ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 10
Issue 4/2010

157 – 162

30/4

Effect of pressure in mould on the mould cavity filling in Lost Foam process

T. Pacyniak*, R. Kaczorowski
Department of Materials Engineering and Production Systems, Technical University of Lodz,
Stefanowskiego 1/15, 90-924, Lodz, Poland
*Corresponding author. E-mail address: tadeusz.pacyniak@p.lodz.pl

Received 01.07.2010; accepted in revised form 07.07.2010

Abstract

In this study, the analysis of the influence of the pressure in mould on manufacture process of castings by the Lost Foam method was introduced. In particular, numerical simulation results of effect of pressure in mould on pouring rate, gas gap pressure and gas gap size were analyzed. For simulating investigations of the Lost Foam process introduced mathematical model of the process was used. In this model in detail was described and derived equation relating to the changes of the gas pressure in the gas gap. The mathematical description uses the equation of gas state and the equation of Darcy's rate of filtration. Presented studies indicated, that with decrease of pressure in mould the pouring rate increased and the gas pressure in gas gap and gas gap size decreased. For pressures in mould from the range of 20÷100 kPa, pouring rates achieved values from 30÷3 cm/s respectively.

Keywords: Foundry engineering, Lost foam, Foamed polystyrene patterns

1. Introduction

Lost foam method, where patterns made of high-molecular materials was introduced by H.F. Shroyer. In 1958 he patented the technology, in which foamed polystyrene patterns were placed in classic moulding sand [1]. Solution proposed by T.R. Smith in 1964 [2], in which moulding sand was replaced by dry sand without clay addition caused development of this method.

This technology is characterized by low investment and manufacture costs. This technology does not need cores, parting face, drafts, what results in higher precision of castings. Dry sand application eliminates moisture influence on casting flaws, moreover sand reclamation of moulding sands is cheaper. This technology can be applied for small production, because patterns can be prepared with use of thermal cutting plotters or dies manufactured with use of rapid prototyping techniques [3].

Phenomena connected with mould cavity filling in lost foam process are much more complicated than those in classic foundry techniques such as casting in sand moulds. On pouring rate the main influence has the pressure distribution affecting the surface of liquid metal filling mould cavity. Pressure inside the gas gap related with gasification of the pattern counteracts the metallostatic pressure resulting from metal column in the gating system. This pressure inside the gas gap is related to gas volume arising during thermal degradation of the polystyrene pattern, increasing with the increase of polystyrene density [4],volume of gas flowing through refractory coating – what is connected with coating permeability and its thickness [5, 6, 7]. Gas pressure is also related to gas gap size which is connected with foamed polystyrene gasification kinetics.

Nomenclature

d_2	diameter of pattern, m
K, K_{pok}	permeability of (sand, coating), $m^2/(Pa\cdot s)$
l	sand deposit thickness, m
P_p, P_g, P_k, P_{atm}	pressure (transient, in gas gap, in mould, atmospheric), Pa
q	mass flux, kg/s
R	gas constant, J/(kg·K)
s	coating thickness, m
T	temperature, K
V	volume, m^3
y_1, y_2	position coordinate (molten alloy surface, gasification front of pattern), m
η	absolute viscosity, Pa·s
ρ_1, ρ_2, ρ_3	density (metal, pattern, gases in gap), kg/m^3
τ	time, s
v_1, v_2	pouring rate, gasification rate of pattern, m/s

2. Equation of pressure change in gas gap

To determine changes of gas pressure in the gas gap, the equation of gas state was used:

$$P \cdot V = m \cdot R \cdot T \tag{1}$$

Substituting $V=F_1\cdot(y_2-y_1)$ for the gas gap volume and differentiating the equation of gas state (1) in terms of time, the following formula was obtained:

$$\frac{dP_g}{d\tau}\cdot(y_2-y_1)\cdot F_1 + P_g\frac{d(y_2-y_1)}{d\tau}\cdot F_1 = \frac{dm}{d\tau}\cdot R\cdot T \tag{2}$$

The gas volume present in gap equals the gas volume formed due to the effect of pattern evaporation and gasification minus volume filtrated through the coating and sand bed, which can be written down as:

$$\frac{dm}{d\tau} = v_1\cdot\rho_2\cdot F_2 - q \tag{3}$$

The gas volume filtrated through the coating was determined from J.S. Lejbenzon's relationship concerning flow of liquids and gases through porous media [8, 9]. The coefficient of permeability k was determined from the following equation:

$$k = \frac{2\cdot Q\cdot\eta\cdot l\cdot P_{atm}}{F\cdot\left(P_g{}^2 - P_p{}^2\right)} \tag{4}$$

