CRITICAL RUNNER LENGTH AS A CONSTRAINING FACTOR IN GATING SYSTEM DESIGN

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The objective of gating system design and construction process using high pressure die casting is manufacturing of castings with good mechanical and quality properties. The design must take into account various parameters, ranging from the alloy properties through technical parameters of the casting cycle to the construction of the machine and the mould dimensions. If the design of gating system is meant for an existing mould, the runner length depends on the dimensions of the mould. If the design of gating system intends to use a new mould, the runner length depends on the alloy properties, mainly on the melt solidification time when passing the gating system. The article presented deals with the maximum allowed runner length and introduce and defines the term "critical runner length". When designing gating system for a new type of casting, measures were taken using a simulation program, in order to identify the critical runner length, on which the design of mould multiplicity and placement of casting in the mould depend. The critical runner length is defined on the basis of the maximum melt temperature at selected parts of the gating system and the proportion of solid phase in the melt. Based on the measures taken, the temperatures of the melt are described in dependence on time, heat losses are determined in dependence on the runner length and subsequently the maximum allowed runner length is determined. The measurements, the results and conclusions described in the article are further directly implemented in the innovations of die casting in the production.

KEYWORDS

high pressure die casting, runner, construction, solidification, simulation

1 INTRODUCTION

In high pressure die casting, when achieving appropriate mechanical and quality properties, emphasis is put on the conciliation of technical parameters of die casting with construction of a gating system. The main problem lies in placing the melt from the filling chamber to the mould cavity in the shortest time possible and under such conditions as to achieve the melt flow in the gating system similar to laminar flow. The melt flow is influenced by the casting qualitative properties. Fast filling is required by the reason of filling the mould cavity with the melt with the temperature excessing the temperature of the liquidus. In order to achieve the appropriate filling of the mould cavity, in practice the melt is overheated to the temperature which is 50 – 150 °C higher than the temperature of its liquidus. [Murgaš 2002] As the solidification process starts in the moment of taking the melt out of the melting furnace, the length of the metal flow from the filling chamber to the mould cavity should be as short as possible. However, die casting with the emphasis on the maximum use of production capacity uses also multiple moulds; it depends on engineers and on what type they decide for. If more mould cavities are connected to one runner, it is necessary to determine the maximum allowed length of the runner. This depends on the degree of the melt overheating, solidification range and thermal conductivity of the mould material.[Gašpár 2017] [Ružbarský 2014]

2 CRITICAL RUNNER LENGTH

The solidification process starts when the metal flow passes through the individual parts of the gating system. To fill in the mould cavity only with liquid melt is not technically possible. When designing gating system this fact is taken into account and a coefficient of percentage of metal solidification during the filling time S [%] is involved in the calculation. The coefficient is determined based on the casting wall thickness. For aluminium alloys, the allowed percentage of solid components in dependence on the required surface quality is up to 50 %. This parameter is used for the calculation of mould cavity filling time, from which subsequently the dimensions of the gate and runner cross section area are inferred. However, the runner length is not determined. By extending the length of runners, the time of melt flow passing through the runner increases. It is therefore important to identify the maximum allowed runner length in order to determine the possibilities when designing the gate system.[Majerník 2017][Gašpár 2016] For this reason, the term "critical runner length l_{crit}" is introduced.

The critical runner length is defined as such a runner length for which the melt temperature decreases to a value close to the solidus temperature, and therefore the allowed proportion of solidification S is exceeded and the fluidity of the melt is decreased, which influences the appropriate and effective filling of the mould cavity. [Majerník 2014]

To identify the critical runner length it is convenient to use simulation programmes. The critical runner length is evaluated based on two different factors: temperature and the proportion of solidus in the melt.

3 CAST CHARACTERISTICS AND DETERMINING MEASUREMENT POINTS OF THE VALUES OBSERVED

The critical length of the casting was verified when designing gating system for a specific type of cast of thrust face of the gear pump (see Fig. 1). The casting was designed for the alloy EN AC 47 100 – AlSi12Cu(Fe).

Figure 1. Thrust face of the gear pump

Based on the technical drawings, a 3D model of cast was created which was used to identify the basic values necessary for the calculation and design of volume and dimensional characteristics of the gating system. To ensure a sufficient range of different runner lengths, a model of octuple mould with centric arrangement was created to serve as a test gating system (see Fig. 2). Fig. 2 shows the measuring points in the runners.

