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Features of Process Control in the Foundry

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Abstract: *This article is the result of an analysis of the features of casting process control in the "casting - nonmetallic form" system by technological methods, leading to an improvement in the quality of castings from iron-carbon alloys when casting in shell forms on thermosetting binders. The data on the control features when using various additives for the manufacture of the mold, leading to improved casting.*

Keywords: *manufacture, casting processes, mold, casting defects.*

1. Introduction

The search for the best technological solutions in the design and management of casting processes is reduced to solving multicriteria optimization problems.

It is necessary to create adequate mathematical models of the corresponding CAD () and ACS (), including the control object - a mold.

The tasks of modeling objects with distributed parameters (ODP), to which the "casting - form" system belongs, have long attracted the attention of researchers. The urgency of these tasks is due to the fact that the true state of the ODP cannot be fully measured, and therefore optimization tasks can be solved only with a certain degree of approximation determined by the structure of the object, the linearity of its characteristics, stability of parameters and boundary conditions, and accessibility to control the required points of the object.

Such tasks are especially difficult in the foundry industry, when objects are non-linear, have variable parameters, function in highly non-stationary modes and do not allow control of the controlled quantity [1].

2. Statement of the problem

It is necessary to analyze the possibilities and features of controlling the heat and mass transfer processes in the "casting-nonmetallic form" system by technological methods leading to an improvement in the quality of castings from iron-carbon alloys during casting into shell forms on thermosetting binders.

3. Analysis

The problem of managing technological processes of a modern foundry is solved in different ways, depending on which parameter of the object is chosen as the manager. In particular, a very specific control option is the change in permeability of heterogeneous media, percolation (flow) through which a particular substance (heat, electricity, liquid, gas) sufficiently affects the whole process [2].

In this case, the existence of a relationship between the structure and the effective properties of heterogeneous media creates the prerequisites for controlling the cooling of the casting using available technological methods, which makes it possible to select the optimal modes for cooling the castings and, consequently, to influence their quality.

Calculations of the values of real control actions under such a control are very difficult, since the transfer processes through heterogeneous environments from the point of view of building their mathematical models are extremely complex. Constant and unpredictable changes in the properties of the components of a heterogeneous environment and other parameters determining their integral permeability require, in the management of, especially, fast processes, the availability of a high-speed information model that solves all necessary tasks in real time. Otherwise, management may not keep pace with the process, which leads to significant technical and economic losses, and sometimes even more serious consequences..

When creating an ACS for systems with distributed parameters, it is possible to use both linear control laws that are optimal by a quadratic criterion and a number of procedures for synthesizing various suboptimal control laws.

However, the distributed parameters contribute their features to the design methodology of control devices. The simplest possible method of synthesis is the initial discretization, that is, the replacement of the initial information model with distributed parameters by a simplified model with lumped parameters in the form of a system of ordinary differential equations at the earliest stages of the calculation. After this replacement, you can use the information model, not taking into account the distribution of parameters.

This approach has significant drawbacks. First, the conditions of controllability, stabilizability, etc. in this case, they are determined not only by the structure of the system and the choice of control actions, but also by the method of approximation, location of discretization points, etc. Secondly, the structure of the original problem statement is lost, as a result of which the resulting regulator may turn out to be "naive" not using all available information.

An alternative approach — the final discretization - fully utilizes all the advantages of the theory of control of systems with distributed parameters in analyzing controllability, stabilizability, choosing the optimal structure of regulators, etc. All constructions are carried out according to partial differential equations, and only at the last stage, after the control strategy has already been obtained, is the approximation performed in order to realize it numerically. This approach preserves the structure of the original problem without any distortions.

The properties of systems with distributed parameters are determined by the type of the corresponding partial differential equations (parabolic, elliptic, or hyperbolic).

4. Purpose of the work

It is necessary to show, by the example of casting into shell molds on a thermosetting binder, features of controlling the process of heat and mass transfer in the system "casting - nonmetallic form", which lead to an improvement in the quality of casting.

