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INVESTIGATION OF METHODS FOR OBTAINING LARGE-DIAMETER STEEL GRINDING BALLS

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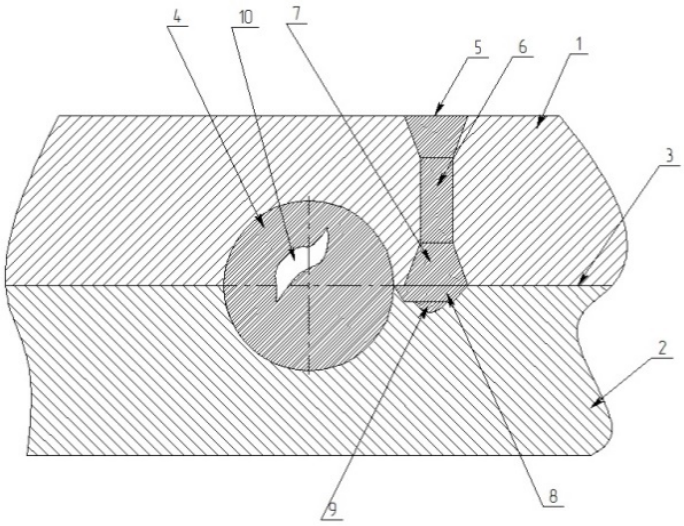
The article conducts research on the production of large-diameter steel grinding balls by coquille casting in a garland way, which provides the necessary density of castings. The paper analyzes the material costs for the production of grinding balls Ø 100 mm by casting and screw rolling, which showed a lower value for the casting method. Also in the work, the calculation of the wall thickness of the coquille was carried out using several methods, on the basis of which the structural elements of the existing coquille installation were selected. The conducted research allowed us to propose a new method of coquille casting balls in a garland way with a central calculated refrigerator, which provides the necessary density of castings.

Keywords: water-cooled coquille, garland casting, central refrigerator, model equipment, special casting box, casting unit

1 INTRODUCTION

The main method of production of grinding balls in Kazakhstan is screw rolling in the ball rolling workshops of metallurgical enterprises of “Casting” LLP and “KSP Steel” LLP [1]. The disadvantages of this method include the consumption of a large amount of thermal and electrical energy for heating workpieces [2]. For example, a furnace with a walking hearth for heating continuously cast blanks installed in the workshop of “Casting” LLP operates on an imported propane-butane gas mixture, the ball rolling mill itself consumes 441 kW/h of energy.
Analytical calculations show that the material costs for the production of grinding balls Ø 100 mm by casting have a lower value compared to the production of the same balls by screw rolling.
Cast balls are obtained by traditional casting into sand-clay molds (SCM), the disadvantage of which is the development of shrinkage cavity and porosity in the central part of the castings [3].



1 – upper half-form, 2 – lower half-form, 3 – form connector, 4 – casted ball, 5 – sprue funnel, 6 – riser, 7 – skim gate, 8 – feeder, 9 – sump, 10 – shrinkage cavity.

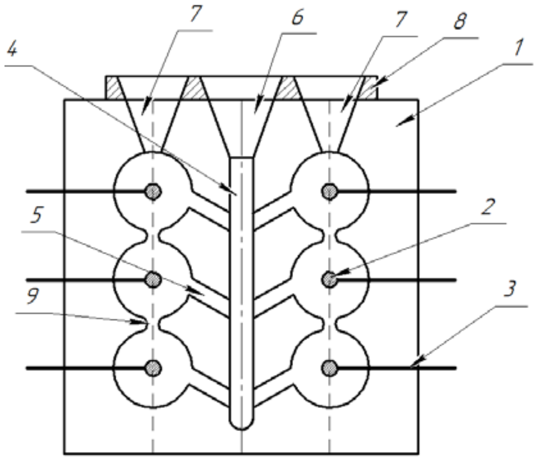
Fig. 1. Fragment of the form

In the work, the task was set to reduce the development of shrinkage cavities and porosity in grinding balls.
The material for the manufacture of cast grinding balls is medium- and high-carbon low-alloy structural steels. The use of cast-iron balls is considered unacceptable, because they are brittle in their structure and insufficiently resistant to shock loads [4].
Experimental studies were carried out in the foundry laboratory of the Department of Metallurgy of Toraighyrov University and the foundry of the plant "SNN" LLP (Pavlodar, Republic of Kazakhstan). Experimental samples of cast grinding balls were obtained by coquille casting.