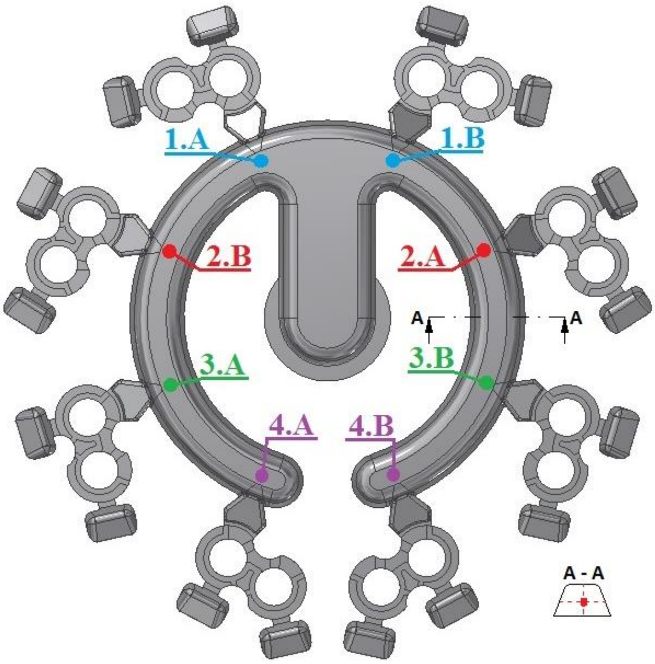

Figure 2. Measuring points in the gate system

The measurements were taken in the centre of the runners (Fig. 2, A-A sections), at the median diameter. The measuring points are placed opposite the gates. This was determined in order to identify the state of the alloy before filling in the mould cavity. The length of the runner or the mean length of the metal flow lS to the measuring point are given in Tab. 1.

Measuring point	Mean length of metal flow l_S [mm]			
	l_{S1}	l_{S2}	l_{S3}	l_{S4}
1.A / 1.B	139.25	----	----	----
2.A / 2.B	----	217.75	----	----
3.A / 3.B	----	----	296.25	----
4.A / 4.B	----	----	----	374.75

Table 1. Mean length of metal flow in runners

Casting simulation was performed using NovaFlow&Solid software. The values observed were the melt temperature and the proportion of solid phase at the measuring points. As two measuring points are assigned to one mean length of the metal flow, the values measured were averaged. On the basis of the values measured, time courses of the observed parameters were described.

4 EVALUATING TEMPERATURE CHANGES

Evaluation of the temperatures at selected measuring points is the first step in determining the critical runner length. Determining the maximum and minimum melt temperature at the measuring points helps to predict the melt behaviour when filling in the mould cavity. Overheating of the melt which was filled into the bale chamber of the casting machine was determined at 110 °C, which means that the melt temperature reaches 700 °C. According to the values obtained during the simulation testing of the model gating system, the results were obtained on the basis of which the time course of the temperatures at the selected measuring points in the runners was identified. The time courses are showed in Fig. 3.

