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Improving The Mechanical Properties Of Gray Cast Iron By Controlling The Solidification Rate

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Abstract: This article aims to improve the mechanical properties of the ingot by controlling the cooling process of the ingot by sending air at a certain pressure in addition to the cooling rate during the cooling of gray cast iron melted in an induction furnace in a sand-clay mold.
Keywords: Grey cast iron, induction furnace, melting, mechanical properties, solidification, corrosion resistance.

Introduction

Currently, gray cast iron is the main structural material in machine building due to its fluid flow properties, sufficient strength and corrosion resistance. Compared to alloy steel, the lower melting temperature and smaller temperature range for crystallization provide good casting properties of gray cast iron in machinery, such as good casting and low shrinkage.

Conventional crystallization of low-carbon and low-silicon iron does not ensure stable high properties in castings. It is possible to obtain the mechanical properties of such iron by adding silicon and calcium elements [1-3]. Components operating at high temperatures usually require the use of gray cast iron, an alloy that additionally contains chromium, nickel, molybdenum, and aluminum [1, 4, 6].

At the same time, gray cast iron is used as a structural material that is very sensitive to the kinetic conditions of crystallization and cooling [5, 7-10]. Depending on the cooling rate, a change in the properties of this gray cast iron occurs, and in general they can be compared with the use of alloying additions.

An increase in the cooling rate in the temperature range of iron hardening is accompanied by an expansion of the dispersion of eutectic cells, a decrease in the total amount of the eutectic component, and an increase in the amount of primary austenite dendrite crystals. The eutectic of gray cast iron, i.e. austenite-graphite eutectic, is meta-stable and can transform into austenite-cementite (ledeburite) at a high cooling rate [7-12]. In this case, gray cast iron turns into white cast iron, and its properties change accordingly. Delaying or accelerating the cooling of cast iron in the recrystallization temperature range will inevitably reflect the correlation of pearlite and ferrite in the metal base structure. If the cooling rate is increased (which is characteristic of thin-walled castings), the amount of pearlite in the structure, as well as its dispersion, increases. If the cooling rate is slower, the amount of ferrite increases, and the pearlite first becomes medium-layered and then coarse-layered, significantly losing its hardness and strength [13, 14].

Thus, the structure of gray cast iron occurs in several structurally sensitive temperature ranges, and each of them requires an individual cooling rate to achieve the best set of mechanical and technological properties for the casting.

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In order to obtain the desired results, a unilateral change in the cooling rate of metal casting is widely used in practice [15-18]. If the cooling rate is increased, the formation of the cementite eutectic is accelerated, which can lead to embrittlement of the alloy. If the cooling rate is delayed in the eutectic interval, it is possible to obtain gray cast iron due to the formation of graphite eutectic.

MATERIALS AND METHODS

In order to study the effect of casting cooling rate on molds, experimental equipment was designed and manufactured, which allows the production of experimental and control castings at the same time. The dimensions of the castings were 120 × 60 × 10 mm. The control casting was separated from the experimental one, and the exothermic reaction of the carbonaceous additive began around the experimental casting; the process occurred along with a sharp delay in removing the heat from the mold. Increasing the cooling rate of the experimental casting was carried out at the beginning of dendrite crystallization by injecting it with compressed air under a pressure of 3 atmospheres and was completed after the formation of primary austenite crystals. An exothermic carbonaceous insert combustion process was then initiated with oxygen from the supplied air. Temperatures of structurally sensitive crystallization intervals of gray cast iron obtained as ingots were determined in advance using the technique described in the “Crystallograf” software package [19] according to the results of differential thermal analysis.

Activation of the additive containing the carbon element in the exothermic process and heat extraction at the stage of eutectic formation coincided with the moment of eutectic transformation. To control the start of the combustion reaction, it was done by choosing the amount of compressed air consumption and the amount of added carbon included. It should be noted that such a technique depends on the necessary time determined by the temperature of system sensitive intervals by starting and stopping the exothermic combustion reaction of the carbon-containing additive faster, by sending or stopping the compressed air into the casting mold [20].

As soon as the experimental casting reached the supercritical temperature of the eutectoid transformation, the mold was again blown with air under the same pressure. An increase in the cooling rate during the eutectoid transition was achieved due to secondary air filtration through the already processed reaction layers.

The comparison of the obtained results was carried out by simultaneously recording the cooling curves of castings with adjustable and non-adjustable cooling in an experimental casting mold. The temperature of the castings was measured with “A” type thermocouples (BP5/BP20 tungsten-rhenium thermocouple). "SpectroLAB-10M" equipment was used to determine the chemical composition of the sample.