2 METHODOLOGY

2.1 Production of balls in coquille with central cooling

The essence of the method lies in the fact that the liquid metal poured into the coquille cavity, as in SCM, is cooled with the periphery of the mold only with the difference that crystallization will go intensively, leaving a compact shrinkage cavity in the centers of the castings [5]. At the same time, the rest of the castings will be quite dense. To enhance the effect, central ball refrigerators are installed in the coquille, as shown in Figure 2.



1 – detachable half- coquille, 2 – refrigerator ball, 3 – rod soldier, 4 – riser, 5 – feeder, 6 – funnel, 7 – supplier of liquid metal, 8 – removable nozzles, 9 – jumper

Fig. 2. The proposed method of coquille casting of steel balls

The number of balls in the coquille cavity depends on the durability of the coquille installation. The installation consists of two vertically separable plates, where the ball cavities of the molds and the central gating system are located. The plates are water-cooled, and one of them is stationary, the cooled water is constantly circulating through the pumping station, thereby intensively cooling the mold cavities. Figure 3 shows the simplest schematic diagram of the working cavity of the installation. A distinctive feature of this installation is the presence of spherical forged refrigerators on rod soldiers, which are attached and fixed on a fixed plate. Refrigerators are installed strictly in the center of the ball cavities.

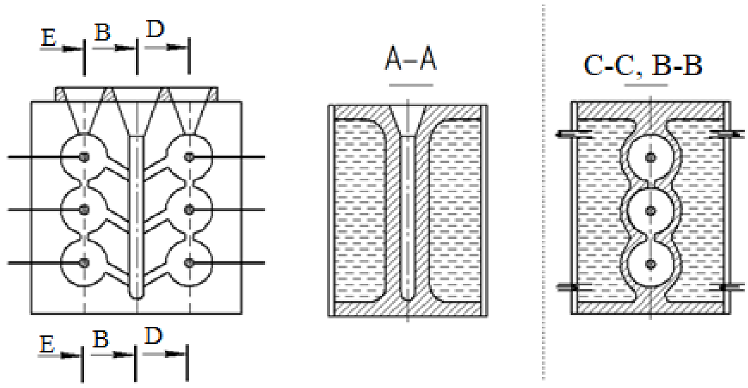
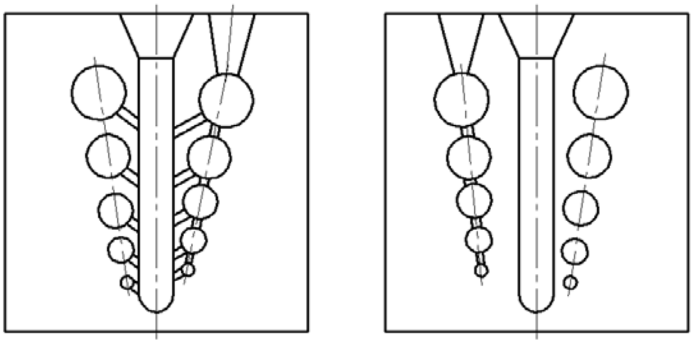


Fig. 3. Sections of the central water-cooled coquille cavities

A distinctive feature of this method is that the poured liquid metal crystallizes not only peripherally from the side of the coquille cavity, but also from the center of the casting itself. There is no special requirement for strict sphericity of refrigerators, but they must have a high density and a calculated mass, forged (stamped) from rod blanks, according to the chemical composition of the corresponding ball castings.