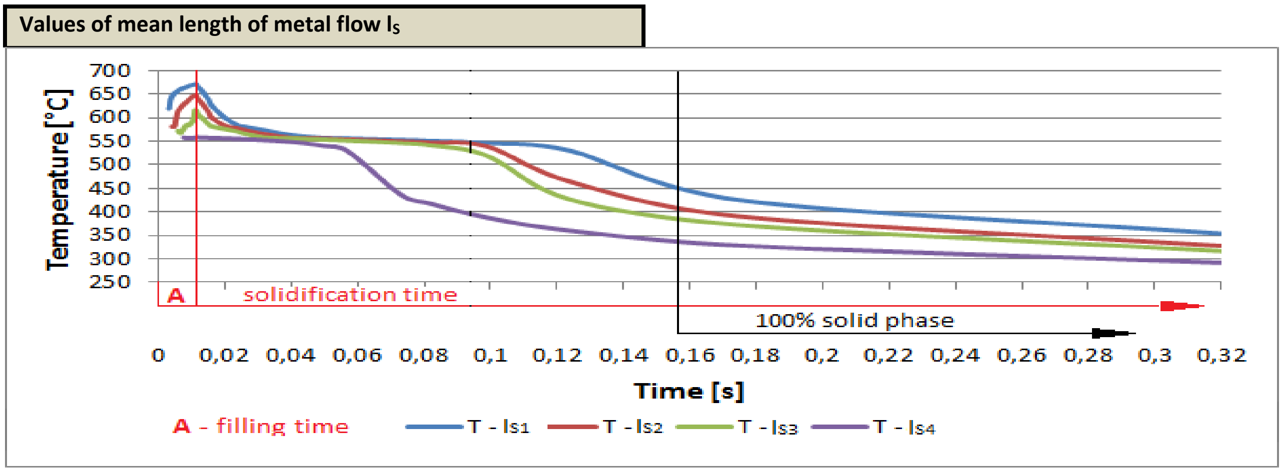

Figure 3. Time courses of temperatures at measuring points

As critical runner length has been defined, it is necessary to avoid such runner length for which the temperature in the runner during the process of filling in mould cavity is close to the temperature of the solidus of the alloy. For EN AC 47 100 – AlSi12Cu(Fe) alloy, the solidus temperature is defined as T_S = 560°C. Similar temperatures are measured at 4.A and 4.B measuring points, which corresponds to the length l_{S4} = 374.75 mm. The maximum and minimum melt temperatures at measuring points during the filling time are showed in Tab. 2.

Temperature range based on the mean length of metal flow				
Temperature [°C]	Mean length of metal flow l_S			
	l_{S1}	l_{S2}	l_{S3}	l_{S4}
T_{min}	618.830	580.615	566.875	556.505
T_{max}	671.125	647.395	615.830	558.230

Table 2. Threshold values of temperatures during the filling time

The minimum value of overheating the melt to the temperature excessing the temperature of its liquidus is reached only at l_{S1} distance. It should be taken into account that the front of the metal flow consists primarily of solidified layer of oxidized metal, which is collected in the overflow after passing the casting. The measuring point after the passing of the solidified metal through it is supplied with new metal flow from the filling chamber, which has a higher temperature. The minimum value of the melt temperature is of indicative nature determining temperature range of the melt.

5 EVALUATING CHANGES OF PROPORTION OF SOLID PHASE

Evaluation of changes in the proportion of solid phase has only complementary character describing the melt ability to fill in the mould cavity so that the required qualitative properties of the casting surface are achieved. In the design of the gating system for the casting of thrust face of a gear pump, the maximum solidification percentage was S = 20 % when finishing the filling process. Fig. 4 shows the time courses of the changes in the proportion of the melt solid phase at individual measuring points.

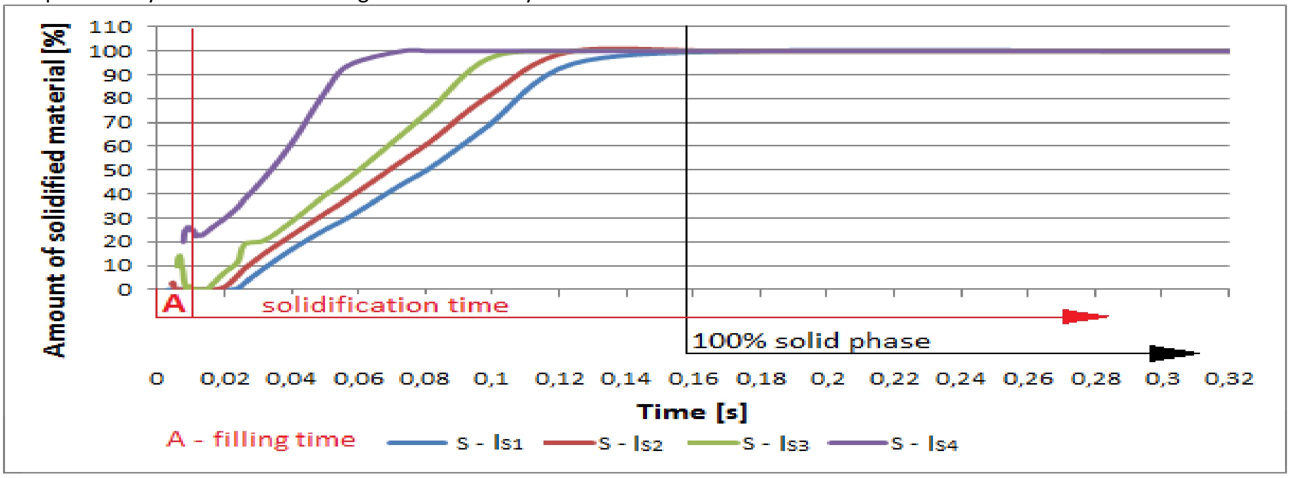

Figure 4. Changes in proportion of solid phase at measuring points

Tab. 3 shows the maximum and minimum values of the proportion of solid phase in the melt during filling in the mould cavity.

