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SIMULATION OF THE PROCESS OF FILLING POLYSTYRENE FOAM FOUNDRY MOLD WITH THE METAL

Modern approaches to prefabrication production consist in the maximum approximation of the shape and size of the blanks to the finished part, which essentially makes the final part cheaper. One of the methods of precision casting is casting in gasified models, or foam models. The basis is the task of developing a theoretical model of filling a polystyrene foam model with liquid metal. The analysis of the process of filling the mold with a gasified model and the process of filling the mold with a closed sprue system are considered.

The analysis of the obtained solutions shows that the movement of the metal has the character of aperiodic oscillations. The speed of metal in quantity is maximum at the initial moment of metal processing in the form and happens as it is filled. The pressure of the steam-gas mixture at the initial moment of time exceeds the pressure of the weak metal in the riser, which provides the possibility of metal ejection from the bowl. At the same time, the pressure in the mold cavity changes little with the increase in gas permeability of the mold, which is explained by the small gap between the melting front of the model and the metal mirror. However, with an increase in gas permeability due to a decrease in back pressure, the speed of the metal in the mold cavity and the path traveled by it increase. The analysis of the system of equations allows predicting the behavior of metal during the design of molds for the summer, which reduces the probability of production defects.

Keywords: casting, gasified models, polystyrene, gas, foundry form, castings.

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МОДЕЛЮВАННЯ ПРОЦЕСУ ЗАПОВНЕННЯ МЕТАЛОМ ПІНОПОЛІСТИРОВОЇ ЛИВАРНОЇ ФОРМИ

Сучасні підходи до заготівельного виробництва полягають в максимальному наближенні форми і розмірів заготовок до готової деталі, що суттєво здешевлює кінцеву деталь. Одним з методів точного лиття є лиття в газифіковані моделі, або пономоделі. В основу поставлено задачу розробити теоретичну модель заповнення пінополістирольної моделі рідким металом. Розглянуто аналіз процесу заповнення форми з газифікованою моделлю та процес заповнення форми при замкнутій системі литника.

Аналіз отриманих рішень показує, що рух металу має характер аперіодичних коливань. Швидкість металу в формі максимальна в початковий момент подачі металу в форму і убуває по мірі її заповнення. Тиск парогазової суміші в початковий момент часу перевершує напір рідкого металу в стояку, що свідчить про можливість викиду металу з чаші. При цьому тиск в порожнині форми мало змінюється зі збільшенням газопроникності форми, що пояснюється порівняно невеликим зазором між фронтом плавлення моделі і дзеркалом металу. Однак зі збільшенням газопроникності внаслідок зменшення протитиску, збільшується швидкість металу в порожнині форми і пройдений ним шлях. Аналіз системи рівнянь дозволяє прогнозувати поведінку металу при конструюванні форм для лиття, що зменшує вірогідність виробничого браку.

Ключові слова: лиття, газифіковані моделі, полістирол, газ, ливарна форма, відливки.

Formulation of the problem. Modern approaches to pre-fabrication production consist in the maximum approximation of the shape and size of the blanks to the finished part, which substantially lowers the price of the final part. One of the methods of precision casting is casting in gasified models, or foam models.

The technological process of manufacturing castings according to gasified models is the following. In special metal molds, models of parts and sprue systems are manufactured by mechanical processing, using suspended polystyrene in the form of pre-foamed granules or normalized polystyrene blocks and plates. The models are connected by gluing or welding to the elements of the sprue system, after which they are painted once with paint or a suspension of a binding solution and dusty fore-resistant material, which is applied by dipping, brushing or spraying from a paint sprayer in special chambers. The painted layer is dried in the air and in this way a thin-walled, fire-resistant, gas-permeable shell up to 2 mm thick, which is firmly connected to the polystyrene model, is obtained. After that, it is placed in a special pot-container and evenly, carefully so as not to deform the model, it is covered with a granular fire-resistant filler. Quartz, olivine, zircon sand, fireclay, magnesite, electrocorundum are used as fillers. In some cases, during the production of massive castings, ordinary molding mixtures are used, such as sand-clay, sand-cement, etc. After the molds are made, they are filled with liquid metal, while the polystyrene model is gasified under the influence of heat, freeing the cavity of the mold. After the casting is formed, the pot-container is turned over. The molding material is poured, the casting is pulled out and goes to the finishing operations - cutting, processing, cleaning and control.