Before pouring the assembled coquille, a removable guide is installed on top, which is temporarily fixed to the plates before pouring. The extension is a small casting box stuffed with a rod mixture with the formation of three conical cavities. The last portions of liquid metal are poured into these cavities to improve the recharge of the upper balls. Feeders are arranged so that each upper ball constantly feeds the underlying one (Figure 4). Before opening the cavities, the removable guide is broken, the flask is removed. When the cavities are opened, spring ejectors mounted on a fixed plate are triggered and push the bush of castings down into a container with water, where self-quenching takes place at a knock-out temperature of 800-850 °C.



1 – cast steel casting box; 2 – submodel plate; 3 – models; 4 – molded half-forms

Fig. 4. Separate molding of the “Top” and “Bottom” models of garland casting of balls of various diameters

With proper operation, such a coking plant, according to preliminary calculations, should withstand 85-100 thousand castings.

This method of producing balls ø 80-100 mm is used in those industries where ball castings are needed in small quantities, but requiring high surface hardness and high density.

For a coquille installation, the main priority factors are the exact calculation of the wall thickness of the coquille, the material used for the design of the coquille cavity and the methods of cooling the coquille cavity [7]. In the work, verification calculations were carried out according to several recommendations.

2.2 Calculation of the coquille wall thickness

1) According to Veynik

Set:

X_1 = 0,025 mm – casting wall thickness

γ_1 = 6 900 kg/m^3 – specific gravity of the casting

C_1 = 0,09 kcal/kg •°C – heat capacity of the casting material

$\Delta t_{пер}$ = 230 °C – overheating for filling

ρ_1 = $t_{пер}$ = 230 °C – 51 kcal/kg – latent heat of solidification

C_2 = 0,174 kcal/kg·°C – heat capacity of the coquille material

γ_2 = 7 860 kg/m^3 – specific gravity of the coquille material

$t_{кр}$ = 920 °C – the start of crystallization of the casting

$t_{2нач}$ = 100 °C – initial coquille temperature

λ_2 = 6,26 ккал/м·ч·°C – heat loss by coquille

λ_1 = 5,22 ккал/м·ч·°C – heat loss by casting

$\lambda_{общ}$ = 5,74 ккал/м·ч·°C – total heat loss

Coquille wall thickness:

$$X_2 = K \cdot X_m, \text{ where } K < 1$$

$X_m = \frac{1}{2} \cdot A \cdot \left(1 + \sqrt{1 + \frac{8}{A} \cdot \frac{\lambda_2}{\beta}}\right)$ – the depth of penetration of heat into the wall of the coquille during the solidification of the casting in the coquille.

$$A = \frac{3 \cdot Q}{\gamma_2 \cdot C_2 \cdot (t_{кр} - t_{2нач})} = \frac{3 \cdot 12\,368}{7\,860 \cdot 0{,}174 \cdot (920 - 100)} = 0{,}033$$

$$\beta = \frac{\lambda}{X} = \frac{5{,}74}{0{,}001} = 5\,740$$

$$Q = X_1 \cdot \gamma_1 \cdot (C_1 \cdot \Delta t_{пер} + \rho_1) = 0{,}025 \cdot 6\,900 \cdot (0{,}09 \cdot 230 + 51) = 16\,491\ kcal/m^2$$

$$X_m = \frac{1}{2} \cdot 0{,}33 \cdot \left(1 + \sqrt{1 + \frac{8}{0{,}033} \cdot \frac{6{,}26}{5\,740}}\right) = 0{,}034\ m$$

$$X_2 = 0{,}95 \cdot 0{,}034 = 33\ mm$$

2) By Dubinkin:

$$X_2^1 = 13 + 0{,}6 \cdot X_1^1 = 13 + 0{,}6 \cdot 25 = 28\,mm$$

$$X_2^H = 13 + 0{,}6 \cdot X_1^2 = 13 + 0{,}6 \cdot 70 = 55\,mm$$

3) According to Petrichenko:

$$X_2 = \frac{3 \cdot R_1}{4} \cdot \left(K_B + \frac{1 + K_B}{\theta_{зал}} \cdot K_C\right) = \frac{3 \cdot 0{,}025}{4} \cdot \left(1{,}6 + \frac{1 + 1{,}6}{1\,050} \cdot 567\right) = 56\,mm$$