Table 1

Chemical composition of the studied grey cast iron, mass.%

C	Mn	Si	P	S	Cr	Ni	Cu	Mo	V
3.30	0.55	1.72	0.073	0.111	0.173	0.118	0.162	0.010	0.013

Experimental melting was carried out in an induction furnace in the laboratory of the manufacturing plant.

RESULTS

The cooling curves of the sample castings are shown in Fig. 1. It can be seen from the figure that the cooling rate of the sample casting can be practically increased by a factor of 2 by injecting

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compressed air into the mold during the dendrite crystallization interval.

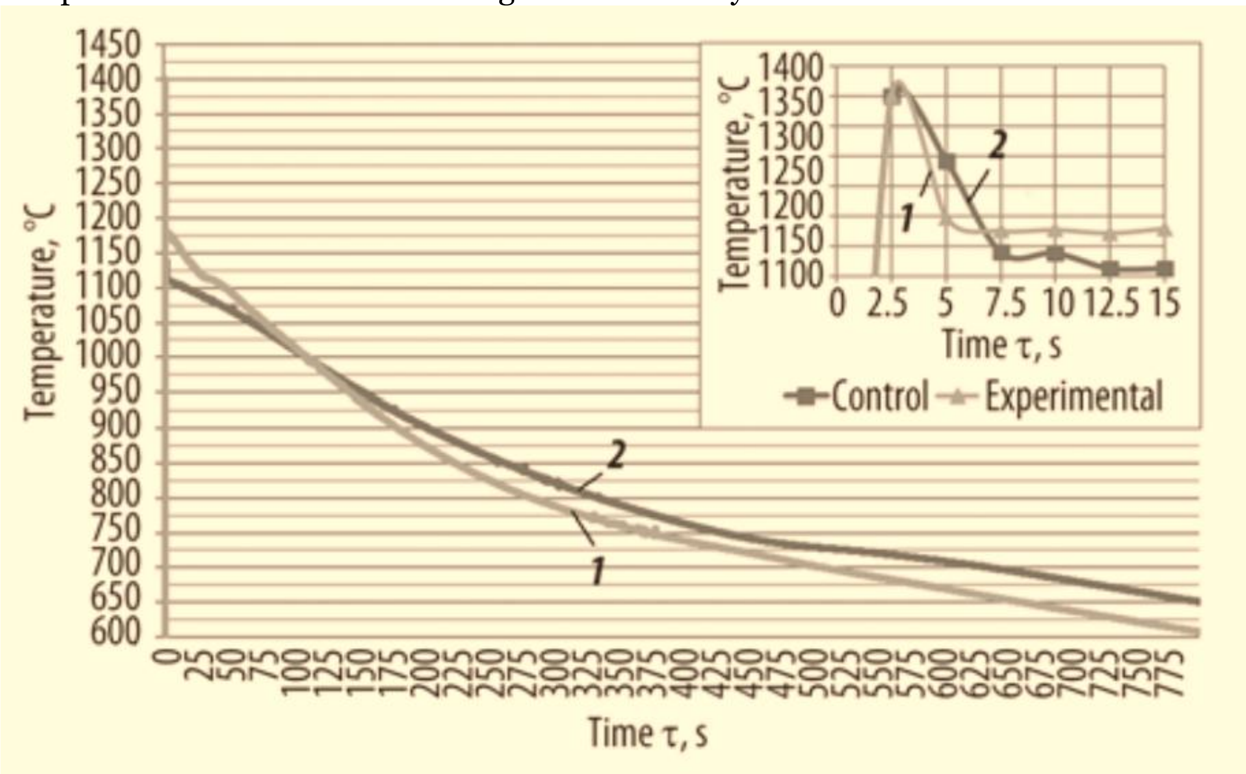
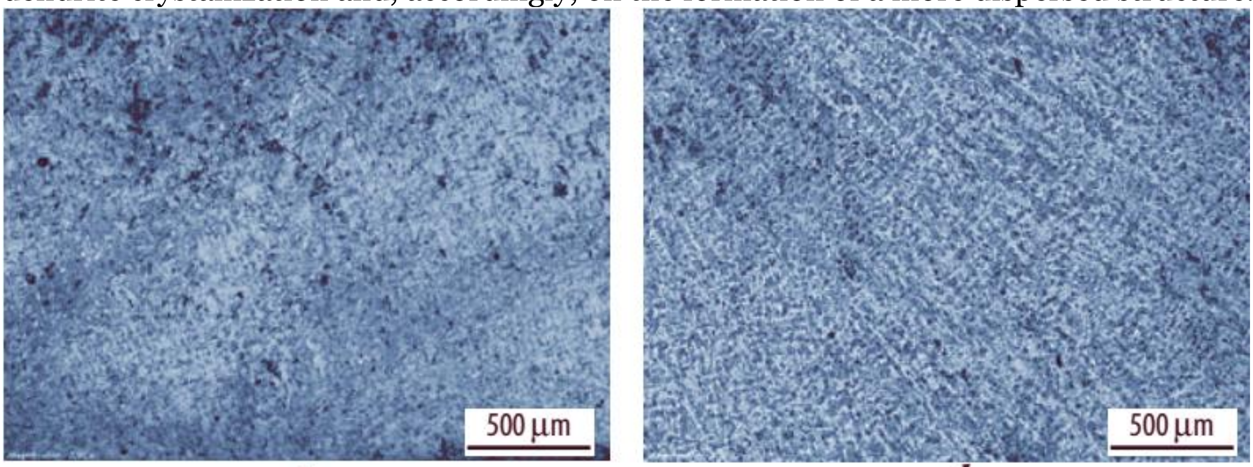