At the same time, the processes that take place when filling a polystyrene mold with metal, how the speed of filling the mold affects the quality of castings, remain unexplored.

Analysis of the latest research. Such scientists as Movchan V.P., Berezhny M.M., Repiakh S.Y. were engaged in the development of the technology of casting on gasified models. Analyzing the stages of development of the casting process on gasified models, it can be noted that this process develops in two independent directions.

The first direction is related to the production of large, massive castings in the conditions of experimental and small-scale production according to models obtained by mechanical processing of polystyrene plates and blocks and, if necessary, gluing.

The second direction is related to the production of complex castings weighing up to 15 kg with increased dimensional accuracy in conditions of large-scale and mass production according to models obtained from suspension polystyrene that has undergone special heat treatment (pre-foaming) and is finally foamed in molds until complete design configurations of casting models.

Currently, both directions of gasification models are successfully developed in casting, which contributes to the technical progress of various branches of mechanical engineering [1].

There is a well-known work in which it is proposed to improve the quality and durability of castings made of cast iron with the use of special paints [2]. The disadvantage of this method is that the use of tellurium paints without precautionary measures can be accompanied by significant mechanical sticking of the molding mixtures before pouring in the places where molds and rods are painted. To eliminate sticking, it is necessary to use non-stick paint, which is previously applied to the places of the mold that are to be covered with tellurium paint. There is a difficulty in regulating the concentration of tellurium depending on specific technological features, since at a high temperature of pouring and a large number of carbide-forming elements in the chemical composition of cast iron, the content of tellurium in the paint must be reduced, and vice versa, at a low temperature of pouring the metal into the mold and with a small amount of carbide-forming agents, the amount of tellurium in the paint should be increased.

There is also a known method of improving the gas permeability, knock-out, and malleability of molds, according to which chopped polystyrene foam waste is introduced into the mold [3].

The disadvantage of this method is that when drying the molds or when pouring raw molds, the polystyrene bestrides with the formation of a significant number of gases that are released into the atmosphere of the foundry. When more than 25% of polystyrene foam is added to the mixture, the compactibility of the mixture decreases, the surface cleanliness of the molds and rods deteriorates.

The production of gasified models for cast blanks of cutting tools is also known. At the same time, only the element of the model, which forms the cutting part of the cast blank, is made of alloyed polystyrene foam [3].

The disadvantage of this method is the technological complexity of manufacturing a model with different parts due to the need for a container in the mold that cannot be pulled out and separates the volume of the working cavity that forms the alloyed element of the model from the other part of the model made of non-alloyed foamed polystyrene.

There is a well-known method of manufacturing polystyrene models, which includes feeding foamed polystyrene granules into the cavity of the mold simultaneously with alloying or modifying impurities and the final sintering of polystyrene granules together with the impurities [4].

However, in the process of blowing granules and impurities, the amount of rarefaction, which acts on impurities from the side of the polystyrene flow, changes. At the beginning of the blowing operation, the amount of rarefaction is maximum due to the smallest resistance created by the walls of the mold to the flow of air with granules and impurities. Gradually, the volume of the mold fills up, the resistance increases, and the rarefaction gradually decreases. As a result, impurities are placed unevenly in the volume of the mold.

One of the best methods of manufacturing models from polystyrene is the method in which alloying or modifying impurities are applied to granules of foamed polystyrene before sintering them in a mold [5]. The disadvantage of this method is the use of quite expensive binding material.

