Investigation of Ductile Casting Iron Risers in the Simulation Method

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On one hand, risers are one of the most important means to avoid shrinkage defects in castings; on the other hand, they increase greatly metal consumption for castings. Due to weight of a casting, weight of a riser can make about 50 – 100 % of weight of the casting. However, volume shrinkage of metal and the size of a riser can be influenced, as well, by technological casting factors. Influence of technological casting factors to shrinkage of castings was investigated in the method of digital simulation, using an original computer program. Research results show that the mould pouring time, metal temperature, thermo-physical characteristics of a casting mould, and relevant wall thickness of a casting have a significant effect on the volume shrinkage of ductile iron castings and on the dimensions of risers. These results will help to predict volume shrinkage of ductile iron castings more precisely and to decrease metal consumption for a casting.

Keywords: ductile iron, riser, simulation, crystallization.

1. INTRODUCTION

Most castings of different alloys need risers. It depends on shrinkage of an alloy during casting and on the casting conditions. Risers are not necessary in some cases, i.e. when castings are thin-walled or they do not have thermal centres. Risers are not necessary sometimes due to specific alloy properties. Alloys, which have a big crystallization interval and bad castability in the liquid state, form shrinkage cavities in the porous state, and do not form shrinkage cavities [1]. Other alloys have big gas solubility in the liquid state. Gas solubility increases especially with the rise of liquid metal temperature. During crystallization of such alloys, gas separates from them and forms microporosity, which greatly decreases or even eliminates a concentrated shrinkage cavity [2]. Grey cast iron does not need risers in most cases, too. Crystallization of cast iron plays a major role because graphite separates during crystallization in iron castings. Graphite inclusions decrease density of cast iron, therefore, a shrinkage cavity almost does not appear [3].

Castings of alloys, which form a concentrated shrinkage cavity during freezing, need risers. Under some technological casting conditions, the same alloy can form a shrinkage cavity of different sizes. The formation of a shrinkage cavity is complicated, and it depends on many factors. The size of a shrinkage cavity during crystallization of a casting determines the dimensions of a casting riser: dimensions and volume [4].

The main technological factor, which determines the size of a shrinkage cavity in a casting, is the temperature of metal poured into a mould. Volume shrinkage rate of alloys in a liquid state is some ten times greater than for crystallized alloys [5], therefore, when temperature of liquid metal is changed in a relatively small range, volume shrinkage becomes very different.

A very important factor, which determines the size of a shrinkage cavity in a casting, is heat exchange between a casting and a casting mould during mould pouring. During mould pouring, metal shrinks partly, and the lacking quantity is taken from the gating system. A lot of technological casting factors have their role in this heat exchange. Usually, shrinkage of an alloy during mould pouring depends on the time of mould pouring and on heat exchange between metal and a casting mould.

Mould pouring time changes when cross-section of feeders or hydrostatic pressure of metal are decreased or increased. The rate of heat exchange depends on thermo-physical properties of metal and a casting mould, as well as on relevant wall thickness of a casting.

The aim of this study was to determine the effect of technological casting factors on the volume shrinkage of ductile iron castings and to apply the obtained results for risers calculations.

2. RESEARCH METHOD

On the basis of the mathematical model for cooling of liquid metal during mould pouring [6], a digital calculation program was created. Cooling of a casting is simulated with this program, considering all ways of heat exchange: conductivity, radiation, and convection. The program is based on the method of definite differences.

Simulation was applied for ductile iron castings. Simulation of cooling and shrinkage of a casting was performed under the following initial technological casting parameters and cooling conditions of a casting: metal pouring temperature was 1300 °C, metal freezing temperature was 1147 °C, temperature of environment was 20 °C, metal heat conductivity was 16.7 V/(m·K), metal temperature conductivity was $2.7 \cdot 10^{-6}$ m^2/s, a ratio of metal kinetic viscosity was 0.48 m^2/s, a heat accumulation ratio of a casting mould was 1377 W·s$^{0.5}$/(m^3·K).

The program calculates parameters of a gating system, cross-section areas of feeders and pouring time for each element of a casting. It is then calculated how metal gives heat away during mould pouring: by conductivity in x and y directions to walls of a casting mould and by radiation in z direction. While flowing from one mould element to the other, metal mixes, and its temperature becomes the same. The previous mould cavity element becomes as a feeder

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for the next cavity, and its temperature field remains constant because it has a constant metal flow through it. After mould pouring, heat exchange is then calculated by conductivity in all directions – *x*, *y* and *z*. The initial condition for further calculation of heat exchange is $T_1(x, y, z, 0) = \varphi(x, y, z)$, i.e. the gradient field that appeared during mould pouring.