The volume flow rate can be expressed with the following relationship:

$$Q = \frac{q}{\rho_3} \tag{5}$$

A relationship between the permeability K and the coefficient of permeability k assumes the following form:

$$K = \frac{k}{\eta} \tag{6}$$

For the model adopted, the surface of gas filtration F was expressed by the following equation:

$$F = \pi\cdot d_2\cdot(y_2-y_1) \tag{7}$$

Substituting relationships (5÷7) to equation (4) and transforming them in a proper way, a relationship for mass velocity of the gas filtration was obtained in the form of:

$$q = \frac{\pi\cdot\left(P_p{}^2 - P_k{}^2\right)\cdot K\cdot\rho_3\cdot(d_2+s)\cdot(y_2-y_1)}{2\cdot l\cdot P_{atm}} \tag{8}$$

where:
P_k – pressure in mould, Pa.

For determination of transient pressure P_p at the coating layer/sand interface, the gas filtration through mould was taken into consideration. Changes in gas pressure during the process of filtration are schematically drawn in Figure 1.

The mass velocity of filtration assumes the same value in the layer of refractory coating s as in the layer of dry sand l. The mass velocity of filtration through coating q_{pok} was expressed by the following formula:

$$q_{pok} = \frac{\pi\cdot\left(P_g{}^2 - P_k{}^2\right)\cdot K\cdot\rho_3\cdot d_2\cdot(y_2-y_1)}{2\cdot s\cdot P_{atm}} \tag{9}$$

while the mass velocity of filtration through a sand layer q was expressed by:

$$q = \frac{\pi\cdot\left(P_p{}^2 - P_k{}^2\right)\cdot K\cdot\rho_3\cdot(d_2+s)\cdot(y_2-y_1)}{2\cdot l\cdot P_{atm}} \tag{10}$$

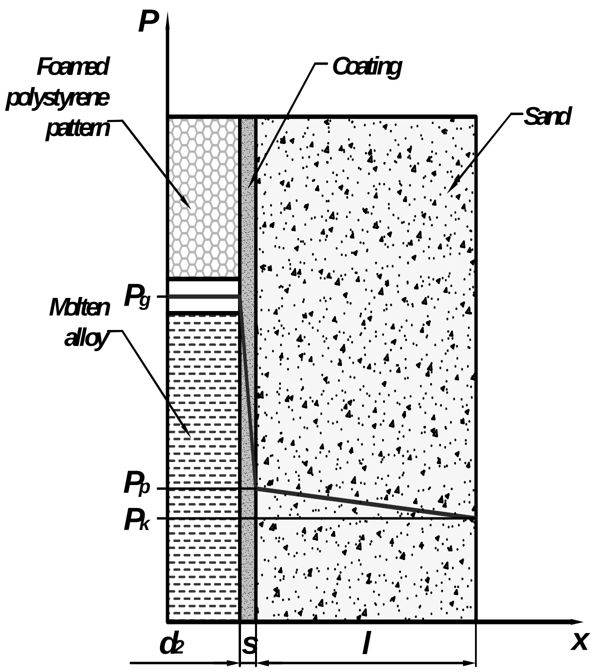

Fig. 1. Schematic representation of pressure changes during gas filtration

Because mass velocities are equal, after comparison and transformation, the following relationship was obtained:

$$P_p{}^2 = \frac{P_g{}^2 \cdot l \cdot K_{pok} \cdot d_2 + P_k{}^2 \cdot s \cdot K \cdot (d_2 + s)}{l \cdot K_{pok} \cdot d_2 + s \cdot K \cdot (d_2 + s)} \tag{11}$$

Substituting to equation (2) relationships (5÷7) and (11) after transformation, an equation describing changes of pressure P_g in the gas gap during filling of mould with molten alloy was obtained:

$$\frac{dP_g}{d\tau} = \frac{v_1 \cdot \rho_2 \cdot F_2 \cdot R \cdot T}{(y_2 - y_1) \cdot F_1} - \frac{P_g}{(y_2 - y_1)} \cdot \frac{d(y_2 - y_1)}{d\tau} + - \frac{\pi \cdot \left(P_p{}^2 - P_k^2\right) \cdot K \cdot \rho_3 \cdot (d_2 + s) \cdot R \cdot T}{2 \cdot F_1 \cdot l \cdot P_{atm}} \tag{12}$$

