PROGNOSTICATION OF MAIN PARAMETERS DURING CASTING UNDER PRESSURE AND CRYSTALLIZATION OF METAL ALLOYS - AN ASSESSMENT OF TECHNOLOGICAL IMPROVEMENTS AND BENEFITS

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ABSTRACT

Possibilities for mathematical modelling of heat transfer processes during crystallization of model metal alloys with different chemical composition, manufactured in a laboratory furnace injection moulding to 5.0 MPa, are discussed in this work. A method for experimental measurement of the temperature in the volume of the metal during crystallization and its dependence on the registered time to complete hardening of the metal is applied.

The adequacy of the mathematical model is tested. The proposed approach allows for prognostication of the main features of the processes and assessment of technological improvements that directly increase the yield of the production with around 68 %.

Keywords: solidification, mathematical modeling, production yield.

INTRODUCTION

The pressure in the process of casting and crystallization of the steel ingots offers possibilities for their further alloying with volatile components (particularly nitrogen) in higher than equilibrium concentrations. The interest in this type of metal products is huge and the implementation of this technology is evolving as a function of the balance of the funds for the production and sale. Prices of ferroalloys and insufficiently high yield (percentage of fit metal upon completion of the process) do not always meet the market requirements and often become a serious economic problem. Recently, the cost of the main ferroalloys grew dramatically up to more than 10 times, which further made expensive the processes for obtaining alloys on a metal base, with preset and unusual composition. Therefore, it is necessary to work to increase the usability of the resulting metal alloys and their market price, so that they are technologically attractive. Generally, the casting technology of metals and alloys under gas pressure is as follows:

- a metal charge is melted in a crucible in a closed furnace;
- after melting, the necessary ferroalloys are added to the charge in the open furnace;
- the machine closed again, it is evacuated and nitrogen is fed in;
- once the metal is melted, through the sluice of the chamber, a container with nitriding ferroalloys or volatile components and de-oxidants is fed;
- after homogenization, the metal is poured in a pre-prepared crucible.

Statistical studies of metal, cast in conventional sand molds of the Leybold Heraeus machine show, that from the average mass of the metal block of around 9 kg, after cutting the feeder head remains on average 4.2 kg of high-grade metal. The resulting yield (percent fit metal) is not more than 46 %. This fact and the high market prices of ferro-alloys demonstrate the necessity to explore the best opportunities for production of metal-based materials under gas pressure. There are two possible scientific approaches to the work in this direction, namely:

- replacement of the traditional sand mould by casting the steel in a metal form.
- improvement of the existing way of casting in a

sand mould.

One way to avoid the disadvantages of the single use of forms from sand or ceramic is the use metal forms. This work reports on an attempt to create a metal form that can withstand repeated casting and provide a higher yield than the sand form.

EXPERIMENTAL

Development of a technology for casting in a metal form, according to the kinetics of solidification

In order to prevent thermal and phase changes in the wall of the form, a model, configuration, placement and dimensions of the feeder head and the wall thickness of the mould, must be chosen. The determination of the physical parameters of the form depends on the thermodynamic and kinetic studies of the solidification of metallic materials in similar-sized blocks.

Kinetics of solidification

Comparison of the curves of temperature distribution in the cross section of the form shows, (see Fig. 3), that with a change in the wall-thickness not only time to complete solidification is changed, but the slope of the curves is changed as well. An important feature of a thin-walled form is the uniformity of the process of solidification of the metal at the vertical section of the ingot [1-3, 5]. This explains why over the solidification time the heat-transfer coefficient of the outer surface of the form, and thus - the heat flux from the ingot surface is changed slightly. In the initial moment of time, the massive form takes a large amount of heat from the flow, the rate of heat removal decreases dramatically, this leads to non-uniformity of the process, and the quality of the metal gets worse [6].