$$K_B = \frac{\sqrt{\lambda_2 \cdot C_2 \cdot \gamma_2}}{\sqrt{\lambda_1 \cdot C_1 \cdot \gamma_1}} = \frac{\sqrt{6{,}26 \cdot 0{,}174 \cdot 7\,860}}{\sqrt{5{,}22 \cdot 0{,}99 \cdot 6\,900}} = 1{,}6$$

$$\theta_{зал} = 1\,150 - 100 = 1\,050\,°C$$

$$K_C = \frac{\rho_1}{C_1} = \frac{51}{0{,}09} = 567$$

4) ccording to Gorbulsky:

$$X_2 = 11 \cdot \sqrt{X_1} = 11 \cdot \sqrt{25} = 55\,mm$$

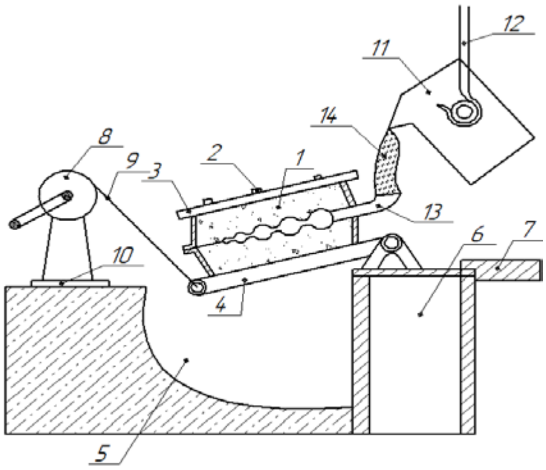
The average value of the coquille thickness for cast iron castings:

$$X_2 = \frac{33 + 55 + 56 + 55}{4} = 50\,mm$$

The wall thickness of the coquille for balls is assumed to be ∅ 125 mm δ = 50 mm.

The found values of the coquille wall thickness are shown in Figure 3.

The model equipment shown in Figure 4, proposed by us, has some feature of obtaining garland castings. The peculiarity is as follows; the coquille is assembled horizontally (Figure 5). The installation shown in Figure 5 is an approbation one, because it simulates the process of obtaining garland castings, forming horizontally, and pouring liquid metal starting from 25° with a table slope up to 90°. This technique is necessary for the smooth filling of the mold cavity with liquid metal.



1 – sand-clay mold assembled mounted on a turntable 4 installations; 2 – fastening ties for holding the top cover of 3 forms; 5 – semicircular pit for turning the installation table of a manual winch 8 mounted on a special bracket 10; 6 – channel racks for the rotary unit; 7 – flooring of the filling area; 9 – winch cable; 11 – filling bucket; 12 crane beam hooks; 13 – removable filling horn made of refractory ceramics; 14 – liquid metal jet.

Fig. 5. Scheme for obtaining garland casting of balls in the rotary form of the installation of “SNN” LLP

3 DISCUSSION OF THE RESULTS

To study the influence of the suitability of this method proposed by us, one branch of the castings are connected vertically to each other, forming short jumpers that look like Christmas tree "garlands". Therefore, we gave this method the name "garland filling". The essence of this method lies in the fact that the volume of each proper ball with liquid metal is a supplier of liquid metal lfor the subject balls.

In contrast to this method, on the second branch of the castings vertically, we placed the same balls in the same arrangement, but without jumpers. That is, now, each ball was filled separately from each other.

Figure 6 shows the model and section of the castings obtained in the foundry of "SNN" LLP, where it is visually possible to determine the advantage of the garland casting method.

Fig. 6. Casting model and section

By this method, it is possible to obtain dense grinding balls of various diameters in one operation, without shrinkage cavities.

4 CONCLUSIONS

1. A new method of coquille casting of balls with a central calculated refrigerator is proposed and the calculation of the wall thickness of the coquille from various sources is given.
2. A new method for producing cast steel balls of various diameters by a garland method is proposed, which provides the necessary density of castings.

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