Process parameter influence on selected quality features in high-pressure die casting

F. Schmidt M.Sc., M. Müller M.Sc., U. Vroomen, A. Bührig-Polaczek

The comprehension of coherences between process parameters and cast part quality in high-pressure die casting is an important step towards a robust process. The presented study focusses on the influence of process parameters that are believed to be of great importance on the cast part quality such as the filling velocity, the intensification pressure or the die temperature. Quality measures like the cast part porosity and mechanical properties are to be linked with process conditions in order to separate the influence of the die layout and the effects resulting from process variations from each other. In the presented paper, the conduction routine and results of a detailed study which has been performed in order to understand these interdependencies for a twin cavity die are shown. This die is used to produce plate shaped cast parts, featuring a highly modular setup consisting of seven different inserts. The variable setup is the foundation for further investigations e.g. the influence of conformal cooling and additive manufacturing for die inserts such as Selective Laser Melting. In addition to the modular setup, the die is equipped with more than ten temperature sensors per cavity, which are used to monitor the influence of the process parameters on the die itself.

The collected data and the interchangeability of the die components will be used for further improvement of a numerical optimization routine that is developed in this context.

KEYWORDS: HIGH-PRESSURE DIE CASTING - CAST PART QUALITY - NUMERICAL OPTIMIZATION - POROSITY - MECHANICAL PROPERTIES

INTRODUCTION

The need for robust high quality processes is rising and therefore a detailed understanding of the processes interdependencies is gaining importance. In order to achieve such an understanding in general and in particular for the experimental die that will be described later on, an extensive experimental study has been performed. Not only will the results be used to show the interdependencies but also to verify and improve the results of the numerical optimization routine that is developed within the Cluster of Excellence [1]. The presented study is part of the experiments that will be the foundation for development, improvement and verification of this routine which shall later on result in automatically designed die features that are manufactured with generative manufacturing technologies such as Selective Laser Melting, if necessary.

Frank Schmidt M.Sc., Marcel Müller M.Sc.,
Dr.-Ing. Uwe Vroomen,
Prof. Dr.-Ing. Andreas Bührig-Polaczek
Foundry Institute RWTH Aachen University

EXPERIMENTAL SETUP

The presented research has been carried out on a Bühler H-630 SC high-pressure die casting machine with a locking force of 700 tons. The experiments were performed with an AlSi9Cu3Fe alloy since it is still one of the most used alloys in the high-pressure die casting industry. A square plate with a side length of 160 mm has been chosen as cast part geometry. The average wall-thickness of the part is 4 mm but the wall thickness is decreasing from 6 down to 2 mm along the diagonal of the plate. Since the die is a twin-cavity die, two identical plates are casted within one cycle. A more detailed description of the modular die setup and the implemented measurement concept is given in [2]. The main focus of the experiments were the influence of process parameters on the thermal balance of the die on one hand and the process parameter influence on the cast part quality on the other. Within these context the overheating of the melt, the piston velocity during the filling phase, the die temperature and the intensification pressure are believed to be the most important [3-8]. With a full fractional design of experiments the number of experiments, each parameter combination including six and more casting cycles, would have been too high. Therefore the Taguchi approach was chosen in order to reduce the amount of casting experiments to a reasonable amount [9]. In addition a full fractional experimental design including the parameters die temperature and intensification has been used since these parameters are believed to be the most important factors. For those experiments the melt temperature was kept at 720 °C and the piston velocity at 1,3 $^m/_s$. The experimental design that was chosen is shown in table 1. The remaining process parameters have been kept constant.

Tab. 1 - Design of Experiments

DESIGN OF EXPERIMENTS				
Melt Overheating [K]	90	120	150	170
Piston Velocity [m/s]	0,7	1,3	1,9	2,5
Set Die Temperature [°C]	150	180	210	250
Intensification Pressure [bar]	100	250	400	600

In order to investigate the influence of the parameters described above several analytical methods have been used. In a first step, the density of each cast part has been determined using the Archimedes principle. This was followed by an x-ray analysis with an XT H 320 LC unit (Nikon Corporation) of representative castings in order to determine the average porosity distribution within the casting. Tensile tests using flat bar specimens machined from the diagonal with a constant wall thickness (4 mm) have been performed in the interest of showing a possible correlation between process parameters, porosity and mechanical properties of the cast part. The measurements have been conducted according to DIN EN ISO 6892-1 using a Zwick Roell testing machine.