RESULTS AND DISCUSSION

Determining the wall thickness of the form

The wall thickness of the mould affects differently the process of solidification, depending on its dimensions, the temperature conditions of the process, etc. [4, 7]. It is known, that the time of solidification increases with increasing the wall thickness, but the rate of crystallization is reduced. This is due to the thermal resistance of the mold during heat transfer to the environment. When heat transfer to the environment decreases, the heat-accumulating ability of the form increases. Fig. 1 shows the data for the kinetic of solidification as dependence of the time for solidification on the wall thickness of the form.

It is seen that with the increase of the wall thickness the rate of crystallization expectedly is reduced. The highest speed of the process is in for a thickness of 10 mm and after 25 - 30 mm the dependence become linear.

Determination of the geometric dimensions of the mold

After processing the data from the experiments, the following dimensions of the form have been chosen: wall thickness - 20 mm, thickness of the metal plate at the bottom - 33 mm; width of the form - 140 mm; height of the form - 280 mm. The dimensions of the ingot were approximately 44/100/185 mm and of the feeder head – 30/60/117 mm. The metal block had a mass of about 6 kg and a 3.5 kg riser [7, 8].

According to Fig. 1, it is sufficient for the wall thickness of the mold to be above 12 - 14 mm. The choice of thickness 20 mm thus ensures a sufficient mechanical strength of the mold.

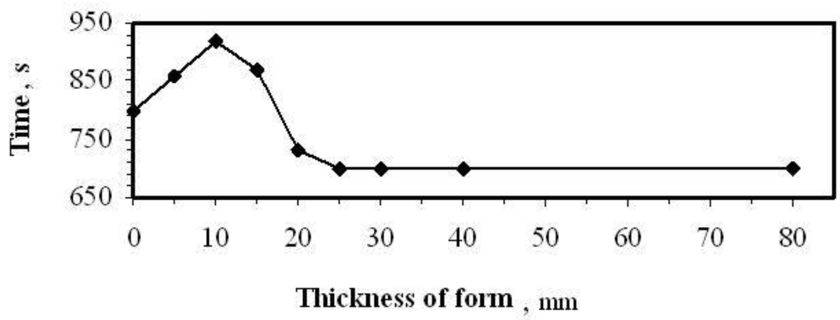

Fig. 1. Dependence of time of solidification on wall thickness.

Table 1. Chemical composition of the produced metal alloys

C, %	Cr, %	Mn, %	Si, %	S, %	N, %
0.02-0.04	20.05-20.6	0.79-0.83	0.20-0.42	0.01-0.013	0.9-1.2

Implementation of the casting process

In order to to realize the optimization concept of the casting process, ingots with 10 kg mass of model alloys, with the chemical composition shown in Table 1, were produced in the laboratory installation Leybold Heraeus - Germany, (Fig. 2). The concentration of nitrogen was controlled with an accuracy of 0.0002 %.

The experimental installation allows casting with simultaneous measurement of the temperature in the volume of metal (Fig. 2).

The induction furnace (6) is located in an autoclave (5). Through the sluice chamber (1), the supplements – ferroalloys are fed in. Position (2) is an opening for direct observation, (3) is the control panel, (4) - the casting form.

The bottom of the mould is a metal plate, which leads-off the heat directly. The surface of the feeder head is covered with an exothermic mixture of "Foseko", which early in the process ignites and burns for about 10 s. The scheme of the ingot, form and thermocouples W/Re-5/20 is shown in Fig. 3.

Development of a mathematical model based on the process technology

To determine the main characteristics of the crystallization process a mathematical model has been developed. It includes a physical description of object, the geometry of object, initial and boundary conditions of the task, thermo-physical characteristics of the studied steel and ingot. A numerical method and a computer program were developed to solve the problem. The information about the main characteristics of the process was obtained from the model. The results of mathematical modeling were compared with those from the experiments and analyzed. The mathematical model of the crystallization process was numerically solved by

