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Regulation of Heat Transfer in the Horizontal Continuous Casting Moulds

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Abstract: The methods of regulation of the heat transfer in continuous casting moulds were developed. Heat transfer intensification methods are based on applying heat conductive pastes and fusible metals. Artificial air gaps are used for the reduction of heat transfer in the mould. Aluminium, copper, bronze, and graphite powders with silicon organic binders are most suitable for the pastes production. Pastes enabled to increase productivity by 10-15%. The productivity of continuous casting process with fusible metals in the moulds was higher about 100% for the cylindrical castings, and about 25% - for the complex castings.

Key-Words: continuous casting, cast iron, mould, heat transfer, solidification, microstructure, productivity.

1 Introduction

The rapid progress of technology requires improve the mechanical and operational properties of the main casting alloy - cast iron. As is well known, the casting practice has a marked influence on the mechanical properties of materials. In this respect continuously cast iron is in exceptional position by its properties. Wide use of continuously cast iron is determined by its significance in a processing (high productivity, good quality, low cost and ecological safety). Continuous casting with high cooling rates and directional crystallization of liquid cast iron causes the dense macro- and microstructure of castings and high mechanical properties [1-4]. In the horizontal continuous casting molten metal is first chilled in a mould, then further cooled by water sprays and finally by free convection and radiation. The mould comprised a graphite sleeve and a water cooled jacket is one of the major components of horizontal continuous caster. Its purpose is formation of the castings of given configuration and dimensions as well as directional and controllable their cooling. It is shown that the heat transfer coefficient has a significant effect on the shell thickness which is formed at the end of mould [5]. Great efforts have been made to achieve a better understanding of the transporting and solidifying processes of the liquid metal pool in a continuous casting mould, however, less attention has been paid to the corresponding improvement of ones [6]. It is known that the quality of castings and cast rate are affected strongly by the distribution of temperature in the mould. The much of the copious heat released during the solidifying process of a casting is retained in the mould. The mould can be analyzed as a multilayer wall transferring heat of the solidifying casting to cooling water [7]. In cooled moulds, the overall metal/mould heat transfer coefficient can be defined by a series of thermal resistances [8, 9]:

$$\frac{1}{h}=\frac{1}{h_a}+\frac{\delta_g}{\lambda_g}+\frac{\delta_i}{\lambda_i}+\frac{\delta_s}{\lambda_s}+\frac{1}{h_w} \tag{1}$$

where h is the overall heat transfer coefficient over the length of the mould between the casting surface and the coolant fluid, h_a is a heat transfer coefficient between the metal and mould, δ_g, and δ_s are, respectively, the graphite sleeve thickness and the water cooled jacket thickness, δ_i is the gap between the sleeve and the jacket, λ_g; λ_t and λ_s are the sleeve, the gap and the jacket thermal conductivities, respectively, and h_w is the mould-coolant heat transfer coefficient.

Any of those thermal resistances has a different effect on the total heat transfer coefficient. Thermal resistance of gap between the graphite sleeve and the water cooled jacket is 25-50% of the total crystallizer heat resistance [9, 10]. Therefore, effective control of the heat transfer from casting to coolant can be performed by increase or decrease of that resistance.

Simple section castings already are very successfully cast by horizontal continuous casting, but, unfortunately, this is not related to complex shape castings. The heat removal from separate elements of complex castings and, simultaneously, the solidifying rates at cross sections of ones are uneven and castings are cast at very slow rate. In order to increase the cast rate, it is necessary to increase the intensity of heat transfer in the mould and to unify the rates of solidifying at cross sections of castings. The creation of the methods of heat transfer intensification and differentiation through the casting perimeter was the goal of this paper.

2 Methods of heat transfer regulation. Development and investigation

The round mould with graphite sleeve ensures even heat removing around the perimeter from the bar during horizontal continuous casting of the round bars. In case of casting square bars, plates or another shape bars, heat is removed not evenly around its perimeter ($q_1 \neq q_2$) (Fig.1). It is so, because the thickness of graphite sleeve is not the same in all directions and when the sleeve is thick, in spite of high graphite conductivity, it can change evidently the thermal resistance of the mould. Uneven solidification of casting acts on the cast rate because it is necessary to ensure the sufficient thickness of solidified shell around the whole casting perimeter in order to avoid the eruption of a liquid metal. The uniform casting solidification acts negatively on the structure in its angle too. Rectangular castings solidified in the round mould more evenly when in the zones of casting angles, between the graphite sleeve 1 and the water cooled jacket 2, artificial clearances 3 were made. The total mould resistance increased when clearances were made. It was necessary to increase the intensity of heat removing from the casting in all the other places aiming not to decrease the average cast rate. It was been done by heat resistant pastes 4.

