oxide powder and heat-treated vegetable oil);
- non-stick material ASPF-2/RgU on the basis of graphite powder and heat-treated vegetable oil;
- mixture of superdispersed zirconium dioxide powder (~85 wt.%) with I-80 industrial oil (~15 wt.%) – patent # 2297300;
- mixture of superdispersed alumina powder (~85 wt.%) with I-80 industrial oil (~15 wt.%).

The particle size of the superdispersed alumina and zirconium dioxide powders were in the range from 0.1 to 0.5μm.

3. Results
When die casting without coatings, the rate of the finished castings rejection caused by gas defects reached 50% or even more. Steel molds with the 1:10 ratio of the casting mass to the mold mass were used. Mold temperature upon pouring was approximately 20°C. Increase in the cooling rate in this case did not lead to a decrease in the number of defective products. Conversely, numerous cold shuts and knots were formed on the castings’ surface. Figure 1 shows the image of a casting obtained under the given conditions.

![Figure 1. Appearance of a cast when casting at room temperature](image-url)
Some improvement was observed when using non-stick coatings (a mixture of low-dispersed chromium oxide powder and heat-treated vegetable oil, and the anti-seize lubricant ASPF-2/RgU). The particle size of the powders composing these coatings was in the range from 0.3 to 0.06 mm. Prior to pouring, the mold was heated to a temperature of 250-300°C in order to improve the process of applying the coating and reduce the cooling rate. By using the described technique it became possible to reduce the rate of defective pieces from 50% to 40% when using the coating on the basis of chromium oxide powder, and to 25%-30% when using the ASPF-2/RgU anti-seize lubricant. Defective products, in this case, occurred due to the formation of pinhole porosity on the casting surface. Pinholes are known to be able to penetrate to a significant depth in a casting; the depth of penetration depends on the casting’s thickness [7, 8]. In our case pinholes were found on the surface at a depth of about 5-6 mm (see figure 2).

Figure 2. Pinholes in horizontal centrifugal casting from multicomponent bronze (with bronze, tin, lead, zinc, and nickel content): a – lateral face; b – lateral face after turning

The formation of pinhole porosity indicates that gas cannot go out in any other way than through the surface of the mold. The chromium powder particles in the coating of the first composition and graphite powder particles in the coating of the second composition are characterized by low porosity, which means that the gas flow through them is hindered. Application of superdispersed powders as
coating fillers can be a solution to this problem. The following coating composition has been developed: patent #2297300 (a mixture of superdispersed zirconium dioxide powder with industrial oil). Application of the coating based on superdispersed zirconium dioxide powder leads to the elimination of both burn-on and pinhole porosity of a casting (see figure 3). Gas defects on the casting surface are still observed, but they are much less numerous and their shape is changed. When using conventional composition coatings the surface pores occur at a considerable depth and have sharp edges (see figure 2b), while when using superdispersed powders their shape tends to be conical (see figure 3). At the same time, the depth of the defects is not more than 1-1.5 mm, which does not extend beyond the lap.

![Figure 3. Surface of horizontal centrifugal casting from multicomponent bronze (with bronze, tin, lead, zinc, and nickel content): a – lateral face; b – lateral face after turning](image)

During the first moments after pouring the melt into the mold the binder (in our case, industrial oil) is burned out, the evidence of which are the flames coming from the gating system. Gas gap occurs typically between the mold wall and the molten metal [9]. This resultant gas goes outwardly partially along the mold surface. In those sections where the melt having touched the mold solidifies, knots are formed. When the coating contains superdispersed powder particles in its composition, there appears a gas slurry consisting of nanopowder particles and the combustion products of industrial oil [6]. The nanopowder is uniformly distributed over the mold surface due to a small particle size (< 0.5 microns). Visual inspection of the mold after removal of the casting verifies the uniformity of nanoparticles distribution: the coated surface is covered with regular white film composed of the residual nanopowders. Thus, superdispersed powder particles prevent the contact of the molten metal with the mold surface and at the same time contribute to the removal of gases through themselves. Due to the
extremely low thermal conductivity of the powder suspension the poured metal remains liquid for a longer period, which allows it to flow into the surfaces of the mold splitting with a thickness of 0.2-0.3 mm. The same phenomenon did not occur without the use of the developed coatings. As a result, a prolonged period of a metal being in the liquid state allows us to remove gases without the formation of pinholes, fill the entire mold space avoiding cold shuts and misruns, and produce castings with lower surface irregularity. By and large, when using the coating of the developed composition it has become possible to almost eliminate the presence of defective castings.

It is worth mentioning that the described coating composition allows us to achieve a casting surface roughness of Rz 30-40. Application of conventional coatings allows a surface roughness of only Rz 100-150 (on those surfaces where no gas porosity is formed). When using a coating based on superdispersed alumina powder a surface roughness of Rz 40-50 can be achieved.

4. Conclusions
Application of foundry coatings containing superdispersed metal oxide powders allows us to decrease castings’ surface roughness by 2-4 times, eliminate gas porosity on the surface, and avoid cold shuts when casting leaded tin bronzes. This makes it possible to significantly reduce the machining allowance. This effect is achieved due to the small size of powder particles (< 1 mm): gases exuded from the mold surface and during the binder combustion pass between the powder particles as if through a sponge and are released in this way from the metal casting zone. The resulting layer between the mold walls and the poured metal consisting of the superdispersed powder coating and escaping gases will enable the melt to be in the liquid state for a longer period. As a result, molten metal occupies the entire mold cavity avoiding the formation of cold shuts and misruns.

5. Acknowledgments
The results presented herein were obtained with the assistance from Russian Presidential Grant MK-6661.2013.8.

6. References
[1] Martyushev N.V., Pashkov E.N. 2013 Tribotechnical properties lead bronzes Applied Mechanics and Materials. 379 87 - 90
[2] Martyushev N.V., Pashkov E.N. 2013 Bronze sealing rings defects and ways of its elimination Applied Mechanics and Materials. 379 82 - 86
[3] Pashkov E.N., Zijakaev G.R., Tsigankova M.V. 2013 Differential equations of processes for the hydropuls power mechanism of drill machines Applied Mechanics and Materials. 379 91 - 94
[4] Sorokova S.N., Knyazeva A.G. 2010 Numerical study of the influence of the technological parameters on the composition and stressed-deformed state of a coating synthesized under electron-beam heating Theoretical Foundations of Chemical Engineering. 2 172 - 185
[5] Nekrasova T.V., Melnikov A.G., Martyushev N.V. 2013 Creation of ceramic nanocomposite material on the basis of ZrO₂-Y₂O₃-Al₂O₃ with improved operational properties of the working surface Applied Mechanics and Materials. 379 77 - 81
[6] Chinakhov D.A., Vorobyov A.V., Tomchik A.A. 2013 Simulation of active shielding gas impact on heat distribution in the weld zone Materials Science Forum. 762 717-721
[7] Gromov A.A., Pautova Y.I., Lider A.M., Korotkikh A.G., Teipel U., Chaplina E.V. 2011 Sigfusson T.I., Interaction of powdery Al, Zr and Ti with atmospheric nitrogen and subsequent nitride formation under the metal powder combustion in air Powder Technology. 214 229 – 236
[8] Rubtsov V.E., Kolubaev A.V. 2004 Plastic deformation and quasi-periodic vibrations in a tribological system Technical Physics. 49 1457 - 1463
[9] Sorokova S.N., Knyazeva A.G. 2009 Estimation of the stresses in a coating growing on a flat plate under nonisothermal conditions Russian Physics Journal. 12 1309 - 1316