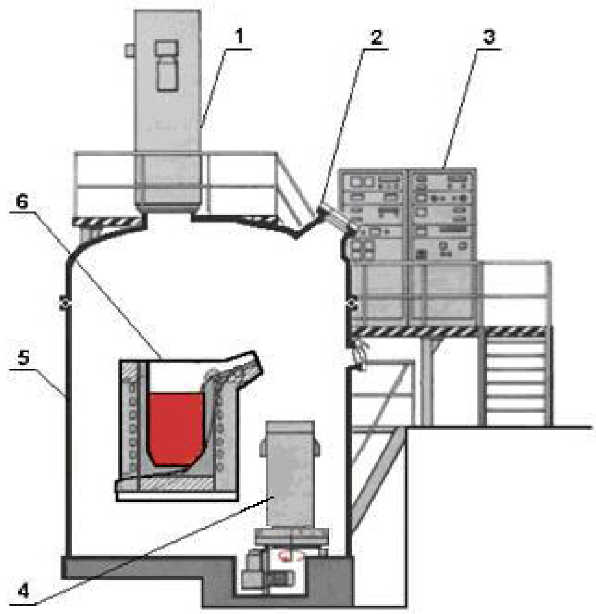

Fig. 2. Overview of installation Leybold Heraeus-10.

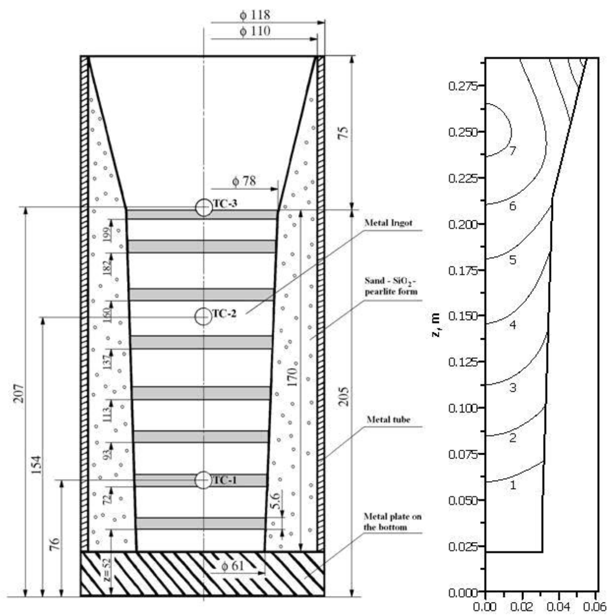

Fig. 3. Scheme of the ingot with feeder head, ramming and form. TC_i-thermo-couples, i - 1, 2, 3.

the finite element method, the ANSYS software package. Data of the temperature fields, the local time of crystallization, and the cooling rate at any point of the metal block have been obtained.

The changes of the temperature in the volume of the ingot were registered with thermocouples, placed as shown in Fig. 4: TC1 (at the bottom), r = 0.005 m, z = 0.076 m; TC2 (medium), r = 0.010 m, z = 0.154 m;

Fig. 4. Location of the thermocouples in the volume of the ingot.

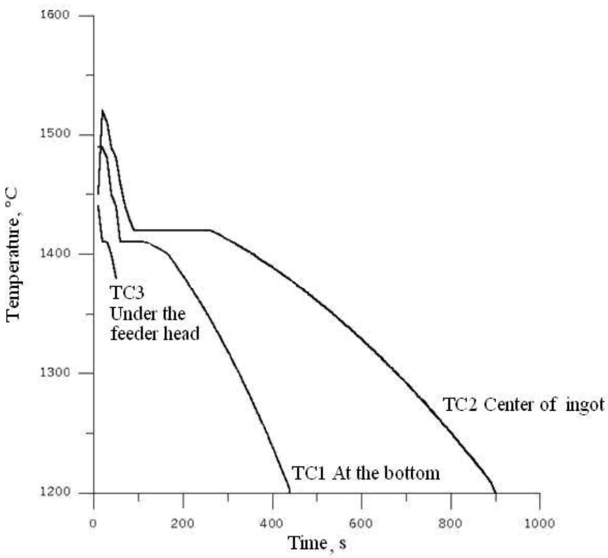

Fig. 5. Temperature in the body of the ingot as a function of time.