3. Basic material

Optimization of processes in management assumes the existence of a consistent objective function - some optimality criterion. However, in most cases, managed processes can be easily divided into separate stages with a pronounced difference in terms of management [3].

Let the object "casting - non-metallic form" consist of two parallel and independently operating components (the state of each component does not depend on the states of the other components). The state of such an object is defined as a tuple whose members are the states of each of the constituent objects. The state diagram then splits into two independent state diagrams of each of the components.

The basic and related requirements for composite processes (CP) are often contradictory. In addition, each requirement is determined by a series of arguments, which is not always possible to formalize. In this connection, a multicriterial dependence appears, requiring additional (known or justified) conditions, equations that specify the limits of the reliability of the desired function [1,4].

Determination of the optimal solution of such technical problems is quite laborious; it is not always possible to bring them to single-criteria tasks. In this case, multicriteria methods are used: steep ascension - the Box-Wilson method or the simplex optimization method.

Dynamic and stationary multicriteria problems can be reduced to the connection of the main optimization criterion of the designed object with the criteria affecting it.

Under the main criterion for optimization is meant a parameter with superiority: heat transfer during cooling, pressure of gases in the mold, etc.

The internal criteria include all parameters included in the description of the mathematical model of the object, taking into account the full interrelation of the individual subsystems of the object, as well as those involved in ensuring its life cycle.

The external criteria that apply to products include parameters that translate a product from a stationary state to a non-stationary state, included in a mathematical model in the form of equations of boundary conditions, restrictions at the beginning or end of a certain time interval or conditions for their change over a time interval.

Important is the case when recurrent parameter constraints appear, i.e. their self influence. For example, a change in the temperature field during the destruction and burning of an organic binder is determined by the temperature field itself..

Unrecorded parameters for any task include those that, a priori, do not have a tangible effect on the change in the main parameter.

The initial data in optimization problems are often statistical, which takes time to accumulate, and data from forced testing of products. To evaluate the effect of a minor parameter on the main one, it is necessary to solve a multi-objective task..

Thus, a mathematical model of functioning of CP is a description of irreversible time-dependent processes. τ and connections of the main parameter with the others. The optimization problem should often be solved in real time over a strictly limited period of time. $\Delta\tau$ or path x, when the product (system), or process comes to an equilibrium or reaches its extreme value..

A special class should represent the optimization problem, if we are talking about processes occurring in two or more objects at the same time. So far it has been about heat and mass transfer in a mold. However, many years of experience in studying the structure and properties of metallic materials obtained from a liquid state (by casting) also indicate a decisive role in their crystalline structure, and hence in mechanical, chemical, electrical and other characteristics, the cooling rate of casting.

Methods of dealing with casting defects in non-metallic molds must satisfy the main requirement: they must be technological. Many good ideas could not be implemented due to the fact that their practical implementation required unacceptably complex and expensive solutions: changes in technology, equipment, etc.

To systematize the types of technological impacts on the "casting - form" system, we will perform the last discretization in space for the "casting" and "form" subsystems and "fill" and "cooling" in time (Fig. 1) [3, 5].

