# The Influence of Ingate Size on the Lost Foam Casting Process

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## Abstract

The article presents analysis of the influence of ingate size on the Lost Foam casting process. In particular, analysis of simulation tests has been carried out to determine the ingate size influence on the rate of filling of the mould cavity, pressure in the gas gap and size of the gas gap. A specially prepared mathematical model of the process and an original calculation algorithm were used in simulation tests of full-mould casting. The tests have indicated that the increase of the ingate size results in the increase of filling rate and increase of pressure of gases in the gas gap. However, significant influence on mould cavity filling occurs only when the ingate size is less than ~1 cm$^2$.

## 1. Introduction

Lost Foam casting is a foundry technology that is gaining popularity all over the world. It is related with a number of advantages of the process, such as reduction of production costs, possibility of production of inner cast surfaces without use of cores, lack of division surfaces, etc. In Lost Foam casting mainly EPS patterns are used, that are sand moulded without a binder. A mould prepared this way is filled with molten alloy, which gasifies the EPS pattern as a result of contact and replaces it, assuming the shape of the model.

The quality of castings produced with use of this technology is determined by numerous factors, such as:

- EPS density, which determines pattern strength and quality of its surface, (the influence of expanding and sintering on the quality of the EPS model has been described in article [1], whereas the influence of the density of the pattern on mould cavity filling - in article [2]),
- type of sand, in particular its permeability,

- refractory coating of the pattern, which is a working surface of the mould, that guarantees proper casting surface quality and prevents metal penetration into sand. Coat thickness [3] and its permeability [4, 5] have the largest influence on the process of casting,
- type of alloy and casting temperature which determines the amount of liquid and gaseous products of polystyrene decomposition [6, 7],
- gating system structure.

This part of the article presents the influence of the ingate size on the Lost Foam casting process.

## 2. Technological aspects of the ingate size

Metal is delivered to the mould cavity through a gating system, purpose of which is to remove slag and non-metallic inclusions from molten alloy, guarantee undisturbed mould filling and have an effect on the course of metal solidification [8].

The rate of pouring is usually determined by the minimum size of the gating system, that is the ingate size. In the Lost Foam casting process, due to its specific character, when alloy is poured, part of metal thermal energy is transferred for gasification of the EPS pattern. It leads to lowering of metal temperature, which is followed by the increase of its viscosity and difficulties in production of castings with complex shapes. This may be prevented by means of increasing the temperature of the molten alloy, however it may result in deterioration of the casting microstructure. Therefore the aim is to reduce casting time, that is increase the rate of filling the mould cavity with the metal. The rate of casting may be adjusted by changing the ingate size.

# 3. Analysis of the ingate size influence on mould cavity filling with molten alloy

## 3.1. System of equations of the process of mould filling with molten alloy

The considerations included in article [9], concerning kinetics of the process of gasification of the expanded pattern, dynamics of mould cavity filling with molten alloy and variation of pressure of gas gap gases have allowed to describe the process of pattern gasification and mould cavity filling with molten alloy with a system of differential equations presented below:

period I

$$
\frac{dy_2}{d\tau} = \frac{\left(\alpha_c + \frac{\lambda_g}{(y_2 - y_1) - h}\right) \cdot (T_1 - T_{2.par}) \cdot F_{K1} + \left(\alpha_m + \frac{\lambda_g}{y_2 - y_1}\right) \cdot (T_1 - T_{2.top}) \cdot (F_2 - F_{K2})}{\left[r_t + c_{2.m} \cdot (T_{2.top} - T_{2.0})\right] \cdot F_2 \cdot \rho_2} +
$$
$$
- \frac{c \cdot F_{par} \left[r_p + c_{2.c} \cdot (T_{2.par} - T_{2.top})\right]}{\left[r_1 + c_{2.m} \cdot (T_{2.top} - T_{2.0})\right] \cdot F_2 \cdot \rho_2}
$$

(1)

period II

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

(2)

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

(3)

$$
\frac{dy_1}{d\tau} = \upsilon_1
$$

(4)

$$
\frac{dP_g}{d\tau} = \frac{c \cdot F_{par} \cdot R \cdot T}{(y_2 - y_1) \cdot F_1} - \frac{1,57 \cdot (P_p^2 - P_k^2) \cdot K \cdot \rho_3 \cdot (d_2 + s) \cdot R \cdot T}{F_1 \cdot l \cdot P_{atm}} +
$$
$$
- \frac{P_g}{(y_2 - y_1)} \cdot \frac{d(y_2 - y_1)}{d\tau}
$$

(5)

where:

$$
P_p^2 = \frac{P_g^2 \cdot l \cdot K_p \cdot d_2 + P_k^2 \cdot s \cdot K \cdot (d_2 + s)}{l \cdot K_p \cdot d_2 + s \cdot K \cdot (d_2 + s)}
$$

$y_1$ - molten metal surface position coordinate,

$y_2$ - model melting front position coordinate.