A casting of 85 kg was used for simulation, and it consisted of three parts with different cross-section (Fig. 1 – 3). Dimensions of these parts: 0.05 × 0.2 × 0.15 m, 0.2 × 0.2 × 0.1 m, 0.25 × 0.25 × 0.1 m. Such casting would have a shrinkage cavity in its biggest part. In order to avoid shrinkage defects, a riser is built on the biggest part of a casting (Fig. 1, 4). Dimensions of the riser are chosen free at the beginning of simulation, and later on, they are increased or decreased, basing on obtained shrinkage results. After simulation, dimensions of the riser were chosen: ∅0.15 × 0.15 m.

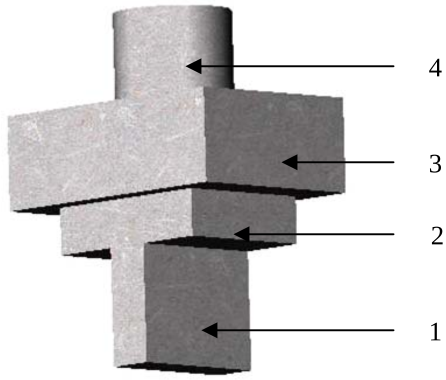

Fig. 1. The investigated casting: 1, 2, 3 – different elements of the casting; 4 – a riser

After optimal dimensions of a casting riser were found, height of a down gate was determined, and cross-section of a feeder, mould pouring time and the size of a shrinkage cavity were calculated. The calculated mould pouring time and the size of a shrinkage cavity were taken as base (nominal) values for calculation of their relative change.

Relative change of a shrinkage cavity and time was calculated as follows:

$$\Delta V_{s.c.} = \frac{V_{s.c.b.} - V_{s.c}}{V_{s.c.b.}} \cdot 100\% \ , \quad (1)$$

where $\Delta V_{s.c.}$ is the relative change of a shrinkage cavity in a casting, %; $V_{s.c.b.}$ is the base size of a shrinkage cavity, m^3; $V_{s.c.}$ is the size of a shrinkage cavity determined by change of technological casting parameters.

$$\Delta t_{m.p.} = \frac{t_{m.p.b.} - t_{m.p.}}{t_{m.p.b.}} \cdot 100\% \ , \quad (2)$$

where $\Delta t_{m.p.}$ is the relative change of mould pouring time, %; $t_{m.p.b.}$ is the base mould pouring time, s; $t_{m.p.}$ is the mould pouring time determined by change of technological casting parameters.

3. EXPERIMENTAL

Height of a down gate was chosen 0.8 m. Following values were calculated: cross-section of an ingate was 0.0000484 m^2, mould pouring time was 23.5 s, the size of a shrinkage cavity in a casting was 0.00177 m^3.

Mould pouring time was changed by means of two technological parameters: cross-section area of an ingate and height of a down gate.

In order to get different rates of heat exchange between a casting mould and metal, a heat accumulation ratio of a casting mould was changed. This ratio depends on materials of a moulding mixture, and can vary greatly (Table 1). In order to find relative change of volume shrinkage, a base value of volume shrinkage was determined by simulation with a heat accumulation ratio of dry high-silica sand.

Table 1. Heat accumulation ratio of some moulding mixtures [7]

A moulding mixture	A heat accumulation ratio, $W \cdot s^{0.5}/(m^2 \cdot K)$
Dry high-silica sand	620
Sand and clay mixture with 20 % asbestos	938
Core mixture with 19 % wood shaves	1377
Quick-hardening mixture with 9 % hardener	1520
Dry sand and clay mixture with 10 % clay	1600
Dry core mixture with 40 % cast iron shaves	1720
Core mixture with 19 % wood shaves	1820
Wet high-silica sand	1970
Chromium magnezite and 6 % liquid glass mixture	3700

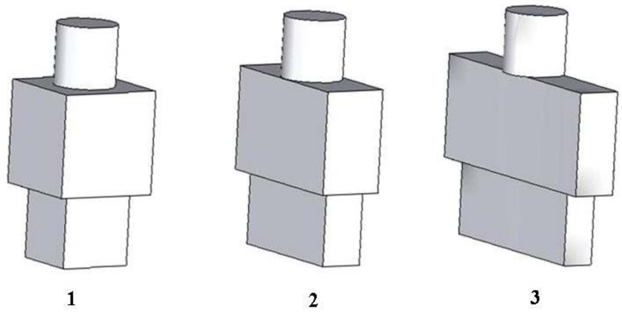

Fig. 2. The castings of the same weight (85 kg) with different relevant wall thickness: 1 – 0.02655 m; 2 – 0.0325 m; 3 – 0.03579 m

In order to find influence of relevant wall thickness to volume shrinkage of a casting, the castings with the same weight, height and gating system were investigated (Fig. 2). Every casting had three elements. Length and width of these elements were changed, and height remained the same. In that way, relevant wall thickness of the casting was changed, and other parameters remained constant.