Therefore, it is quite difficult to predict the movement of metal in polystyrene foam, which can lead to a significant number of shortages of finished products. Therefore, it is advisable to know the basic laws of the behavior of the metal and gas mixture with this method of obtaining blanks.

Presenting main material. The basis is the task of creating a theoretical model that describes the movement of metal and gas transformation of polystyrene in the form of. We will consider the theoretical analysis of the process of filling the mold with a gasified model as the process of filling the mold (Fig. 1) with a closed sprue system [5].

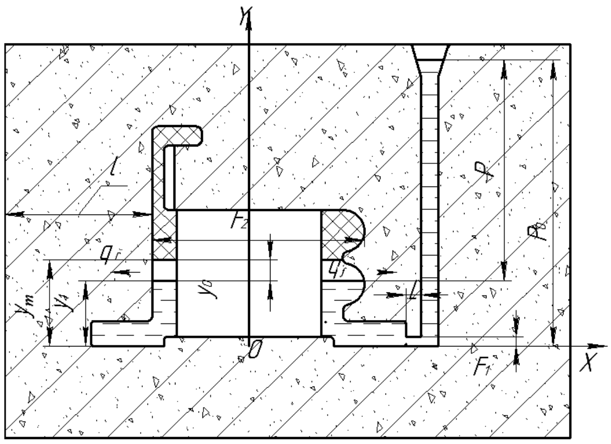

Fig. 1. **Form filling process**

I. To analyze the given task, we will accept the following notations:

τ – time, s; P_o – initial pressure of the metal in the riser, kg/m^2; P_g – pressure of the vapor-gas mixture of decomposition products of the model in the mold cavity, kg/m^2; P_{fr} – pressure losses due to metal friction in the channels of the sprue system, kg/m^2; P_{atm} – atmospheric pressure, kg/m^2; P_{atm} = 1000 kg/m^2; y_o – the gap between the melting front of the model and the metal mirror, m; y_1 – coordinate of the position of the metal level in the form, m; y_m – coordinate of the melting front of the model, m; l – thickness of the mold wall, m; L – feeder length, m; d_{F1} – hydraulic radius of the feeder, m; P – the perimeter of the cross section of the casting in the direction perpendicular to the movement of the metal, m; d_F – hydraulic radius of the mold cavity, m; F_1 – cross-sectional area of the feeder, m^2; F_2 – cross-sectional area of the casting in the direction perpendicular to the movement of the metal, m^2; F_r – riser cross-sectional area, m^2; γ_{met} – specific gravity of liquid metal, N/m^3; ρ_{met} – mass density of liquid metal, N^2/m^4; γ_{mod} – specific weight of the material of the model, N/m^3; γ'' – specific gravity of the steam-gas mixture, N/m^3; m_1 – mass of metal in the sprue system, N^2/m; m_2 – mass of metal in the mold, N^2/m; m_{com} – combined mass of moving material, N^2/m; m_{sp} – mass of metal in to the feeder, N^2/m; G_{sg} – mass of steam-gas mixture in the volume of the mold cavity, kg; T – temperature of the steam-gas mixture in the mold cavity, K; R – gas constant of the steam-gas mixture; v_{met} – speed of metal in the mold cavity, m/s; v_1 – speed of metal in the feeder, m/s; v_{mod} – melting speed of the model, m/s; m_g – specific rate of evaporation and gasification of the liquid phase of the decomposition products of the model, 1/s; K_g – gas permeability of the molding mixture, m^4/N; q_0 – metal consumption through the hole in the sprue bowl, kg/s; q_g – rate of formation of the vapor-gas mixture in the mold cavity, kg/s; q_f – rate of removal of the vapor-gas mixture from the mold cavity, kg/s; λ – metal friction resistance coefficient against the walls of the channels of the sprue of the system; g – acceleration of gravity, m/s^2.

