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Optimizing the Placement of Gates and Dimensioning their Size in an Aluminium Alloy Casting

K. Dobiašovská, F. Radkovský *
VSB - Technical University of Ostrava, Czech Republic
* Corresponding author: E-mail address: filip.radkovsky@vsb.cz

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Abstract

The contribution deals with the effect of the geometry and location of the gates on the filling of the mold and on the resulting state of the aluminum alloy casting. This casting is cast into a sand mold from a uniform bentonite mixture, so there isn't much possibility of significantly interfering with the cooling effect of the mold. This is a casting for the automotive industry, specifically the gearbox cover, made of AlSi7Mg0.6. We are able to prevent errors and possible defects in castings by performing optimization. The aim of the experiment is to optimize the gates from the initial state, which would ensure better conditions for the flow of liquid metal in the mold and improve homogeneity throughout the casting. Optimizing should lead to the best result where all goals are in balance. The optimizations will be processed using the numerical calculation program MAGMASOFT, which allows for detailed simulation of the casting process. Some of the results will be shown graphically and comparisons of designs and variants will be shown in images from the simulations.

Keywords: Aluminium alloy, Gate system, Simulation, Optimization, Sand mold

1. Introduction

Numerical simulation is an integral part of foundry processes nowadays. Advanced tools like MAGMASOFT® improve operations, optimization and competitiveness. Accurate thermophysical data [1] is crucial for the quality of the simulation, especially for sand forms where irreversible changes occur due to thermal decomposition and water evaporation. This causes the cooling performance of the mold to be higher at the beginning of the process and weaker at the end. [2, 3]

Gates lead the metal directly into the cavity of the future casting. The speed of the metal and the possibility of splashing must be monitored when dimensioning them and simulations can help us with it. If the construction of the gates isn't done correctly, in the case of sand molds, the mold could tear off or the metal could penetrate. Their connection to the casting should be as thin as possible, and in places where it can be easily removed, it's ideal to choose flat surfaces. At the same time, the connection should not influence the temperature field of the cast. The size of the gates can be calculated according to the established formulas, specifically its area. However, these calculations often figure only as an input value, from which you can start and then adjust the size according to your own requirements and goals. [4]

Alloys based on aluminium, silicon and magnesium are widely used in industry due to their low density and high strength-to-weight ratio. [5–7] They are used in gravity, low-pressure and high-pressure casting, and they are popular for their low cost and high production speed. [8] Gravity casting allows the production of complex metal components with high operational reliability. Aluminum alloys are the preferred material for their properties such as lightness, attractive appearance, good machinability, corrosion resistance in the automotive industry. Other mechanical properties can be improved by heat treating the casting. [9, 10] However, the microstructure [11] and the associated cooling effect have an main effect on the mechanical properties.

The most common defect in the production of aluminum castings is porosity, which arises as a result of process parameters, the design of the inlet system, the properties of the mold and the alloy itself. The effort is to reduce the porosity, because the porosity of the castings is always undesirable [12], with exceptions [13]. There are two main types of porosity: shrinkage and gas porosity. [14, 15] Shrinkage porosity is results from solidification of the material, while gas porosity is a consequence of casting, mold design, process parameters, and venting. Gas porosity is caused by the entrapment of air, steam and hydrogen. Hydrogen dissolves easily in molten aluminum, this leads to entrapment of gases during casting. Specifically, we try to get rid of hydrogen by bubbling with inert gases, such as nitrogen, which can equalize the partial pressure of hydrogen. [16] Technology which using vacuum can significantly reduce the gas content of casting. [17]

This study describes the production of an aluminum casting using a model plate and sand mold. This is a model case of a real casting that is produced with a significant amount of scrap. The purpose of the study is to optimize the existing production process using the MAGMASOFT® simulation software and ensure three goals: 1) reduce scrap, 2) increase the internal quality of the casting, 3) reduce production costs. These goals can be achieved at low initial costs and in a short time by apply simulations method instead of the experimental method trial-and-error. [18]

2. Experimental description

The purpose of the work is to show the advantages and benefits of data processing in simulation programs. Procedures and input values will be shown and described in the experimental part. The original version will first be simulated in the MAGMASOFT program and risk factors will be evaluated. The individual steps will be gradually simulated and the gate optimized. The evaluation of optimizations is not always clear, parameters are usually improved at the expense of others, and a balance between them needs to be reached. More results will be shown from the resulting simulations, which should be important for the casting process. The implemented changes should ensure an increase in the quality of the castings when the mold is folding. The weight of the raw casting, with the inlet system and feeders, was twice the weight of the clean casting, namely 4,18 kg. The casting temperature was 730–740 °C depending on the ambient conditions and filling the mold took over 13 seconds. It was possible to observe a significant decrease in temperature even before filling the mold and the formation of a solid phase, because the temperature was below the temperature of the liquid during part of the process.