RESUTLS AND DISCUSSION

The density measurement using the Archimedes principle shows an average cast part porosity of 5,5 % for all the experiments performed. This high value of overall porosity is most likely caused by a vacuum system that has been shut off during the casting trials. Combined with a venting system that was designed for a vacuum supported evacuation the amount of entrapped air is higher than usual. Due to the design of experiments that has been chosen the influence of certain process parameters can be determined with the help of the p-value. When the value of this indicator is below 0,05 an influence can be assumed to be significant. If the value is higher than 0,05 a low value might indicate an influence. For the parameters "Melt Overheating" (p-value = 0,975) and "Piston Velocity" (0,996) the analysis shows no influence on the cast part porosity. The missing influence of the overheating of the melt can be explained with the high average porosity. Possible influences like an increased hydrogen content resulting from an increased melt temperature just do not have an impact that is big enough in relation to the high average level. The findings regarding the piston velocity on the other hand have been expected differently. Possible reasons for a missing impact are the simplicity of the cast part, a small wall thickness and the low velocities used for this study. While there might be an influence for higher velocities like in [6-8], for the presented study no interdependencies between porosity and velocity were found. When looking at the resulting p-values the intensification pressure appears to have the strongest and an almost significant influence on the cast part porosity with a p-value of 0,061. On average the cast part porosity was found to be 2 % lower at 600 bar intensification pressure when compared to experiments with 100 bar. This reduction was also found with the x-ray analysis that is shown exemplarily in Figure 1 for minimum and maximum intensification pressure.

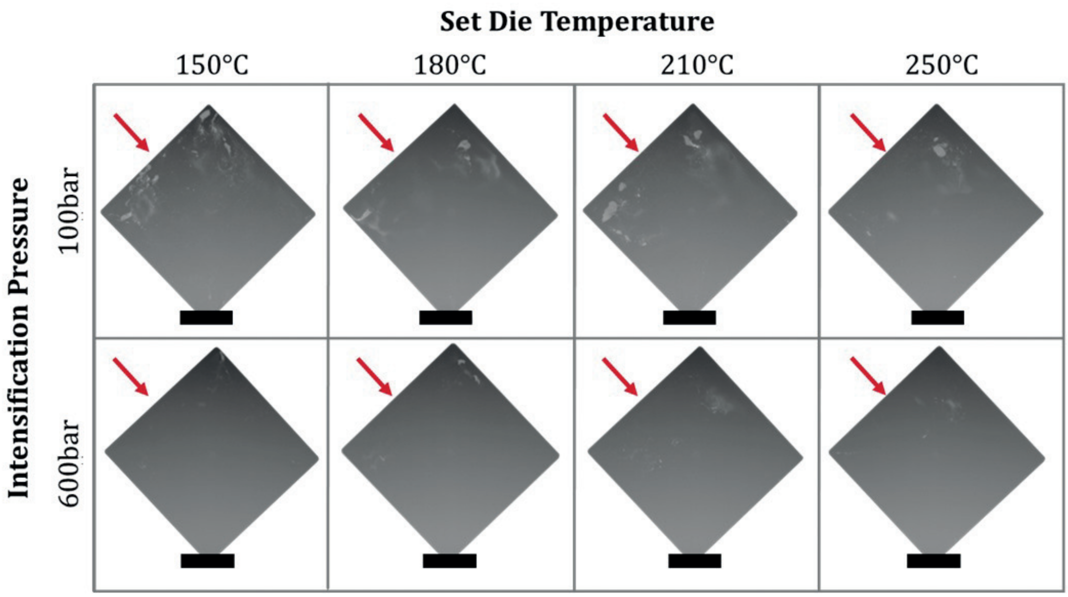

Fig.1 - Porosity distribution within the cast part

The porosity distribution within the cast part has been found to be similar for every parameter setup. The porosity always clusters around the plate's corners that are close to the ingate which is represented by the arrow. This distribution is consistent with the results of the numerical simulations performed previously [10]. A significant influence of the die temperature was not found in this study (p-value = 0,531). But the measured cast part density and the x-ray analysis indicate that an influence might exist. For the minimum die temperature the intensification pressure exposed a much stronger influence than for higher die temperatures which shows an increased need for high pressures when operating relatively cold dies. While the porosity maximum at 150 °C can be explained easily by a shorter gate freezing time, the second maximum at 210 °C could not be explained properly. Further investigations are needed in order to detect possible side effects on this result. A similar result as for the porosity was found for the mechanical properties. Figure 2 shows the correlation of pressure, mechanical properties and cast part porosity within this study.