3. Investigation of an effect of pressure in mould on the mould cavity filling.

Equation (12) simultaneously with equation describing the kinetics of the process of foamed polystyrene pattern evaporation:

$$\frac{dy_2}{d\tau} = \frac{\left\{\left(\alpha_c + \frac{\lambda_g}{(y_2 - y_1) - h}\right) \cdot (T_1 - T_{2.par}) - c \cdot \left[r_p + c_{2.c} \cdot (T_{2.par} - T_{2.top})\right]\right\} \cdot F_{par}}{\left[r_t + c_{2.m} \cdot (T_{2.top} - T_{2.0})\right] \cdot F_2 \cdot \rho_2} \tag{13}$$

and equation describing the dynamics of the process of mould cavity filling with molten alloy:

$$\frac{d\upsilon_1}{d\tau} = \frac{P_{atm} - \frac{1}{2} \cdot \lambda_H \cdot F_1{}^2 \cdot \rho_1 \cdot \upsilon_1{}^2 \left(\frac{L_{wg}}{d_{stwg} \cdot F_{wg}{}^2} + \frac{L_{wd}}{d_{stwd} \cdot F_{wd}{}^2}\right) + \rho_1 \cdot g \cdot (L_{wg} - y_1) - P_g}{F_1 \cdot \rho_1 \cdot \left(\frac{L_{wg}}{F_{wg}} + \frac{L_{wd}}{F_{wd}} + \frac{y_1}{F_1}\right)} \tag{14}$$

forms a system of differential equations enabling analysis among other things the influence of pressure in mould P_k on the mould cavity filling process.

3.1. Simulation of the Lost Foam Process

3.1.1. The scope of simulation tests

The tests concerned the press in mould in a range of P_k=20÷100 kPa analysis. Moreover, in simulation tests, the following parameters were used:

- refractory coating permeability K_{pok}=7,7·10^{-9} m^2/(Pa·s),
- sand permeability K=8,5·10^{-8} m^2/(Pa·s),
- refractory coating thickness s=0,6 mm,
- pattern density ρ_2=20 kg/m^3,
- ingate cross-section F_{wd}=0,5 cm^2,
- diameter of pattern d=30 mm,
- alloy density ρ_1=2700 kg/m^3 and temperature of molten alloy T_1=998 K (in relation to pouring temperature of siluminum AlSi11).

3.1.2. Analysis of simulation tests

Simulation tests were carried out on a model of bottom-poured cylindrical mould showed in Figure 2, and parameters established in the scope of the studies. Basing on the obtained calculations, a relationship was drawn between changes in time of basic quantities characterizing mould cavity filling process and pressure in mould P_k.

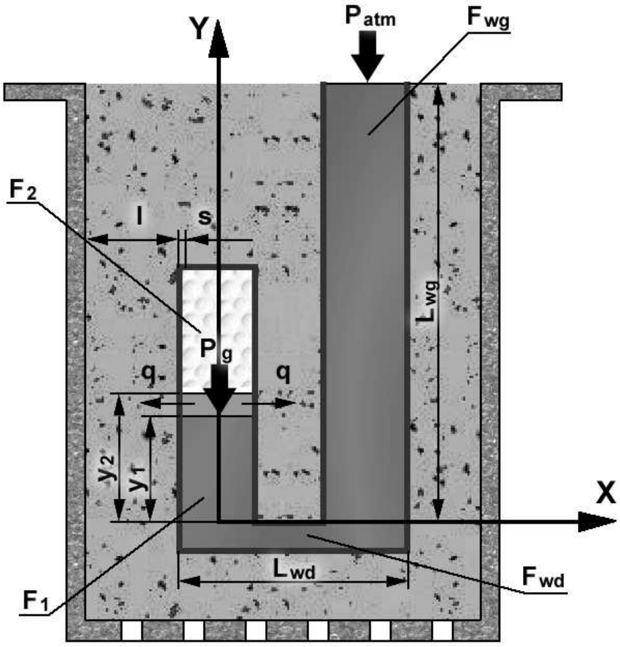

Fig. 2. Model of mould cavity filling

Significant effect on the Lost Foam process has the value of the pressure in the mould P_k during mould cavity filling. The effect of pressure in the mould P_k on pouring rate υ_1 is shown in Figures 3 and 4. From Figure 3 it follows that with decrease of pressure in mould pouring rate strongly increases and for the pressure in the mould P_k = 20 kPa is as high as υ_1=30 cm/s.