4. RESULTS AND DISCUSSION

On the basis of simulation results, a correlation between relative change of a shrinkage cavity in a casting and mould pouring time was made (Fig. 3). The diagram shows that the size of a shrinkage cavity decreases when mould pouring time is increasing. This correlation is exponential, and has decreasing nature. The reason is that temperature gradient between a mould and metal is the biggest at the initial stage of mould pouring, and shrinkage of metal is the most rapid. When mould pouring time increases, this gradient is decreasing at the final stage of mould pouring, therefore, shrinkage of metal becomes less rapid.

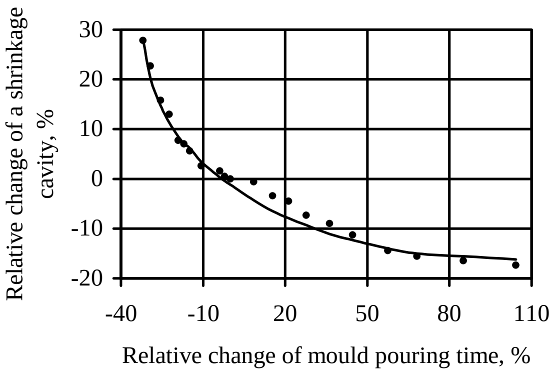

Fig. 3. Relative change of a shrinkage cavity when mould pouring time is changing

When a heat accumulation ratio increases, a shrinkage cavity in a casting decreases significantly (Fig. 4). A big heat accumulation ratio of a mould shows that a big gradient between metal and a casting mould remains for a rather long time, consequently, heat exchange is very rapid. Therefore, metal cools more and shrinks more than under slower heat exchange. When an accumulation ratio of a casting mould is increased for 6 times, volume of a shrinkage cavity in a casting decreased for about 60 %.

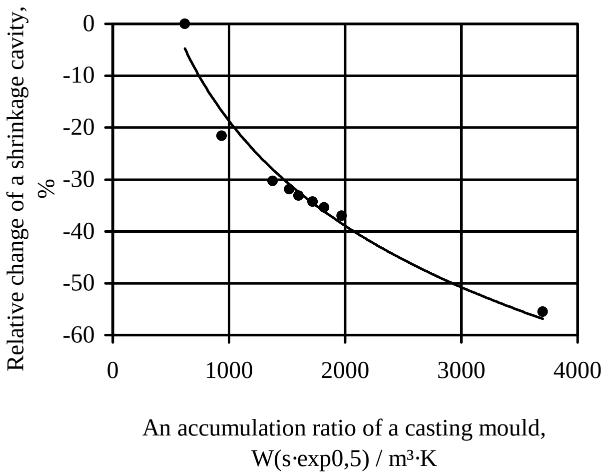

Fig. 4. Decrease of a shrinkage cavity in a riser when an accumulation ratio of a casting mould is changed

Fig. 5 shows that relative change of a shrinkage cavity has a linear correlation when metal pouring temperature is increased. It shows that volume of a shrinkage cavity increases for 1.75 % when metal pouring temperature is increased for one degree.

Heat exchange rate depends not only on the thermophysical characteristics of a casting mould but also on relevant wall thickness of a casting. Relevant wall thickness of our simulated casting was 0.0849 m. Relevant wall thickness of a cube-shaped casting with the same volume was 0.038 m. When all other conditions are the same, simulation results of these castings show that the cube-shaped casting shrinks twice as much, and a riser with the same dimensions is not suitable for that casting at all (Fig. 6).