II. Basic conditions and assumptions.

1. P_o – const; at t = 0; Pн = Po.

2. The flow of the vapor-gas mixture from the cavity of the mold is assumed [6] to be unidirectional (along the X coordinate), obeying the law of constant filtration. Then the flow rate of the vapor-gas mixture from the mold cavity through the gap will be:

$$q_{ф} = \frac{1{,}36 y_0 \cdot K_{г} \left(P_0^2 - P_{атм}^2 \right) \cdot \gamma''}{P_{атм} \cdot \lg \dfrac{l}{d_{ф}}}. \tag{1}$$

3. The process of expansion of the steam-gas mixture in the mold cavity is diabatic.

III. We obtain the following ratios: $P_{н} = P_0 - \gamma_{мет} \cdot y_1 - P_{тр} - P_r$ (2)

The rate of formation of a steam-gas mixture in the mold cavity, kg/s:

$$q_r = \frac{v_{мет} F_2 \gamma_{мод} m_{г} \tau}{(1 + m_{г} \tau)}; \tag{3}$$

Pressure losses due to metal friction in the channels of the sprue system, kg/m^2:

$$P_{тр} = \lambda \frac{L}{dF_1} \frac{\rho_{мет}}{2} y_2^2; \tag{4}$$

$$y_2 = \frac{F_{ст.}}{F_2} v_1; \tag{5}$$

Mass of metal in the sprue system, H^2/m:

$$m_1 = F_{ст} \cdot \rho_{мет} \tag{6}$$

The combined mass of moving metal, H^2/m:

$$m_{пр} = m_1 \cdot \left(\frac{F_2}{F_{сп}} \right)^2 + F_2 \rho_{мет} y_1; \tag{7}$$

Coordinate of the melting front of the model, m;

$$y_{пл} = \int_0^t v_{пл} d\tau. \quad (8)$$

IV. Basic equations for the case of a closed spring system: equation of motion of metal:

$$m_{пр} \frac{d^2 y_1}{d\tau^2} = \left(P_0 - \gamma_{мет} y_1 - Pmm - Pг\right) F_2; \quad (9)$$

- equation of gas balance: $dG_{пг} = \left(q_г - q_ф\right) d\tau$; (10)

- equation of adiabat: $P_г \cdot V_г^k = G_{пг} \cdot RT$; (11)

Adiabatic degree index:: $K = \frac{C''_P}{C''_V}$; (12)

Model melting equation:

$$d_{y0} = V_{пл} \cdot d\tau - dy_1 \quad (13)$$

V. Transformation of basic equations.

We introduce additional notations:

$$\dot{y}_1 = y_2; P_г = (y_3 - 1000); \quad (14)$$

where 1000 is atmospheric pressure, kg/m^2.

A system of equations that describe the movement of metal in the form:

$$\dot{y}_0 = \left[\frac{\left(-\frac{\alpha_0 \Delta t}{r\gamma_{мод}(1+N)} \left(1 - \frac{y_0}{\delta_0}\right) + \frac{\lambda_{пг} \Delta t}{r\gamma_{мод}(1+N) y_0} \right)}{\left(1 + \frac{\alpha_0 \Delta t}{r\gamma_{мод}(1+N)} \cdot \frac{\gamma_{мод}}{\gamma' \psi} \cdot \frac{\tau\left(1 - \frac{y_0}{\delta_0}\right)}{(1 + m_r \tau)} \right)} \right] - y_2;$$

$$\dot{y}_2 = \left(P_0 F_2 - \gamma_{мет} F_2 y_1 - \lambda \frac{L}{dF_1} \frac{\rho_{мет}}{2} \frac{F_2^3}{F_1^2} y_2^2 - F_2 P_г; \right) / \left(m_1 \left(\frac{F_2}{F_{cm}} \right)^2 + F_2 \rho_{мет} y_1 \right) \quad (15)$$

$$\dot{y}_3 = RT \left(\frac{\gamma_{мод} m_г \tau (\dot{y}_0 + y_2)}{y_0 (1 + m_г \tau)} - \frac{1{,}36 y_0 K_г \left(P_0^2 - P_{атм}^2\right) \gamma''}{P_{атм} \lg \frac{l}{d_ф}} \right) - \frac{y_3 \dot{y}_0}{y_0}.$$

Solving the derived systems of equations (15) of the form filling process was carried out with the help of the MATHCAD software. The results are presented in Fig. 2.