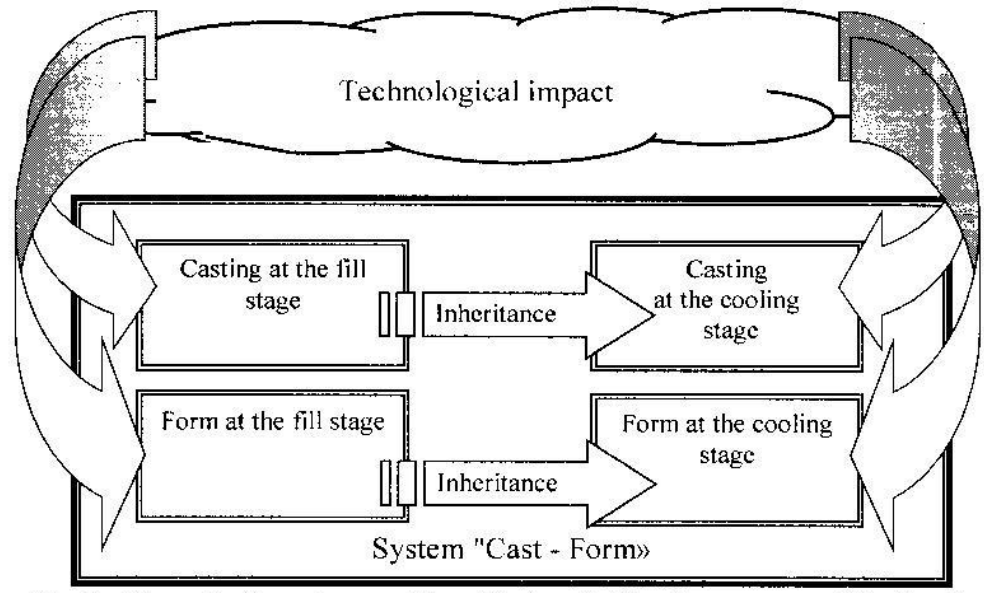


Fig. 1: Discretization scheme of the object model "casting - non-metallic form" along natural spatial-temporal boundaries

The meaning of the picture is that practically any technological impact on the system (on the structure of the molding mixture, on the pressure and composition of gases in the pores of the form, on the processes of formation of surface oxide captivity, on the change in the density of the form) cannot be made targeted: it affects all subsystems at all stages of their life cycle. We will try to prove it.

Let us consider as an example such an important type of external technological impact on the "casting-form" system, such as the forced change in pressure and gas composition in the pores of the form.

The kinetics of the formation of gas pressure at the interface is characterized by the presence of a sharp increase in pressure at the first moment of interaction. Then this pressure quickly decreases to a level lower than the initial one (vacuum is observed).

Subsequently, the vacuum disappears and a gradual increase in pressure is observed. The presence of two pressure peaks is confirmed by many researchers, but the reasons for the occurrence of such peaks, as well as the mechanism of their influence on the quality of the surface layer of castings, are interpreted differently.

The appearance of the first maximum is explained by the greatest gassing at the moment of contact of the metal with the shape and core. According to others, an increase in pressure in the form during the first moments after pouring occurs due to the heating of the air in the mold cavity and the reduction of its free volume. Reducing the thickness of the casting affects the magnitude of the first maximum.

The cause of the second maximum pressure is considered to be a decrease in the gas permeability of the form and an increase in the kinematic viscosity of the gases during heating.

Regarding the value of the absolute maximum pressure, developing in the pores of the shell form, there is the most contradictory information: from 100 to 16000 Pa.

The data on the influence of the second maximum on the formation of gas defects are also contradictory. At the same time, numerous studies have confirmed that it is precisely the second maximum that is the main cause of surface gas defects. This is proved by the absence of such defects in thin-walled forms in which the second pressure maximum is not observed..

At high-temperature destruction of organic materials, solid, liquid and gaseous phases are formed, the ratio of which largely depends on temperature. The total amount of gases released from the mold during heating is proportional to the amount of resin in the mixture. In some cases, it is necessary to take into account the gas creation of the refractory filler.

When assessing the influence of the gas-making ability of a form on the course of processes at the boundary of the casting-form, it is also necessary to take into account the rate of release and movement of the gas source inside the form (for example, during its heating).

The composition of the gas filling the pores also has a noticeable effect on heat transfer. With increasing pressure, the thermal conductivity of gases increases. Naturally, in vacuum, thermal conductivity decreases. Experiments have shown that when replacing a vacuum with a helium atmosphere, the heat transfer rate increased by 35%.

Removal of gases from the open shell form is possible in three ways. The first way is the filtration of gases through the pores of the form with their subsequent removal through the outer surface.