Range of values of solid phase proportion for mean length of metal flow				
Solid phase proportion [%]	Mean length of metal flow l_S			
	l_{S1}	l_{S2}	l_{S3}	l_{S4}
S_{min}	0	0	0.01	20.020
S_{max}	0.055	2.725	14.195	26.220

Table 3. Threshold values of the proportion of solid phase during the filling process

The minimum values S_{min} indicate the proportion of the melt solid phase after finishing the filling process in the mould cavity. The maximum values S_{max} consist exclusively by the values indicating the proportion of solid phase of the primarily solidified layer of the oxidized metal. From the values measured and the graph it is obvious that the data obtained from 4.A and 4.B measuring points exceed the allowed proportion of solid phase S after finishing the filling process.

6 ANALYSIS OF THE RESULTS ACHIEVED

Experiments and measurements conducted on the test gating system are used to analyse the phenomena occurring at the measuring points in the runners. They demonstrate the time course of changes in temperature and proportion of solid phase. By evaluating such information it is possible to determine the critical runner length in the design phase, which enables the engineers to specify the dimensional characteristics of the gating system and helps them determine the mould multiplicity.

The tests carried out proved that the mean length of melt flow at 4.A and 4.B measuring points, that is l_{S4} = 374.75 mm is not acceptable. The castings connected to the gate at a l_{S4} distance would not have the required properties. By simulation it was found that the mould cavity was not filled up completely, or shrinkage occurred due to the melt solidification in the gate, depending on setting the technical parameters of the casting process.

The temperatures measured at the measuring points 3.A and 3.B were close to the solidus temperature. T_{max} exceeded this temperature only by 55.83 °C, which is the minimum required overheating of the melt. The value expressing the proportion of solid phase in the melt, S_{max}, was below the allowed proportion of solid phase S. When performing the simulation of the casting process, the mould cavity was completely filled up without any shrinkage occurring in the casting body. Based on the simulation process results, the mean length of the metal flow l_{S3} appears to be appropriate. It should be noted that simulation represents ideal state when all input parameters are respected. In practice, such state does not exist. The temperature of the melt in the bale chamber of the pressure casting machine during the simulation reached 700 °C. Should the real operation experienced minor overheating, the decrease of the temperature would be reflected also at l_{S3} distance and defects in castings would occur, which was verified by the simulation performed. It can therefore be concluded that on the basis of the simulation and considering possible technical deficiencies, the l_{S3} = 296.25 mm for the given casting is a critical runner length l_{crit} and it should not be exceeded in the design of shape and dimensions of the gating system.

Evaluating the temperatures and proportion of solid phase at the measuring points 1.A, 1.B, 2.A and 2.B was proved that the observed parameters T_{min} and S_{max} are below the critical values. Also, the castings assigned to these points exhibit good properties.

According to the results obtained using simulation it is possible to determine the maximum length of the metal flow, and thereby the length of the runner, in the range between 217.75 mm and 296.25 mm.

7 CONCLUSION

Critical runner length is a constraining factor when designing gating system. By identifying and determining its length, designers are able to focus better on the multiplicity of mould and dimensional characteristics of runners when designing moulds for new types of castings.

Determination of the critical runner length is closely related to identification of temperatures in the runners. Changes in the temperature of the melt, cooling and simultaneous crystallization are reflected in the melt capability to fill in completely the mould cavity. Therefore, when determining l_{crit} it is necessary to monitor the changes in temperature at selected measuring points. The course of the crystallization is demonstrated by the proportion of solid phase in the melt S, which is closely related to the changes in the melt temperature. Therefore, the methods for determining lkrit are based on comparing these two parameters. By comparing the basic temperature characteristics of the alloy with the observed parameters, it is possible to determine lkrit for a specific casting with a high precision and thus avoid unnecessary economic losses in the designing phase.

The main benefit of the article is a proposal of determining possible runner length using simulation software by observing temperatures and proportion of solid phase at measuring points. In the article, the concept of critical runner length is defined and methods for determining l_{crit} on the basis of the measurements taken on the specific casting type are described.

The article presents the results and recommendations arising from the TACR project. One of the tasks arising from the program was a design for manufacturing thrust faces of gear pumps using high pressure die casting. Analyses performed showed that the maximum runner length can be between 217.75 mm and 296.25 mm. These findings were implemented in the design of gating system, mould multiplicity and finally in the design of casting machines.

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