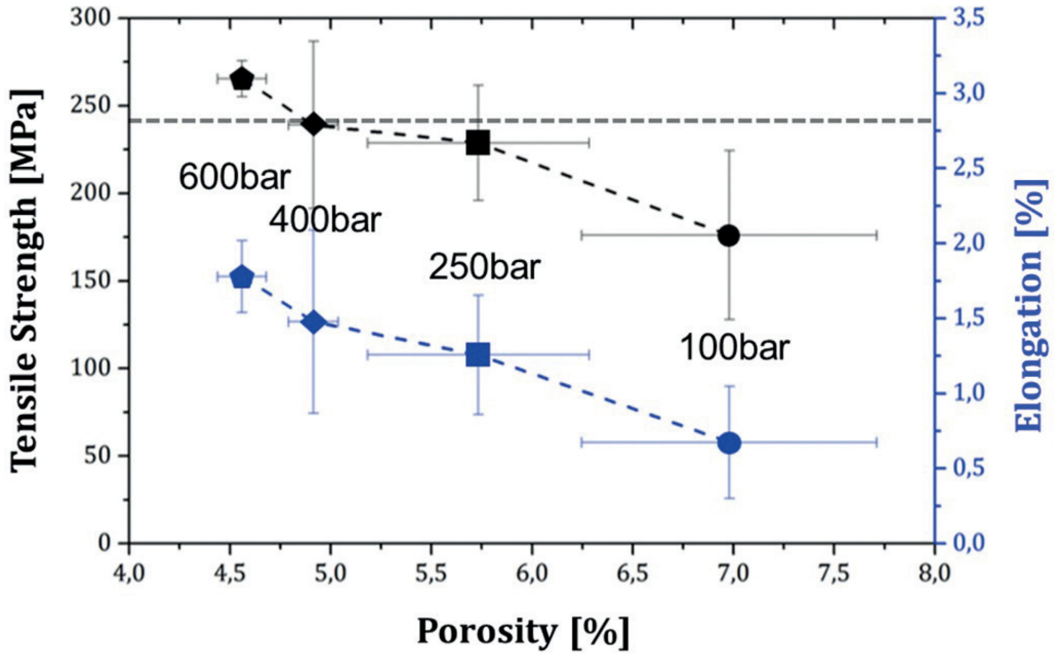

Fig.2 - Mechanical Properties related to cast part porosity

The dominating influence of the intensification pressure along with a lack of an influence of other parameters indicates, that the effect of the pressure on the cast part porosity superimposes other effects for the findings related to mechanical properties. The increasing amount of porosity on the fracture plane with decreasing intensification pressure indicates the same. The dotted line in Figure 2 shows the tensile strength of the alloy as demanded in the DIN EN 1706. This tensile strength was only achieved with an intensification pressure of 400 bar and more. A similar influence was found for the elongation of the material, For an intensification pressure of 600 bar, which was the highest pressure analyzed within this study and the highest possible pressure for the die and the machine that were used for this study, every combination of the remaining parameters achieved the necessary mechanical properties. With a decreasing intensification pressure the influence of the remaining parameters such as the die temperature or the filling velocity became more important in order to achieve the mechanical properties that are needed. This is another indicator, that the high average porosity and the therefore dominating influence of the intensification pressure in this study superimpose other influences. This is most likely the reason that for example the grain refining effect of a cold die that should improve the mechanical properties was not determined.

SUMMARY AND CONCLUSIONS

It was shown that the intensification pressure has a significant influence on the cast part quality in terms of porosity and mechanical properties. Other parameters turned out to be less influencing, especially the effect of the filling velocity was much lower than it has been expected. The results regarding the die temperature showed no significance but suggest that there might be an influence that needs to be examined further. Due to the obvious correlation between the cast part porosity and the mechanical properties, a significant impact of the intensification pressure on those properties has been shown. In addition to the findings about the correlation of quality features and process parameters it shall be mentioned, that the porosity distribution detected via X-Ray shows a good match to the results from STAR-Cast which is used for the optimization routine as well [10].

ACKNOWLEDGEMENT

The authors would like to thank the German Research Foundation DFG for the kind support within the Cluster of Excellence „Integrative Production Technology for High-Wage Countries".

REFERENCES

[1] R. SIEGBERT et al., Int. Journal of Advanced Manufacturing Technology 80, (2015), p. 851-858.

[2] F. SCHMIDT et al., Proc. Materials Science and Technology, Columbus, Ohio (2015), p. 283-290.

[3] A. BÜHRIG-POLACZEK, W. MICHAELI, G. SPUR, Handbuch Urformen, Hanser Verlag, Munich (2013).

[4] B. NOGOWIZIN, Theorie und Praxis des Druckgusses, Fachverlag Schiele & Schön, Berlin (2011).

[5] M. S. DARGUSCH et al., Journal of Materials Processing Technology 180(1-3), (2006), p. 37-43.

[6] V. TSOUKALAS et al., Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 218(1), (2004), p. 77-86.

[7] D. GUNASEGARAM et al., Proc. Materials Science and Technology, Detroit, Michigan (2007), p. 847-856.

[8] G. O. VERRAN et al., Journal of Materials Processing Technology 179(1-3), (2006), p. 190-195.

[9] B. KLEIN, Versuchsplanung-DoE: Einführung in die Taguchi/Shainin-Methodik, Oldenburger Verlag, Munich (2007).

[10] J. JAKUMEIT et a., Proc. TMS 2016, Nashville, Tennessee (2016), p. 59-65.