The second way is provided by the removal of gases through the liquid casting.

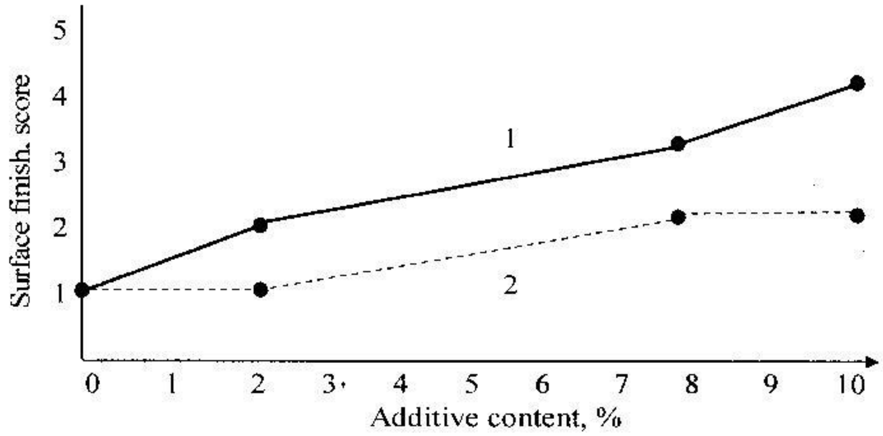
The third way is related to the fact that until the formation of a dense crust, the casting reproduces configurations of varying degrees, then the casting deformation lags behind the shell deformation, therefore there can be a gap between the casting and the shell, which is a channel for removal gases from the metal - form border along the casting surface.

Were conducted a series of experiments on the introduction of various additives in the odds.

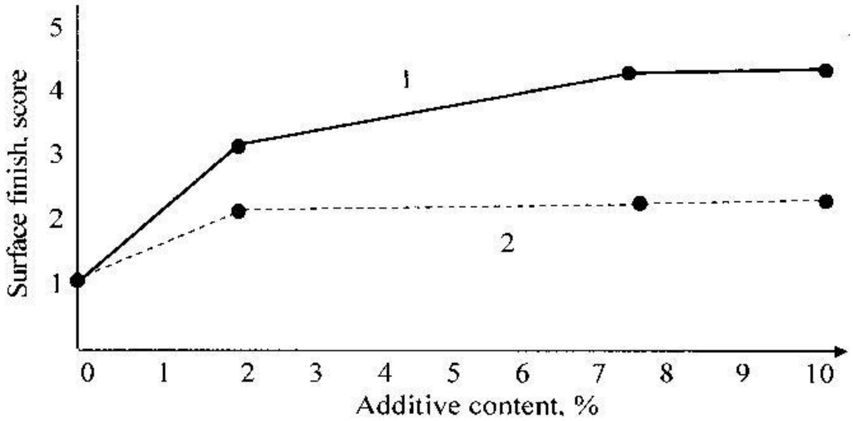
Different additives have different effects on the overall thermophysical properties of GM (heterogeneous materials) under different conditions. Thus, with an increase in the moisture content from 0 to 8%, the thermal conductivity of the GM increases several times, which is associated with an increase in the transfer of heat by evaporating water. Polymers, on the contrary, belong to heat-insulating materials as they possess low heat conductivity.

Calcium and magnesium carbonates were used as endothermic additives. In fig. Figures 1 and 2 show the dependence of the cleanliness of the casting surface on the quantity and quality of endothermic additives. Points of purity characterize the surface as follows: from the worst surface layer - 1 point to the surface layer without defects - 5 points. As can be seen from the figures, when the content in a mixture of 8 - 10% calcium carbonate and chemically pure magnesium carbonate castings have a clean surface, i.e. they do not have defects specific for steel shell casting.