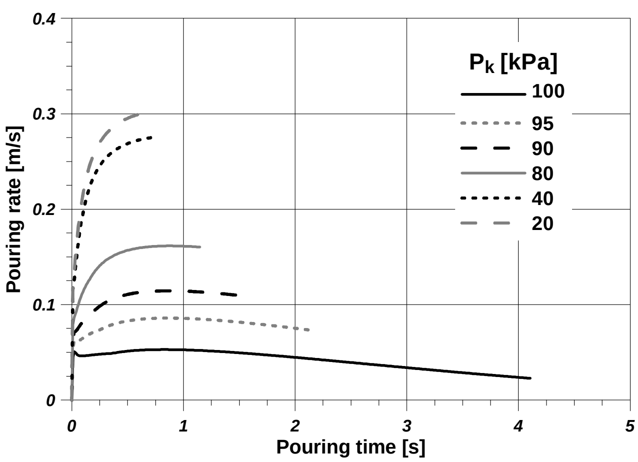

Fig. 3. Changes of pouring rate $\upsilon_1=f(\tau)$ for different values of pressure in mould P_k

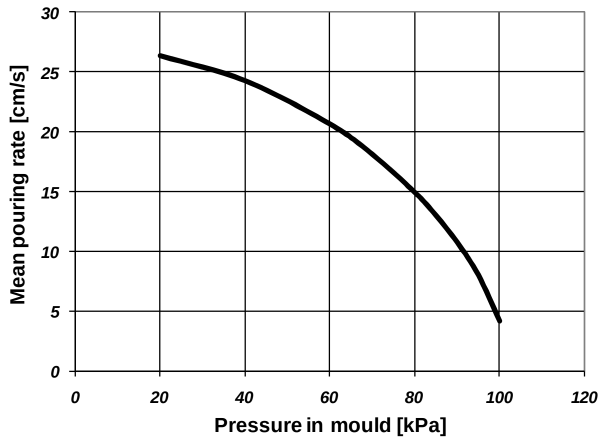

Fig. 4. Relation between mean pouring rate and pressure in mould P_k

The analysis of Figure 4 shows that the pouring rate was in the range of υ_1=5÷10 cm/s, pressure in mould should has P_k=95÷90 kPa.

Effect of pressure in the mould P_k on pressure course in gas gap P_g is shown in Figures 5 and 6. In the initial period of pouring, pressure in the gas gap (for pressure value in mould below P_k=100 kPa) rapidly increases that after reaching the value over P_k=105 kPa decrease depending on the pressure in the form. The curve shown in Figure 6 shows that average pressure in gas gap increases with increasing pressure in mould, what appears to be obvious.

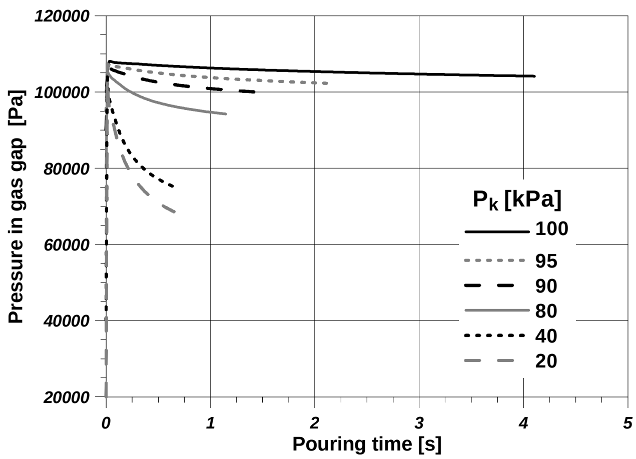

Fig. 5. Changes of pressure in gas gap $P_g=f(\tau)$ for different values of pressure in mould P_k