TC3 (below the feeder head of the ingot), r = 0.015 m, z = 0.207 m. The casting temperature was measured with an optical pyrometer QP-3, produced by Leybold Heraeus, which has readings up to 1525°C.

The data were recorded by connecting the thermocouples with a writing device, which reproduced their time-varying voltage in mV.

During the course of experiment, it became clear that TC3 is destroyed immediately after the start of casting. The remaining two thermocouples tracked the change in the temperature from the beginning to the end of the process.

Fig. 5 shows the measured temperatures in the ingot, as a function of time. The data are reported in m/s and are calculated in °C/s [8]. They were used for verification of the mathematical model.

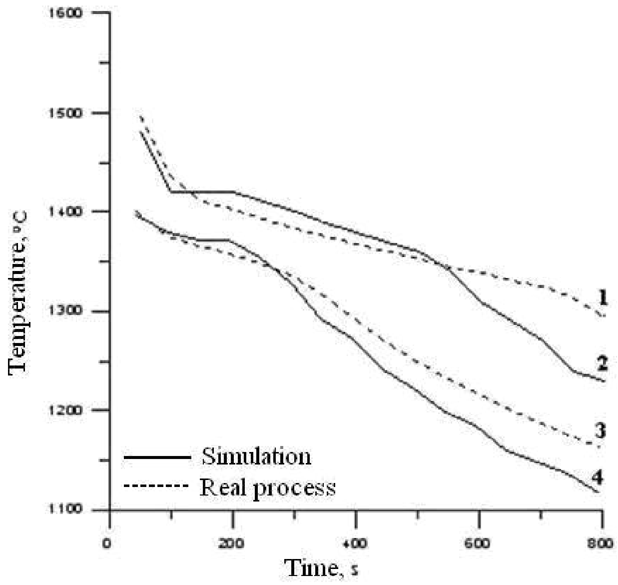

Fig. 6. Dependences of T on time, obtained by experiment (dotted line) and as a result of the mathematical simulation of the process (solid line). Curve 1 and curve 2 are measured with the thermocouple in the middle of the block, (TC2). Curve 3 and curve 4 are from the thermocouple at the bottom of the ingot (TC1).

Adequacy of mathematical model

Figs. 3 and 4 show that thermocouple 1 registers the temperature of the metal during solidification. Thermocouple 3 has been destroyed after time of 50 s at temperature of 1380°C. This was probably due to the high temperature of the liquid metal and its mechanical impact.

Fig. 6 compares the experimentally measured temperatures and those calculated by simulation with the model.

The comparison shows that the experimental curves and those obtained by numerical simulation of the process are similar. The relative deviation between the experimentally measured values (curves 1 and 3) and the calculated (curves 2 and 4) of the temperature vary within the range of 1.09 % to 2.17 % in the middle of the ingot and from 0.3 % to 4.69 % for the bottom of the ingot.

CONCLUSIONS

A form with a metal bottom, intended for casting under pressure of 1 to 10 Mpa, has been designed, built and used for casting of model alloys.

Experimental measurement of the temperature within the body of the ingot during crystallization provided for obtaining the dependence of the temperature on time.

An assessment of the adequacy of model showed that the maximal deviation of the calculated values from the measured temperatures is 2.17 % for the middle and 4.69 % for the bottom of the ingot .

As a result of the replacement of the traditional form with a metallic mould, the yield of cast metal in the installation Leybold Heraus has risen with an average of 16 %.

The presented above approach allows prediction of the main features of the processes and evaluation of technological improvements to increase productivity.

Prognostication of the main characteristics of the process and evaluation of the made improvements directly lead to higher yield in this production technology. Due to the effective removal of heat from the volume of metal in the process of the solidification, non-defective metal is manufactured. With an average mass of the metal with excellent quality of 6 kg and mass of the metal block of 9.5 kg, the yield is more than 63 %, which is a very good result. Compared to the previous 47 %, the increase is of over 16 %.

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