The same concentration of industrial magnesite increases the purity of the casting surface, but does not completely eliminate the specific defects. Entering additives in amounts up to 5% does not significantly affect the quality of the surface of the castings. The data shown in Fig. 1 were obtained by pouring steel into a mold, one of the halves of which was a shell from the tested mixture, and the other from a control (without additives). The purity of the surface formed by the control shell is also shown in Fig. 1 - 2 (dashed lines). The results obtained draw attention to the fact that with an increase in the concentration of the additive in the test shell, the purity of the surface of the casting formed by the control shell also increased. An explanation of this fact can be given if one recognizes a certain role of a change in the gas atmosphere (composition and pressure of gases): the thermal destruction of an additive changes the gas atmosphere in the volume of the whole form [3, 6].



a)



b)

Fig. 2: The effect of calcium carbonate (a) and magnesium carbonate (b) content on the cleanliness of the surface of the steel casting (1 - working mold, 2 - control mold)

Castings samples obtained in shell forms without additives and with the addition of carbonates, were subjected to metallographic examination. The sections were made of a templet, cut from the average height of the part of the casting. The microstructure of each template in the central part of the surface layer of the casting and in the zone of the casting edge was considered. The results of the metallographic study are shown in Fig. 3 and 3.4 [3,7].

An important consequence of these experiments is the instability of their final results. Additives improve the quality of the surface layer, but not always, but only in 70 - 80% of cases. From these results we can draw the following conclusions.

Casting samples obtained in shell forms without additives have a surface layer up to 70 - 250 microns wide, in which the content of perlite is slightly lower than in the core of the casting. Next comes a sublayer up to 1000 microns in width, in which the content of perlite is significantly increased compared with the core of the casting. These data are qualitatively identical to those obtained in the study of the surface layer of steel castings made in shell molds. The results of studies of samples obtained in shell forms with carbonate additions show that as the carbonate content increases, the concentration of pearlite in the surface zone decreases and the carburized sublayer disappears.

The nature of the microstructure of the surface layer of production castings obtained in shell molds, and sample castings obtained in shell molds with and without additives, show that in the molds without additives carbonization of the surface layer of the casting occurs and that carbonates interfere with this process.

Moreover, these additives oxidize the surface layer of the casting, reducing its carbon content in comparison with the core of the casting. The increase in the oxidative potential of the shell form when introducing into it carbonates is in full accordance with the results of the analysis of gases formed during thermal decomposition of the mixture.

a) **b)** **c)**

Fig. 3: Impact $CaCO_3$ on the microstructure of the surface of the steel casting when casting into shell mold: **a)** – 1,5 %; **b)** – 3,5 %; **c)** – 8 %; ×70.

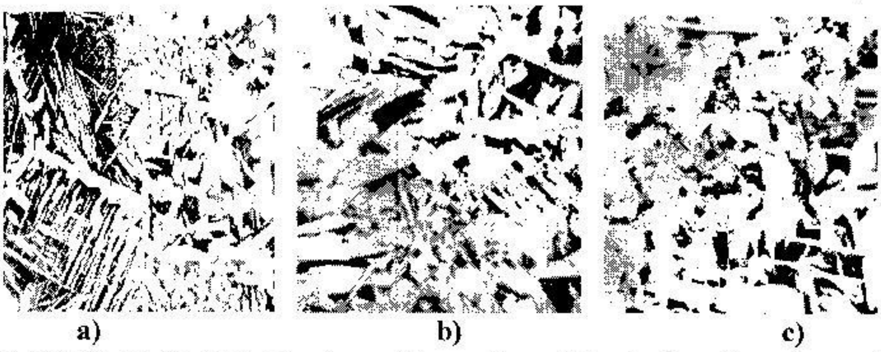
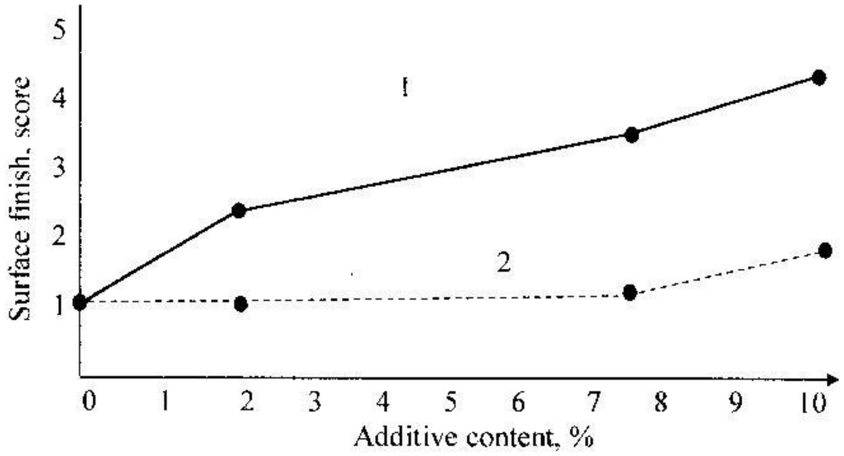