Simulation tests of the lost foam casting process, and in particular the influence of the ingate size on mould filling with molten metal, have been carried out with use of the presented mathematical model of the process and an originally designed calculation algorithm that enabled analysis of the influence of the ingate size on the rate of metal level rise in the mould, pressure of gasses in the gas gap, size of the gas gap, etc.

## 3.2. Simulation tests of the Lost Foam process

### 3.2.1. Scope of the simulations

The tests encompassed the analysis of the ingate size in the following range: $F_{WD}=0.2\div4$ $cm^2$. Additionally, the following values have been taken:

- model density: $\rho_2=20$ $kg/m^3$,
- refractory coating permeability: $K_p=7.7\cdot10^{-9}$ $m^2/Pa\cdot s$,
- coating thickness: $s=0.6$ $mm$,
- sand permeability: $K=8.5\cdot10^{-6}$ $m^2/Pa\cdot s$,
- pressure inside the mould: $P_k = P_{atm}=100$ $kPa$,
- pouring gate size: $F_{WG}=7$ $cm^2$,
- pouring gate height: $L_{WG}=34$ $cm$,

and thermophysical properties of polystyrene:

- heat of decomposition: $r_p = r_t=912$ $kJ/kg$,
- evaporation intensity: $c=0.5$ $kg/(s\cdot m^2)$,
- steam and gas mixture conductivity coefficient: $\lambda_g=0.156$ $W/(m\cdot K)$.

The simulation tests of the influence of ingate size on the process of filling of the mould cavity have been carried out for silumins with density of $\rho_1=2700$ $kg/m^3$ and pouring temperature of $T_1=998$ $K$.

### 3.2.2. Analysis of simulation tests

The simulations have been carried out for a model mould presented in Figure 1 and with the parameters specified in the scope of testing. On the basis of the obtained results of the calculations, dependences of time variation of basic values specific for the process of mould filling with molten alloy have been determined.
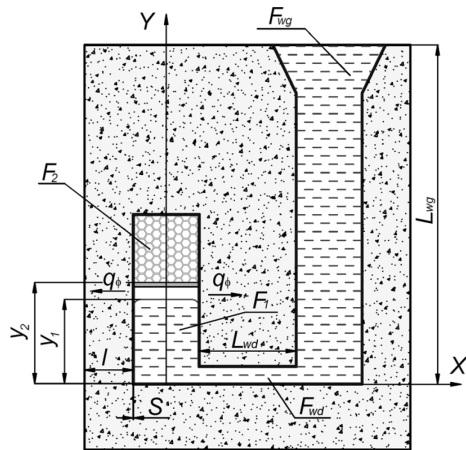
Fig. 1. A schematic representation of mould cavity filling

The size of the ingate has a significant role in the process of casting. The effect of ingate size on pouring rate is presented in Fig. 2 and 3.

The range of ingate sizes has been determined on the basis of the values specified in the standard according to which standardised ingate sizes should fall within the range of $0.2 \div 4$ $cm^2$. According to Figure 2, in case of the experimental casting, increasing the ingate size to more than $F_{WD}=1$ $cm^2$ has a very insignificant influence on the rate of filling the cavity with molten alloy and its pattern of variation, which means that an optimum ingate size exists in case of the given casting.
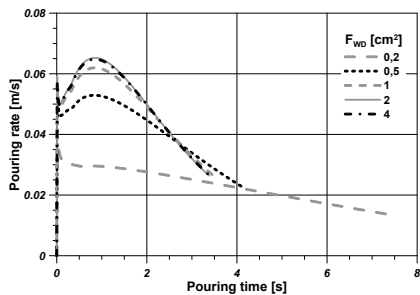


Fig. 2. Variation in pouring rate $v_1=f(\tau)$ for different ingate sizes $F_{WD}$

It confirms the dependence of the average pouring rate and the ingate size, presented in Fig. 3. It indicates that when the ingate size is larger than $F_{WD}=1$ $cm^2$, the average pouring rate practically remains unchanged.
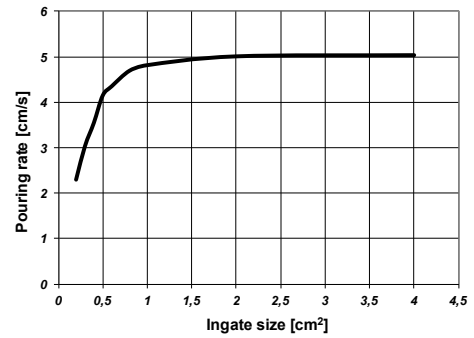


