PHYSICAL MODELING OF THE HYDRODYNAMIC PROCESSES OF CASTING MOLDS POURING FILLED WITH A LOCALLY ORIENTED REINFORCING PHASE

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Abstract: In the process of manufacturing reinforced castings by lost foam casting it is important to determine the laws of gas-hydrodynamic processes that occur during mold pouring. The study of liquid metal filling process a mold filled with a locally oriented reinforcing phase was carried out by the method of physical modeling using cold liquids on a special experimental bench that allows superimposing rarefaction to the front of the liquid metal.

The video frames of the filling process the mold cavity without the reinforcing phase and with the presence of vertically mounted metal rods are obtained. It was established that the filling process without reinforcing elements occurs in three stages:

1) the flow of a gushing free stream into space;
2) the destruction of the free stream with the capture of the gas phase;
3) filling the form with a continuous stream with the removal of smaller gas inclusions from the liquid volume.

It was also established that with an increase in the rarefaction, the character of filling the mold is preserved, only the intervals of existence of the corresponding stages are reduced. In the presence of a reinforcing phase in the cavity, a marked decrease in the height of the gushing of the jet in the initial stage with an increase in the number of installed rods. In addition, crushing by rods of a limited model space creates more favorable conditions for removing the filled gas phase from a moving stream.

Keywords: lost foam casting, macroimplants, reinforcing phase, physical simulation, gas-hydrodynamics processes.

1. Introduction

Today, various industries are increasingly using composite castings produced by various technologies. Recently, to obtain cast reinforced parts, the lost foam casting method [1, 2], as well as other new methods [3, 4], are increasingly used. The processes that occur during the formation of reinforced castings using new technologies have not yet been fully studied. And without an understanding of these processes, it is impossible to obtain quality parts with predictable properties.

When castings are obtained by reinforcing them with macroimplants located in the mold cavity or in the foam pattern, multicomponent systems new for the foundry theory arise: «metal-pattern-implant-mold» and "metal-reinforcing phase-mold". It is important to determine the conditions and relations of the influence of the reinforcing phase on the gas-hydrodynamic processes of the melt pouring, which will make it possible to determine the deterministic relationship between the technological parameters and ultimately control the quality of the casting [5].

A clear visual representation of the foundry processes is provided by physical and computer simulations. So computer simulation has been successfully used to study heat and mass transfer processes in castings with a macro-reinforcing phase oriented in the form of discrete elements [6]. However, hydrodynamic processes cannot always be adequately modeled using computer programs, since the algorithms and mathematical models underlying them have assumptions and do not take into account the influence of all parameters.

In connection with the known difficulties of a full-scale experiment, observations of the processes of flow of a liquid metal are carried out by the method of physical modeling using cold liquids [7]. For example, in [8], using this method, the hydrodynamics of mold casting with a close-packed reinforcing phase was successfully studied.

The study of casting a mold with a polystyrene foam model using the photographing technique [9] shows that the gas-hydrodynamic situation depends on various parameters, primarily on the alloy temperature, model density and coating thickness. However, in this work, the dependence of gas-hydrodynamic processes on the presence of the reinforcing phase and the magnitude of the vacuum, which, as the study [10] shows, has a significant effect on the quality of the bimetallic casting, was not studied.

Therefore, the aim of research is to study and establish the laws of gas-hydrodynamic processes of the flow of liquid metal in a form filled with a locally oriented reinforcing phase, when applying an excess of controlled pressure.

2. Methods

The study of gas and hydrodynamic flows in the mold cavity filled with vertical metal elements (in our case rods), with the application of excess controlled pressure, was carried out on an experimental bench (**Fig. 1**) using the photographing technique.

The bench includes a mold model (casting) 1, which is mounted on a mounting plate 6, and a squeezing chamber 2, on a movable plate 8, which can move along the guides 5. The casting model is connected by feeders through an opening in a stationary press piston 3 with a squeezing chamber. In the center of the movable plate 8, the rod of the hydraulic cylinder 9 is connected, connected to the pump unit 10. A spool valve with a stepper motor is mounted between the pump unit and the hydraulic cylinder. A system for automatic control of the technological parameters of the bench, consisting of a control unit of a step drive 12, an operational control system 11, and a displacement sensor 4 included in the feedback system, is separately mounted.