Fig. 4: Impact $MgCO_3$ on the microstructure of the surface of the steel casting when casting into shell mold: **a)** – no additive; **b)** – 3,5 %; **c)** – 10 %; ×70.

When you enter the carbonate powder additive in the amount of 8–10% into the mixture for shell casting, a sharp drop in the strength of the latter was observed (about 3 times). Such a drop in the strength of the cured mixture led to a drop in the strength of the shell.

In this regard, experiments were carried out with two-layer shells, the inner layer of which was made from a mixture with additives, and the outer layer - from a mixture without additives. Two-layer shells had a high overall strength.

Two-layer shells were tested in the same way as single-layer ones. The research results are shown in Fig. 5.



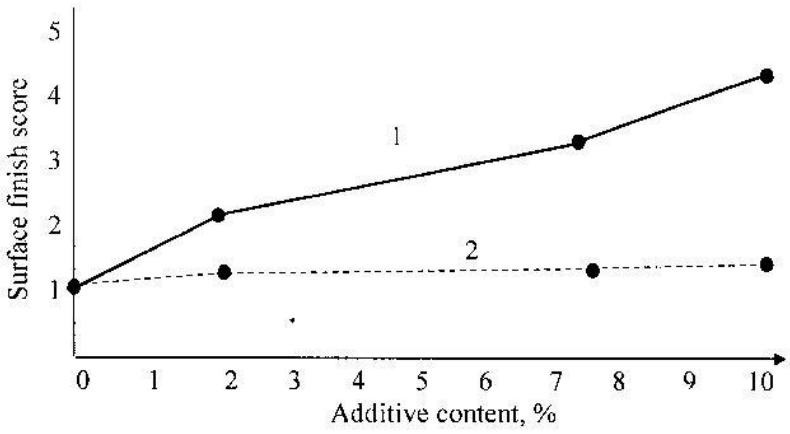


Fig. 5: Effect of calcium carbonates (a) and magnesium (b) on purity the surface of the steel casting, obtained in two-layer form. 1 - working half-form, 2 - control half-form)

5. Conclusions

As can be seen, two-layer shells make it possible to improve the quality of the surface layer of a steel casting, although to a lesser extent than single-layer ones. The remaining patterns are similar to those established in experiments with single-layer shells.

It must be emphasized that two-layer shells solve the problem of increasing the cleanliness of the surface of low-carbon steel castings, while making insignificant the question of a decrease in the strength of the mixture when carbonate is introduced into it.

These results confirmed the previously obtained data on the unstable improvement of the quality of the surface layer of the steel casting with the introduction into the molding mixture $CaCO_3$ and iron ore. For example, experiments have shown the effectiveness of additives only under conditions of high hydrostatic pressure of the metal..

Using the example of casting into shell molds on a thermosetting binder, features of controlling the process of heat and mass transfer in the system "casting - nonmetallic form" were shown, which lead to an improvement in the quality of casting through the use of technological control methods.

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