Fig. 3. Dependence of the average pouring rate and the ingate size $F_{WD}$

The influence of the ingate size on the value of pressure in the gas gap is presented in Figures 4 and 5. While analysing the variation of pressure in the gas gap depending on the ingate size, presented in Figure 4, it is noticeable that in case of ingate size of $F_{WD}=0.2$ $cm^2$, pressure in the gas gap is much lower than in case of ingates of larger sizes, which is the result of much lower filling rate for this particular size. It can be concluded from Figure 5 that increasing the ingate size to more than $F_{WD}=1$ $cm^2$ does not result in the increase of the average pressure in the gas gap. It means that further increase of the ingate size is pointless in case of the given casting and pouring gate parameters.
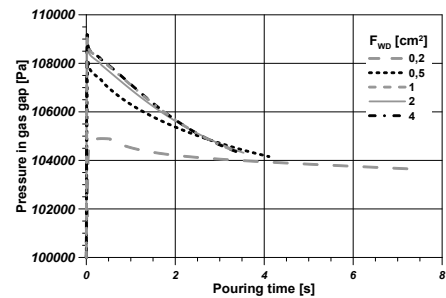


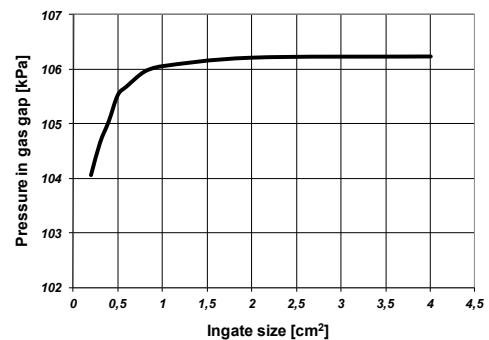Fig. 4. Variation of pressure in the gas gap $P_g=f(\tau)$ for various ingate sizes $F_{WD}$



Fig. 5. Dependence of the average pressure in the gas gap and the ingate size $F_{WD}$

The influence of the ingate size on the size of the gas gap is presented in Figures 6 and 7.

Variation of gas gap size during the pouring process, presented in Figure 6 is practically similar for ingate sizes within the range of $F_{WD}=0.5\div4\ cm^2$. Such gas gap variation is different for the ingate size of $F_{WD}=0.2\ cm^2$. However, in case of all ingate sizes, maximum gas gap size occurs at the end of the pouring process and reaches approximately $(y_2-y_2)-h=\sim1\ mm$. It can be noticed in Figure 7 that the average size of the gas gap practically remains unchanged within the entire range of ingate size.
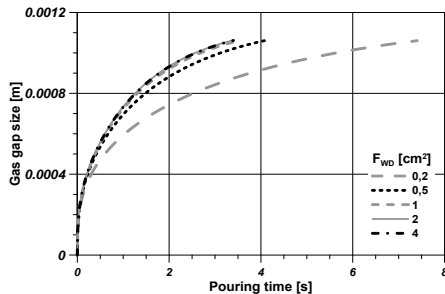


Fig. 6. Variation of gas gap size $(y_2- y_1)-h=f(\tau)$ for various ingate sizes $F_{WD}$
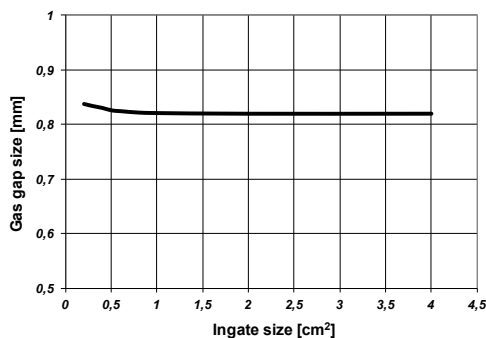


Fig. 7. Dependence of the average gas gap size and the ingate size $F_{WD}$

## 4.   Summary

The presented simulation tests facilitate the analysis of the ingate size influence on the rate of filling of the mould cavity, pressure in the gas gap and size of the gas gap. These tests are helpful in terms of determination of an appropriate *ingate size* that will guarantee sufficiently quick filling of the mould with molten alloy, so that metal does not set during gasification of the EPS model and fills the mould cavity completely. In case of the analysed experimental casting, decreasing the ingate size to less than $F_{WD}=1\ cm^2$ results in significant reduction of filling rate and also lowering of the pressure of gases in the gas gap. Above this value the influence is insignificant, which means that appropriate ingate size can be determined on the basis of the simulation tests carried out with use of the original mathematical model of the process and a specially designed calculation algorithm.

## Acknowledgements

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