Reduction of the thermal resistance between the graphite sleeve and the water cooled jacket was achieved by the use of fusible metals and heat conducting and resistant pastes. But not everyone of the paste is suitable: some of them are burn to the jacket, others - oxidize and burn away. Besides, some pastes, especially those having higher temperature resistance, have only average heat conductivity. For this reason special experimental investigations of various content pastes were carried out in foundry conditions. Pastes with silicon organic binders, like emulsions, ethylsilikates, varnish, are most suitable for that purpose. The fillers of pastes may be aluminium, copper, bronze, graphite and other material powders. The efficiency of the pastes on the heat transfer in the mould was been determined by an overall heat transfer coefficient (h) from the outer surface of the casting to the mould cooling water calculated from:

$$h = \frac{Q}{F\left(T_c - T_w\right)} \tag{2}$$

where Q is a total heat flux at metal-mould interface F, $(T_c - T_w)$ is averaged temperature drop between casting surface and water.

Heat flux was defined as

$$Q = c_w G_w \left(T_w'' - T_w'\right) \tag{3}$$

where c_w is specific heat of water, G_w – mass yield of water, T_w' and T_w'' are, respectively, inlet water temperature and outlet water temperature.

The operating parameters F, T_c, T_w, G_w, T_w', and T_w'' were been determined experimentally using ordinary methods during cast 120 mm diameter casting.

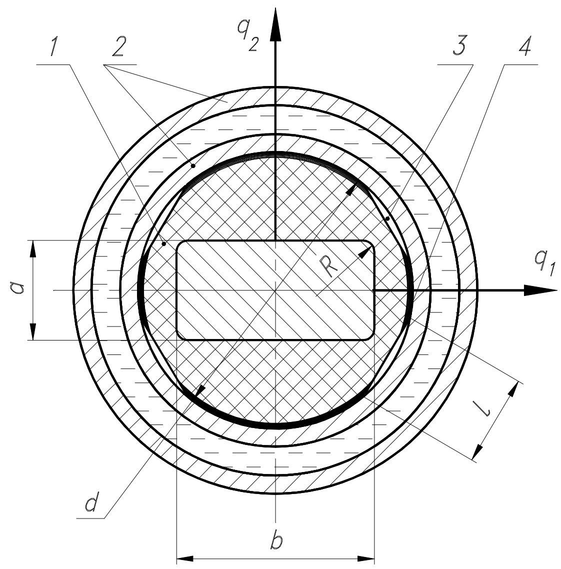

Fig. 1. Scheme of the regulation of heat transfer in the round mould.

The pastes made of aluminium and bronze powder mixed with silicon organic varnish reduced their heat conductivity at high temperatures because volatile materials evaporated and a microporosit formed.

If graphite powder instead of aluminium and bronze powder was used, the results had been positive and stable. Their heat conductivity was not changed during the casting process. Heat transfer coefficient h was 700-750 W/(m^2·K).

The third group of pastes was made of bronze or aluminium powder, ferro-chromium slag and waterglass. These pastes solidify by themselves. Solidification lasts from a few minutes up to 3-4 hours, depending on the percentage of ferro-chromium slag. Heat transfer coefficient of pastes made from bronze or aluminium powder and ferro-chromium slag varied from 400 to 740 W/(m^2·K). Unfortunately, this paste strongly adhered to the coolers walls. This fact complicated preparation of the water cooled jacket for the assembling of the next mould.

The fourth group of pastes was made of bronze or aluminium powder and ethylsilicate-40. The greatest heat transfer coefficient h = 1050 W/(m^2·K) was been obtained using paste with 75% bronze and 25% aluminium powder. Change of the h in service was negligible.

In the same mould by use of a few different content pastes it is possible to differentiate cooling of the casting and attain equal solidification rate around the perimeter of the cross-section. Fig. 2 shows an example of heat transfer in the crystallizer control by use of pastes and air gaps. Surfaces A, B and D of the graphite insert were covered by aluminium and bronze paste (25% of aluminium powder, 75% bronze powder, binder - ethylsilicate-40), and the surface C, aiming to remove heat center, was covered by graphite paste (50% graphite powder and 50% of ethylsilicate-40). When casting in this mould, productivity of the process was increased by 13%. Technological parameters of casting processes with pastes and without pastes are presented in Table 1.