2.1. Foundry experimental parameters

The casting was provided with allowances for machining and had properly defined bevels for easy removal of the mold from the model plate. A SEDEX filter of size 50 x 50 mm with a size of 20 pore per inch is inserted into the inlet system when assembly the mold. Metal compensation due to changes in volume was provided by 4 open feeders, and even so, there were shrinkage and porosity in the casting under the feeders. The yield of liquid metal was only 50% with original geometry.

2.2. Process for changing geometry parameters

The filter was placed in front of the runner and thus its efficiency was reduced in its original state as shown it Fig. 1. Due to the high susceptibility of aluminum alloys to deoxidation, the filter should be placed in close proximity to the casting, so that it can capture inclusions and impurities as best as possible, and thus we obtained a casting without defects. The aim was mainly to adapt the inlet system to the cast alloy, for that reason the use of the distribution channel was first abandoned, which slowed down the entire casting process and at the same time the metal cooled down faster, by the fact that the metal was guided into the mold by a longer path. Before the filling of the entire mold cavity, it was known that a fairly large part of the metal was already below the solidus temperature. It was considered to use only one gate, instead of the original two, which could be connected directly to the filter chamber and would thereby ensure better conditions for the casting and solidification process for the reasons mentioned above.

Changes were made to streamline the inlet system by reducing the original two gates to just one and eliminating the need for a runner. This improved the efficiency of melt filtration, shortening the metal transport path and reducing filling time. Although the surface area for machining has expanded, on the contrary, the connection of the gate to the casting has been narrower. Two variants were designed with side filling and filling from the bottom of the casting. In the case of the bottom connection, this would be an extension of the outlet part of the filter chamber and its narrowing when connected to the casting. Both of these designs have better features than the original classically designed inlet system with a runner. [19]

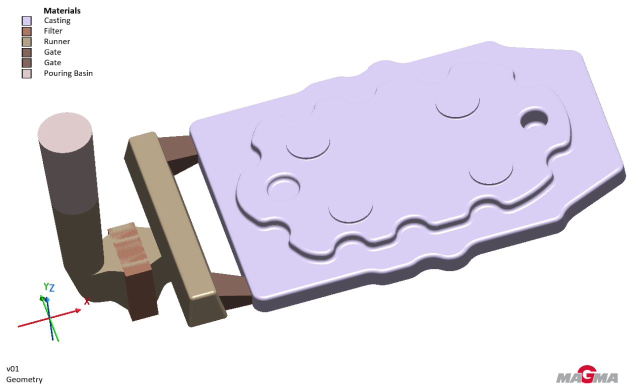

Fig. 1. The original state of the gates

2.3. Side connection of the gate

The input height of the gate and the output area of the gate into the casting, height and width are optimized. The values for optimization are listed in Table 1. The observed goals were the speed in the gates, the time of filling the mold and the improvement of the yield of liquid metal, possibly if it has any effect on the microporosity in the casting. Figure 2 shows velocity in gate with the best fit design when the metal is in the gate and when it comes to future casting.

Table 1.
Gate optimization values with side filling

	Limits from – to	Step
Initial gate height	10-16 mm	1 mm
Output gate height	4-10 mm	1 mm
Output gate width	60-90 mm	10 mm

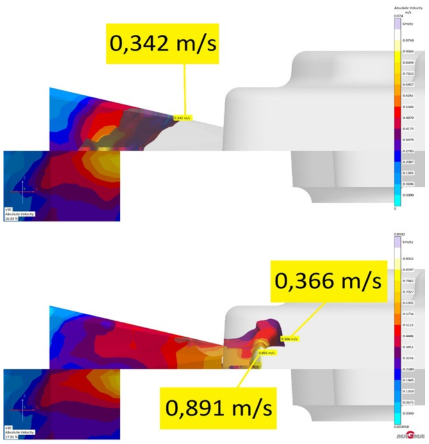

Fig. 2. Total velocity in gate with side connection during pouring

2.4. Bottom connection of the gate

In this case, the gate was connected to the filter chamber directly and was created by connecting the outlet surface of the filter chamber and the surface of the notch connected to the casting. Only the dimensional values of the connection area of the casting were optimized (see Tab. 2). Goals were set in the observed area of mold filling, as well as soundness and the use of liquid metal. A quieter filling of the mold and a lower speed in the gate were assumed. Figure 3 shows a graph with the best optimization suggestions. Four designs were selected, whose dimension values differed significantly in the width of the surface. Designs marked with yellow curves turned out better. [20]

Table 2.
Gate optimization values with bottom filling

	Limits from – to	Step
Output gate height	4-7 mm	1 mm
Output gate width	65-85 mm	5 mm