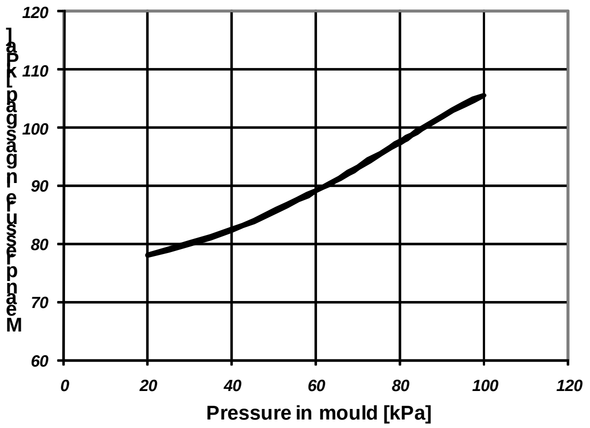

Fig. 6. Relation between mean pressure inside gas gap and pressure in mould P_k

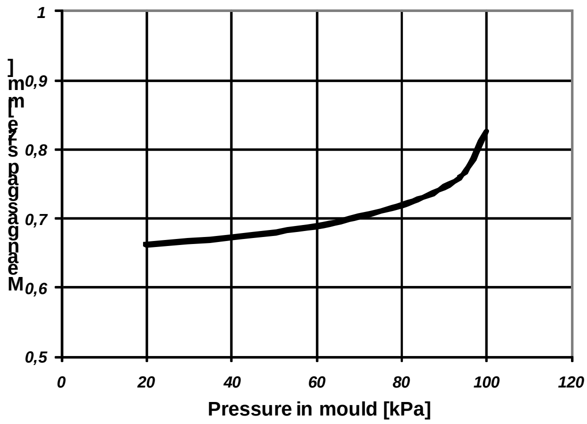

Fig. 8. Relation between mean gas gap size and pressure in mould P_k

Changes in gas gap size in function of mould pressure were shown in figure 7 and 8. The change of gas gap size is more intensive with decreasing pressure in mould and achieve the maximum value of $(y_2 - y_1) - h$ = ~ 1 mm for the pressure P_k = 20÷40 kPa after less than a second. As shown in Figure 8 with increasing pressure in mould increasing the average value of gas gap. The most intensively an average gap value increases for P_k=90÷100 kPa pressure in mould.

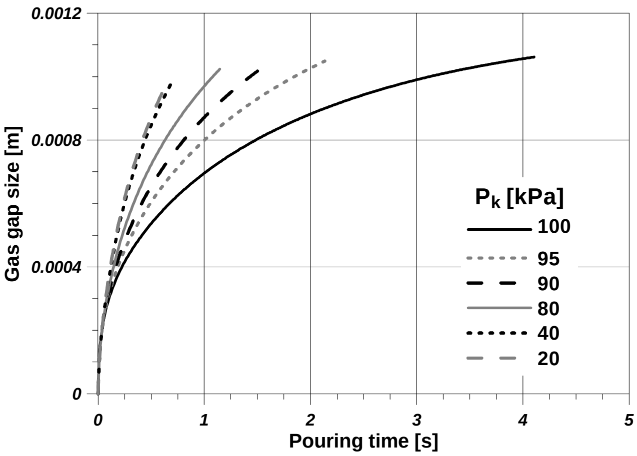

Fig. 7. Changes of gas gap size $(y_2 - y_1) - h = f(\tau)$ for different values of pressure in mould P_k

4. Summary

The simulation studies presented in this article enable determine and analyze of an effect the pressure in mould on basic parameters characterizing mould cavity filling in lost foam process, such as: pouring rate, gas pressure in the gas gap and gas gap size. The studies enable to select the best mould pressure, which should provide correct filling of mould with molten alloy for definite shape and the dimensions of the cast. The investigations showed, that use of already small underpressure in the mould of the order 5÷10 kPa (in the relation to the atmospheric pressure) allow obtain the pouring rate more than 8 cm/s. This value of the pouring rate ensures correct performance of castings even with very intricate shapes and small wall thicknesses. Decrease of mould pressure caused decrease of gas pressure in gas gap, similar as the size of this gap The smaller dimensions of the gas gap and lower pressure of gas in this gap reduce the risk of mould “collapse”.

Acknowledgements

The work was made as a part of the research project No. N N508 443536 financed by funds for science in the years 2009-2011 by the Polish Ministry of Science and Higher Education.

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