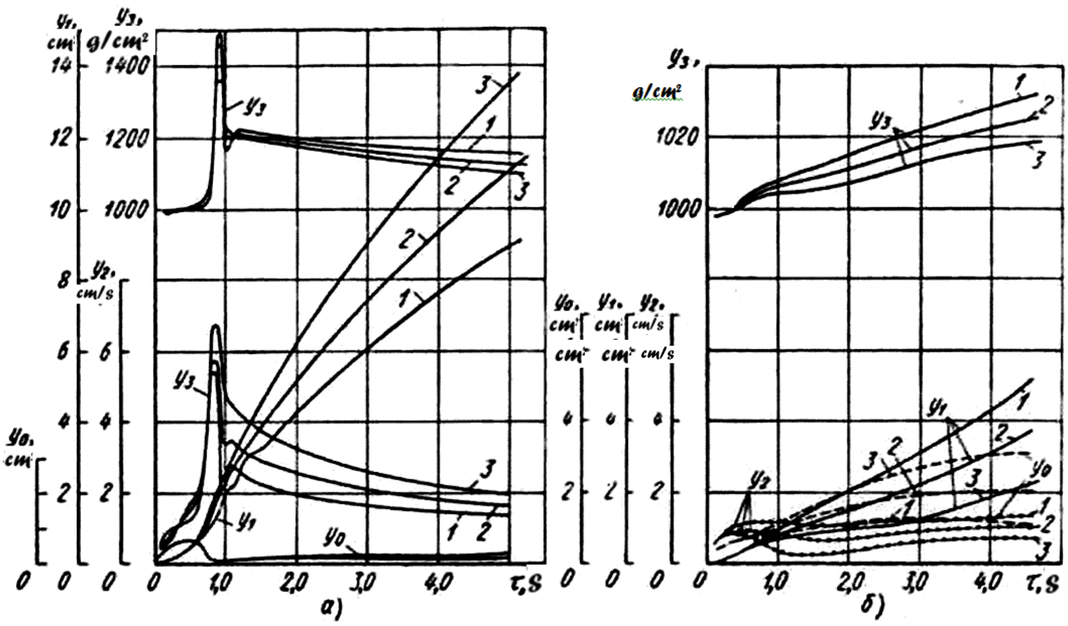

Fig. 2. a) depending on the gas permeability of the form (1-120; 2-240; 3-460 units);
b) depending on the mass rate of pouring (1-740; 2-560; 3-375 g/s)

The analysis of the obtained solutions (Fig. 2, a, b) shows that the movement of the metal has the character of aperiodic oscillations. The speed of the metal in the mold is maximum at the initial moment when the metal enters the mold and decreases as it fills. The pressure of the steam-gas mixture at the initial moment of time exceeds the pressure of the liquid metal in the riser, which indicates the possibility of metal ejection from the bowl. At the same time, the pressure in the mold cavity changes little with an increase in gas permeability of the mold, which is explained by the relatively small gap between the melting front of the model and the metal mirror. However, with an increase in gas permeability due to a decrease in back pressure, the speed of the metal in the mold cavity and the path traveled by it increase.

Conclusions and prospects for the development of the direction

The mathematical model of the process of filling a mold with a gasified model with metal described in this work allows us to draw the following conclusion: when filling a mold with a gasified model through closed spring systems, conditions are created for the occurrence of oscillatory movement of the metal and pressure pulsations in the mold cavity. All this can lead to the ejection of metal from the bowl at the initial moments of filling and a defect in the castings. The occurrence of metal fluctuations in the mold is associated with the transient processes of filling the mold and the spring system. Taking into account these factors, it is possible to design models for casting with a lower percentage of defective products.

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