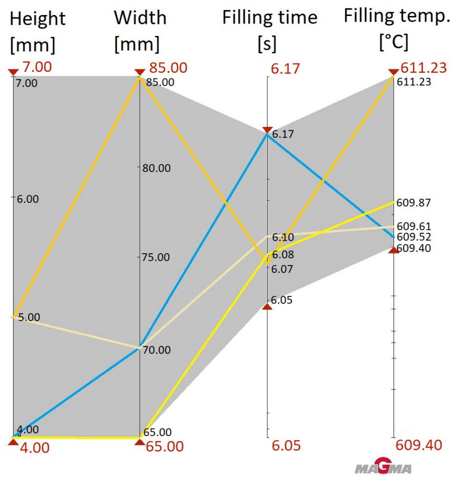

Fig. 3. Graph with best result from optimization

There wasn't much difference in slot filling rates between designs and this parameter didn't influence the selection. The design with the highest filling temperature was chosen because it had the slowest temperature drop. At the same time, the filling was the calmest and the cavity filled consistently. [21]

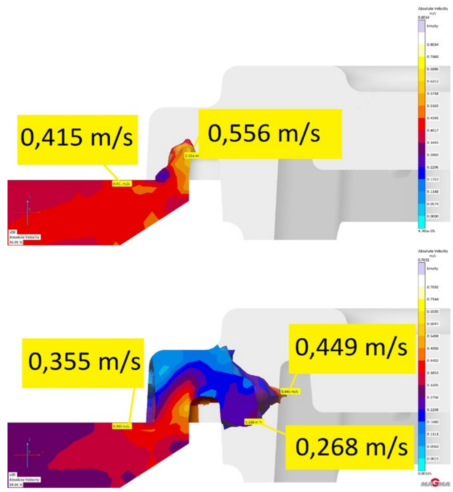

Fig. 4. Total velocity in gate with bottom connection during pouring

3. Achieved results

The bottom-fill version ensured that the highest temperature was maintained, and after filling the entire mold, the casting contained the smallest proportion of solid phase. Figure 5 shows the original, side and bottom fill versions. The volume of the solid fraction was reduced to 14.55% from the original 25%. Fraction of the solid is shown as a red field.

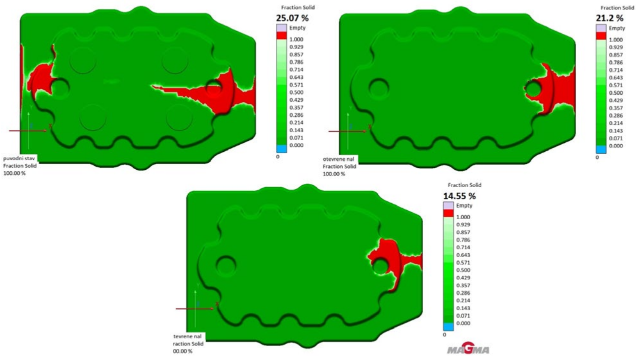

Fig. 5. Fraction solid after fill up the mold

There was also an improvement in internal defects, specifically microporosity. It was mainly located in the places of the thermal axis, under the feeder and in places where the thickness of the casting walls was greater. In the area where the gates connect to the casting (see Fig. 6) there is porosity, which was reduced by changing the gates and concentrated in one location instead of three. These places are marked in green. If we look at the rest of the picture 6 we can see that there is a general reduction of microporosity also in the rest of the casting and most in the central part, although only part of the casting can be seen. An experimental casting would need to be done to confirm that reduction has indeed occurred and if it occurs at all in these locations.

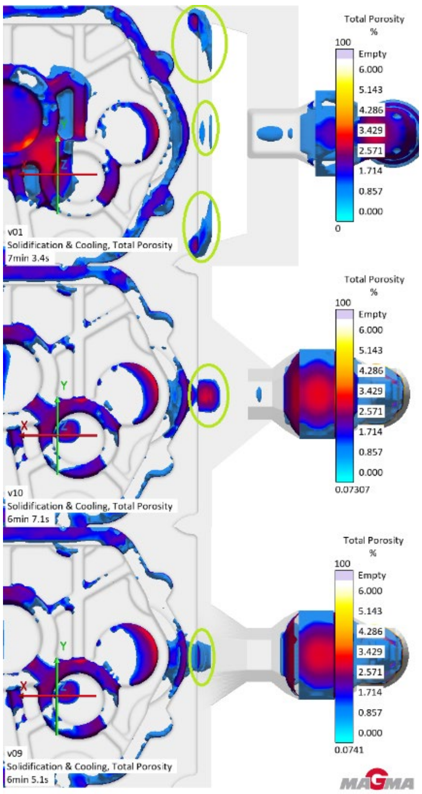

Fig. 6. Total porosity in casting

4. Conclusions

The AlSi7Mg0.6 aluminum alloy casting is cast in a sand mold with low yield of metal and with internal defects. It was investigated whether it's possible to bring about any improvement by change the dimensions and the arrangement of the gates and what effect the change will have. Two variants of gating system, with side and bottom connection, were created and were optimized. Both led to better results.

The selected variant would be bottom filling, which has a smaller area for subsequent machining. The bottom filling met the set objectives with regard to the construction. A greater flow of metal was achieved in the gate, thereby shortening the filling time overall and resulting in an improvement of the temperature field. There was a slower cooling during filling, as far as the temperature is concerned. The area of microporosity also fared significantly better, which was only improved by changing the notches. A suitable measure would also be to lower the casting temperature, which could help the reduction more.

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