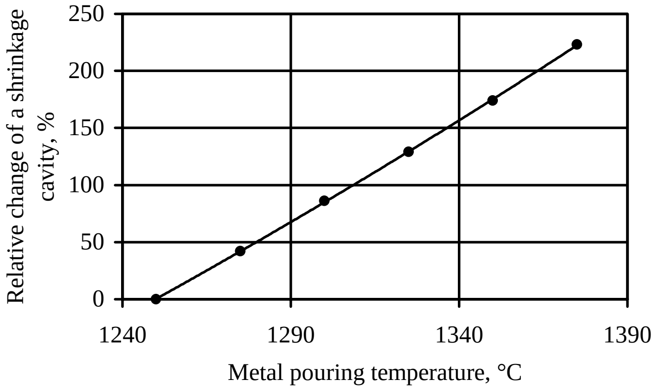

Fig. 5. Increase of a shrinkage cavity in a riser when metal pouring temperature is increased

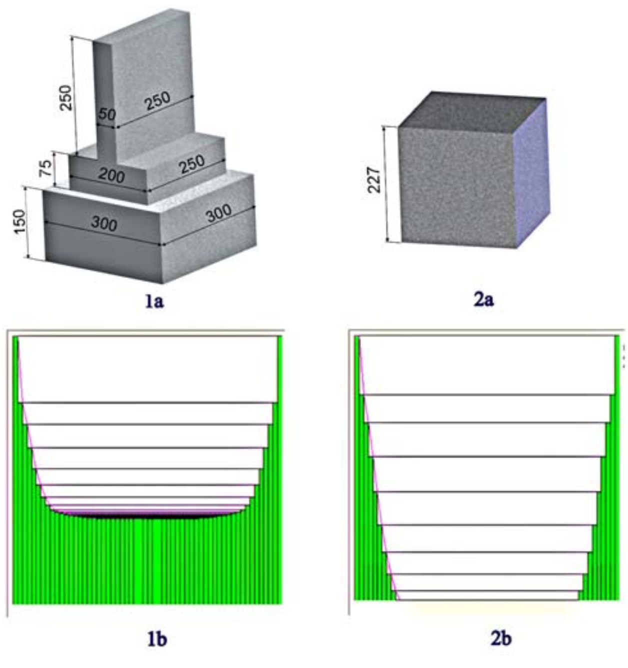

Fig. 6. Research results (1b, 2b) for simulated shrinkage of castings with the same weight but different shape (1a, 2a), when dimensions of a riser are ∅ 150 × 150 mm

Relevant wall thickness is a relative value, and it shows the size of a casting surface for heat exchange. When this value is increased, heat exchange rate increases, too, and during mould pouring, metal cools more quickly, creating smaller volume of a shrinkage cavity in a casting.

It was found that volume shrinkage of a casting increased from 14.1 % up to 16.1 % (Fig. 7) when relevant wall thickness was increased from 0.0265 m to 0.036 m (Fig. 2). However, volume of a riser increased relatively for 13 %, due to such change of relevant wall thickness.

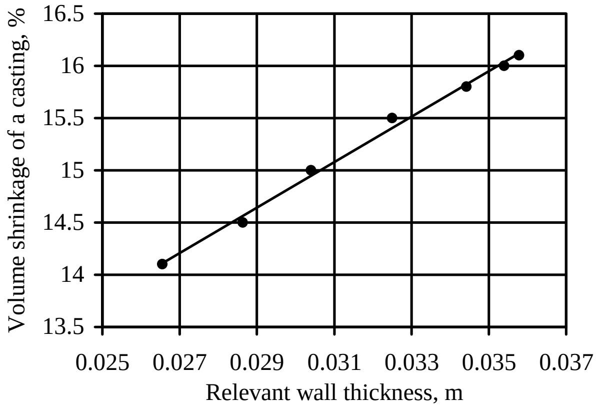

Fig. 7. A correlation between volume shrinkage of a casting and relevant wall thickness

5. CONCLUSIONS

1. Mould pouring time has a big influence to volume of a shrinkage cavity in a casting and to the size of a riser for a casting. It was found that a shrinkage cavity increased for 27 % when pouring time was decreased for 32 %. Increase of mould pouring time has influence to volume of a shrinkage cavity in a casting, too. It was found that a shrinkage cavity decreased for 17 % when pouring time was increased twice, however, this correlation has decreasing nature.
2. Thermophysical characteristics of a casting mould have a big influence to heat exchange rate and shrinkage of an alloy during mould pouring. When a heat accumulation ratio of a casting mould is increased for 6 times, a shrinkage cavity decreases for 60 %.
3. Metal pouring temperature has the biggest influence to volume shrinkage of a casting. It is found that a shrinkage cavity and, consequently, volume of a riser increase for 1.75 % when metal pouring temperature is increased for one degree Celsius.
4. Relevant wall thickness of a casting is a very important casting parameter. It is found that in some cases, when volume of a casting is the same but relevant wall thickness is different, volume of a riser can change for 100 %.

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