The influence of the location of vertical reinforcing rods 200 mm long on the kinetics of the gas phase in the melt was studied according to the variants shown in **Fig. 2.**

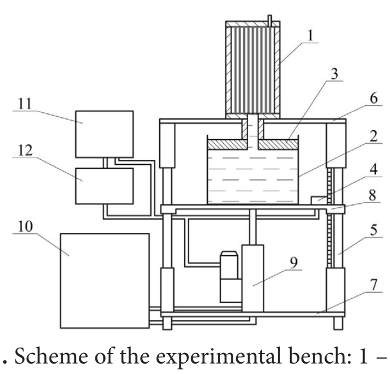


Fig. 1. Scheme of the experimental bench: 1 – mold; 2 – squeezing chamber; 3 – press piston; 4 – displacement sensor; 5 – guides; 6, 7 – mounting plate; 8 – movable plate; 9 – hydraulic cylinder; 10 – pump unit; 11 – operational control system; 12 – control unit of step drive

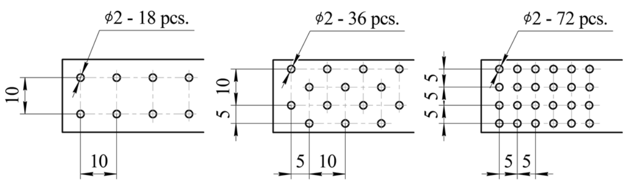


Fig. 2. The layout of the vertical reinforcing rods in the mold model: *a* – double row; *b* – diagonal; *c* – four row

As the basic model of the form, a rectangular container with dimensions of 100×20×200 mm is chosen. Water is used as a model fluid.

3. Results

Fig. 3 shows the video frames of filling the cavity of the base model without reinforcing elements with a vacuum at the flow front equal to 0.025 kg/cm^2 (which, when converted to liquid steel, will be 0.175 kg/cm^2). The process of filling the model is presented in 3 stages. The first stage is the entry into the cavity of the gushing free stream (frame *a*), then the stage of destruction of the free stream with the capture of inclusions of the gas phase (frame *b*). The final stage is the filling of the form with a continuous stream with the removal of smaller gas inclusions from the liquid volume (frame *c*).

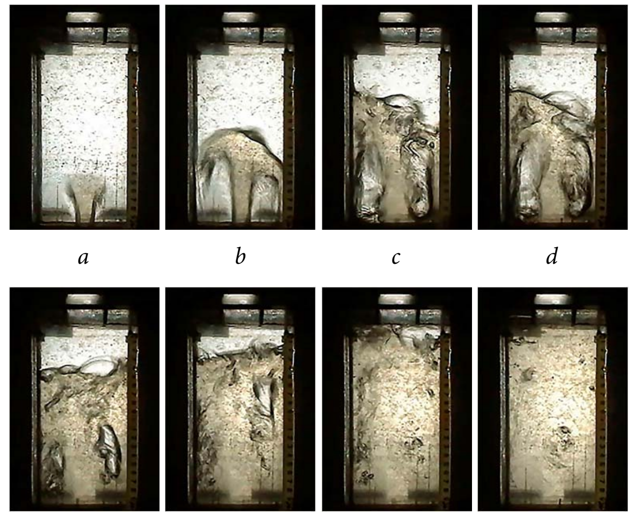
a *b* *c*

Fig. 3. Video frames of model cavity filling with a vacuum of 0.025 kg/cm^2: *a* – initial stage; *b* – jet destruction stage; *c* – final stage

With an increase in vacuum to a value of 0.05 kg/cm^2 (in kind – 0.35 kg/cm^2), **Fig. 4**, the filling pattern of the model as a whole is preserved. The following parameters are changed: gushing up to a height of about 0.5 of the model's height (frames *a*, *b*), filling out the form with a two-phase flow (liquid-gas phase), frames *c*–*h*. The stage of filling the form with a continuous stream is practically absent. After the model is completely filled, the process of removal of gas inclusions under the action of applied vacuum occurs.