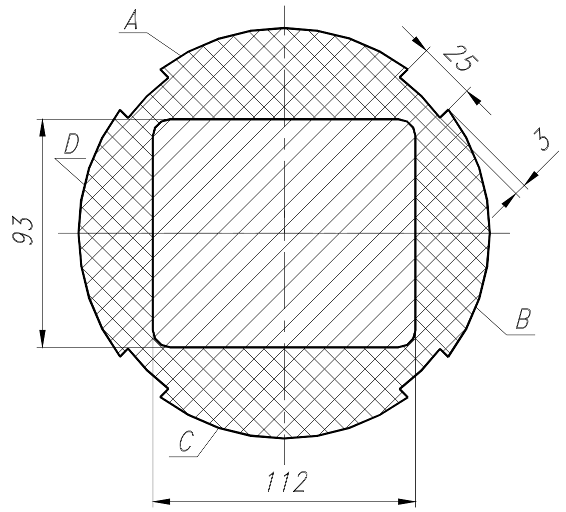

Fig. 2. Cross-sections of graphite sleeve and casting.

Table 1Technological regimes of continuous casting of rectangular cross-section ingots (112×93 mm)

Parameter	Usual mould	Mould with pastes
Drawing time, s	4.0	4.2
Pause duration, s	4.2	3.4
Temperature of molten metal in a crucible, °C	1250	1255
Casting rate, m/h	38.52	43.56

To improve the cooling effectiveness of the casting and to control the heat transfer in the mould fusible metals and alloys were used. These metals melted due to contact with the heated graphite sleeve of the mould, and they filled up the gap between the sleeve and jacket. The molten metal covers the contact surface and thus improves cooling intensity of the casting. Tests showed that fusible interlayer about 2 times increased the heat transfer coefficient. On casting 120 mm diameter cylinder casting without fusible interlayer, the heat transferring coefficient h = 659 W/(m^2·K), and with fusible interlayer - h = 1550 W/(m^2·K). Productivity of the process increased 2 times. It is especially convenient to apply this method for control of the cooling of the complex form castings around their perimeter. The great temperature gradient formed up around the ingot perimeter. In this case cast rate was limited by the hottest part of the ingot. Therefore in these parts cooling intensity was increased using fusible inter-layers. As an example iron casting of machine tool guideway can be presented. Casting was 271 mm width, 104 mm height and has a cavity of 50 mm depth and 102 mm width. Scheme of the mould are shown in the Fig. 3.

When the molten cast iron fills the crucible, walls of the holder were heated and tin melted. Molten tin through the channels 7, 11 and 12 of gating system flowed into the upper 9 and lower 13 cavities and improves heat contact between graphite sleeve and jacket. Cooling intensity of the slot and plane part of the casting increased. In this way it was achieved that solidification rate of this complex casting was approximately the same in all cross-section parts.

Tests in the foundry conditions showed that the cast rate in the moulds with fusible metals was higher about 100% for the cylindrical castings, and about 25% - for the complex castings.

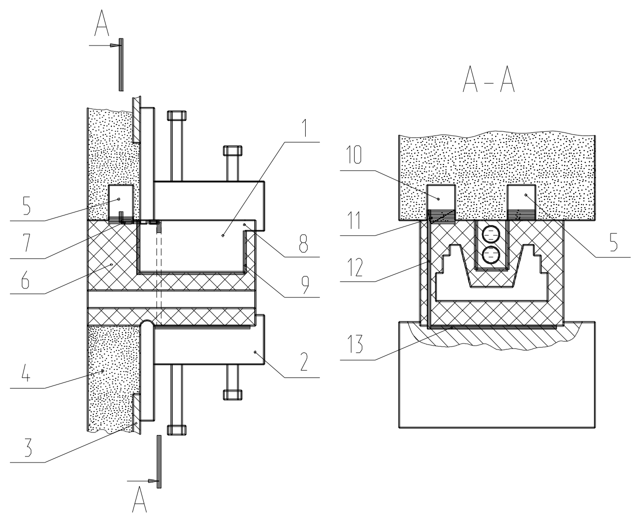

Fig. 3. Scheme of the mould with fusible interlayer: 1 - upper water cooled jacket; 2 - lower water cooled jacket; 3 - crucible wall; 4 - crucible lining; 5 and 10 - tin cylinders; 6 - graphite sleeve; 7, 11 and 12 - gates; 8 - overflow; 9 - upper interlayer; 13 – lower interlayer.