Fig. 1. Cooling curves of experimental (1) (with cooling adjustment) and control (2) castings

This had a significant effect on the formation of a large amount of primary austenite dendrite crystallization and, accordingly, on the formation of a more dispersed structure.



a *b*

Fig. 2. Dendritic microstructure for control (a) and experimental (b) cast

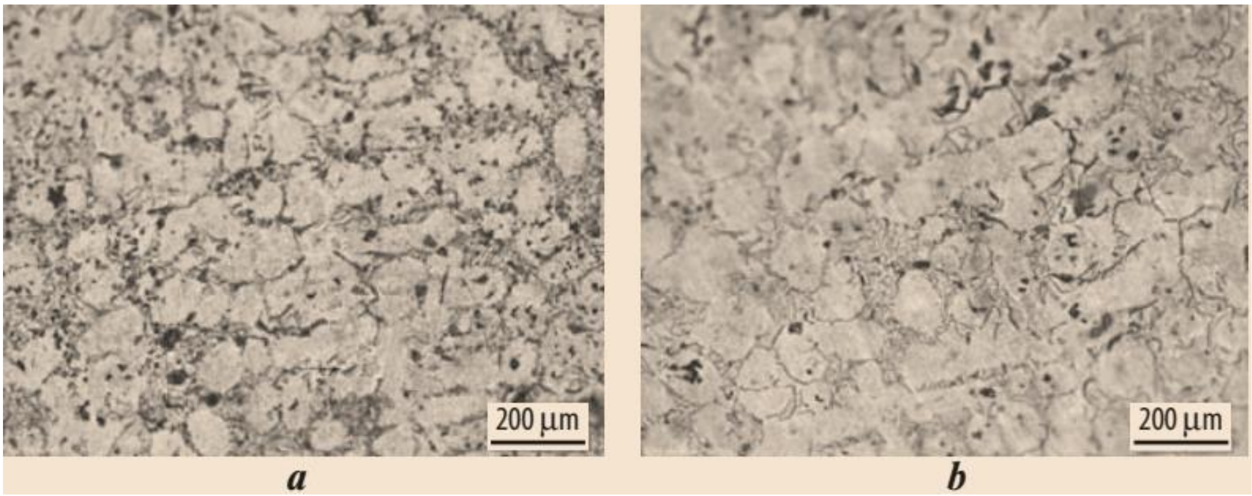


Fig. 3. Control (a) and experimental (b) cast iron eutectic cells

The distances between the second-order branches for the control and experimental castings are $\lambda_к$ = 34 µm and λ_o = 25 µm, respectively (Fig. 2).

After that, in the range of eutectic transformation, the combustion reaction started in the mixed layers adjacent to the castings, and it was carried out due to the heating of the mixed layers to the heating temperature of the combustible additives. At present, the slowing down of the casting cooling rate has led to the formation of austenite-graphite eutectic. In this case, the volume of eutectic cells did not increase (Fig. 3).

CONCLUSION

In conclusion, it can be said that the application of the solidification rate of iron castings in structurally sensitive intervals allows to significantly improve the mechanical properties of the metal without introducing additional elements. An almost identical technological operation provides cooling and heating of the cast mold at rates sufficient to directionally change the structure and properties of the thermokinetically sensitive gray cast iron cast alloy. It is shown that the implementation of the proposed innovation is accompanied by an increase in the number of technological operations. However, it is possible to more strictly control the technological parameters and, as a result, increase the labor productivity of casting production.

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