The filling character of the form similar to that described above is observed at a rarefaction value of 0.075 kg/cm^2 (0.525 kg/cm^2) and 0.10 kg/cm^2 (0.70 kg/cm^2). Only the following parameters are changed: the height of the gushing of the jet, increased capture of the gas phase by the fluid flow, more intensive mixing of the liquid volume. And, of course, the intervals of existence of the corresponding stages are reduced.

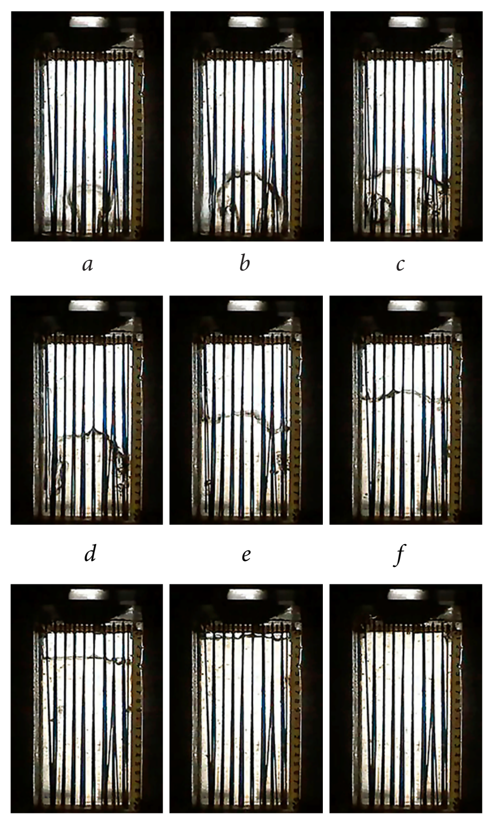
When installing the shape of vertical rods in the model, the general nature of the formation of flows is similar to the basic version. That is, depending on the working vacuum applied to the front of the moving fluid, the same steps are observed. An analysis of the video frames (**Fig. 5**) of filling out the mold model when the rods are arranged in type 1 (**Fig. 2**) shows that the presence of the rods has a certain effect on the liquid stream entering the bounded rectangular region.



a *b* *c* *d*

e *f* *g* *h*

Fig. 4. Video frames of model cavity filling with a vacuum 0.05 kg/cm^2: *a*, *b* – initial stage; *c*, *d* – jet destruction stage; *e*–*h* – final stage



a *b* *c*

d *e* *f*

g *h* *i*

Fig. 5. Video frames of model cavity filling with a reinforcing phase: *a*–*c* – initial stage; *d*–*f* – steady state stage; *g*–*i* – end of filling

It has been established that with an increase in the number of rods, the height of the gushing of the jet in the initial stage decreases. In addition, crushing by rods of a limited model space creates more favorable conditions for removing the filled gas phase from a moving stream.

4. Discussion and conclusions

As a result of experimental studies of gas-hydrodynamic processes of filling molds in which reinforcing elements are placed in the form of vertical rods, under excessive pressure it is found that in the mold at the initial stage of pouring, with an increase in vacuum, significant air capture occurs. The use of reinforcing elements in the form of vertical rods creates better conditions for the removal of the gas phase from the moving stream, as a result of which it is possible to recommend the use of a larger working vacuum. In this case, the filling time of the mold model, depending on the applied vacuum (without rods at P_b=0.025 kg/cm^2, is t=3 s, and at the maximum vacuum equal to P_b=0.14 kg/cm^2, t=0.5 s) decreases accordingly, due to a decrease in the volume of the mold cavity by 10–20 %.

The experimental results confirm that, in the presence of a form of a reinforcing phase in the cavity, the process of its filling takes place in an almost continuous flow with a decrease in the height of the gushing of the metal jet, which is crushed by rods, which together with the applied rarefaction contributes to the complete removal of the gas phase from the metal. Moreover, these results can be applied in the presence of a reinforcing phase in an amount of 10–20 % of the cavity volume, with a larger amount, a decrease in the temperature of the alloy, loss of casting speed and the absence of high-quality interfacial alignment.

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