3 Increased heat transfer and the microstructure of castings

Heat transfer in the moulds with fusible interlayer and different heat conduction pastes are more intense. But higher solidification rate results on the change of castings microstructure and mechanical properties. Therefore a study of complex configuration castings produced in two types of moulds (ordinary and with fusible interlayer) was carried out. To characterize the microstructure an optical microscope was used.

The microstructures of grey cast iron produced in these both types of moulds are shown in Figs. 4-5.

Results of these tests showed that there were more surface layers with smaller graphite inserts (Fig.4) and with feritic structure (Fig. 5) in that zones of castings produced in the moulds with fusible interlayer which solidification rates are higher. Hardness of this grey cast iron produced in the mould with fusible interlayer was about 10 HB units more than hardness of analogous grey cast iron produced in the ordinary moulds.

4 Conclusion

The methods enabling to make uniform the metal solidification rate around the perimeter of the complicated profile ingot were developed. These methods are based on heat transfer control by use of artificial air gaps, heat conductive pastes, and fusible metals. They enable to obtain nearly uniform ingot shell thickness at the end of mould and to increase the cast rate.

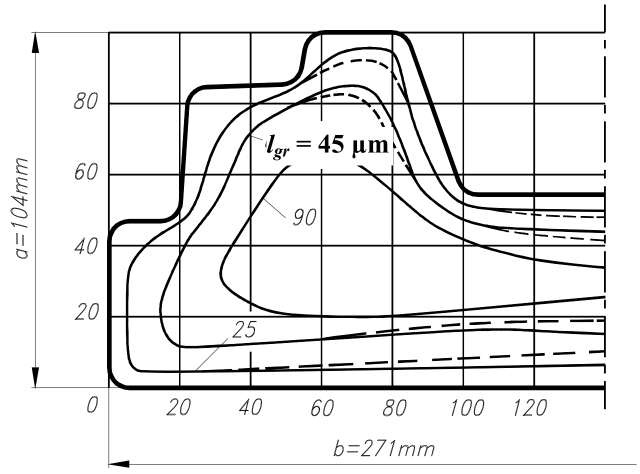

Fig. 4. Exchange of the length of graphite inclusions in the microstructure of grey iron castings produced in the ordinary mould (continuous line) and in the mould with fusible interlayer (dotted line).

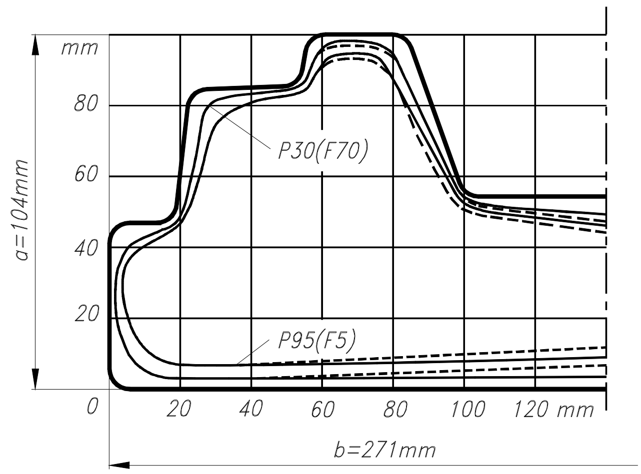

Fig. 5. Quantity of pearlite in the microstructure of castings of grey cast iron produced in the ordinary mould (continuous line) and in the mould with fusible interlayer (dotted line).

Heat conductive pastes were developed. These pastes enabled to change heat transfer coefficient from 400 up to 1050 W/(m^2·K). Pastes significantly simplify and speed up assembling of the mould and enable to increase cast rate by 10-15%.

Heat transfer from the solidifying casting to cooling water coefficient in the moulds with the fusible metals was found to be equal to 1550 W/(m^2·K). Tests in the foundry conditions showed that the cast rate in the moulds with fusible metals was higher about 100% for the cylindrical castings, and about 25% - for the complex castings.

The structure of continuously cast iron was determined. Results of these tests showed that graphite inserts were been smaller in the castings produced in the moulds with fusible interlayer. There were been more surface layers with pearlitic structure in the ingots, cast in the ordinary moulds.

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