USING COMPUTED TOMOGRAPHY TO INVESTIGATE THE EFFECT OF VARIOUS CASTING PARAMETERS ON ZINC ALLOY CASTINGS

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Abstract

Computed tomography (CT) was used to evaluate the internal quality of the zinc alloy castings. The castings are produced by high pressure die casting process from ZP0430 zinc alloy, which contains also aluminium and copper. High pressure die casting process is very complicated and sensitive to casting parameters such as filling rate, solidification time, die tempering and others. A certain percentage of porosity is always present in the castings. As part of the research into the die casting process, the internal porosity of Langmutter castings produced in an eight-cavity die was investigated. Castings produced using normal casting parameters and modified casting parameters based on numerical simulation of the casting process were evaluated. Computed tomography was used to determine the distribution of cavities in the casting, their quantity and subsequently their volume and porosity. In the castings produced using the normal casting parameters, the average number of cavities was 679 and the porosity was 0.108 %. When the modified casting parameters were implemented, the average number of cavities in the castings decreased to 454 and the porosity to 0.077 %. It has been shown that the modified casting parameters are more suitable for the high pressure die casting process in terms of porosity formation.

Keywords: High pressure die casting, computed tomography, zinc alloy, porosity

1. INTRODUCTION

In the die casting process, molten metal is forced into a metal die under high pressure. The pressure is maintained during solidification. This process allows for high volume production, dimensional accuracy, very thin wall thickness, excellent surface quality and by rapid cooling a fine grain structure is achieved which ensures high strength of the castings. However, due to the high velocities during die filling, turbulence in the metal and gas entrapment occur, causing porosity. Thus, a typical casting has a high-quality surface but a large amount of microporosity or larger bubbles [1, 2]. Zinc alloys are processed on hot chamber machines where the hydraulic piston is in contact with the melt. This process minimizes melt contact with oxidizing air and reduces temperature losses and turbulence during the casting cycle. The parameters required to ensure high quality castings are related to timing, material and heat flow, and dimensional stability. Some properties are determined by the geometry of the mould and therefore unchangeable, others are influenced by the setting of the casting machine and can therefore be influenced [3]. If the casting process is incorrectly set, the quality of the castings deteriorates. Porosity has two main causes, entrapped gas and shrinkage. The entrapped air is always present in the castings in some quantity due to turbulent die filling [4].

One of the modern methods of internal cavities detection is computed tomography. It allows the interior of a sample to be examined and defects such as cavities or dimensional inaccuracies to be identified. Computed tomography produces a three-dimensional representation of the casting from individual X-ray images. It has been successfully used, for example, for the evaluation of additively manufactured parts, due to its ability to measure complicated and inaccessible internal dimensions [5]. It is also used to investigate aluminium alloys and defects in castings [6, 7]. Other less common applications include the identification of microfossils [8], or the evaluation of sand samples in hydrology [9].

The aim of the presented work was to use computed tomography to evaluate the internal quality of zinc castings in relation to the modification of casting parameters based on numerical simulations thus expanding on the authors' previous work on the use of computed tomography for the evaluation of castings [10].

2. MATERIALS AND METHODS

The investigated Langmutter casting is produced by die casting from zinc alloy ZP0430 on a Frech DAW 80 RC die casting machine, with a control system for real-time monitoring of the casting cycle. The maximum clamping force of the machine is 900 kN and the piston diameter is 50 mm. The die casting die is eightfold and consists of a fixed and a moving part. To achieve the desired shape of the casting, the die is equipped with a set of cores. From the casting cavity, a set of sprues leads to ensure that the casting is perfectly filled with metal. Throughout the die assembly there is a system of tempering channels to maintain optimum temperature. In the inlet and frame of the fixed part of the die there are two channels that use water as a medium. The movable and fixed insert each contains a tempering channel also working with water. The distributor and the chamber are cooled by the cooling channel with water as cooling medium.

Castings are made of zinc alloy ZP0430, which contains 4 % aluminium, 3 % copper and small amount of magnesium. This alloy offers the highest tensile strength, hardness and creep performance compared to the similar zinc die casting alloys. Aluminium is added to strengthen the alloy, to reduce grain size, and to minimize the attack of the molten metal on the iron and steel in the casting and handling equipment. It also adds to the fluidity of the molten metal and improves its castability. Higher copper content contributes to some of the improved mechanical properties and minimizes the undesirable effects of impurities. Magnesium is added primarily to minimize susceptibility to intergranular corrosion caused by the presence of impurities. This alloy is also easily cast, coated and machined as is typical with each of the ZAMAK alloys [3, 11].

The Langmutter casting itself is of cylindrical shape with an internal hole for the production of M12 thread. Wall thickness decreases down to 0.3 mm. As mentioned before, castings are produced in an eightfold die and are distinguished by dots on the underside marking them 5–12. The rough casting set with the position of the individual castings is shown in **Figure 1**.

Figure 1 Rough casting set with marked positions of eight individual castings

Because the die casting process is quite complex, a large number of parameters including temperatures, cooling, cycle times, speeds, die geometries and more must be controlled to achieve quality castings. In the present work, the effect of casting cycle phase durations in combination with cooling parameters including flow rate and temperatures of the cooling medium - water - was investigated. Thus, 8 castings produced with the original parameters and 8 castings with new parameters modified on the basis of numerical simulations of casting and cycling were evaluated. **Table 1** shows the original and modified cycle phase times. **Table 2** shows the original and new parameters of the cooling channels.

Table 1 Original and modified casting cycle timeline

Parameter	Original	Modified
Total cycle time (s)	12.7	12.3
Die open before casting removal (s)	3.5	4.2
Casting removal time (s)	5.4	5.2
Start spraying (s)	7.0	6.5
End spraying (s)	8.1	8.5
Start blowing (s)	9.0	9.5
End blowing (s)	10.4	10.5
Die close before cycle end (s)	11.5	11.0

Table 2 Original and modified cooling channel parameters

	Channel	Position in die	Medium	Flow (l·min^{-1})	Temperature (°C)	
					In	Out
Original	1	Fixed – Inlet	Water	5.0	25	35
	2	Fixed – Insert	Water	4.0	80	95
	3	Fixed – Frame	Water	5.0	25	35
	4	Movable – Insert	Water	4.0	80	95
	5	Movable – Distributor	Water	5.0	25	35
Modified	1	Fixed – Inlet	Water	5.2	19	23
	2	Fixed – Insert	Water	5.6	85	90
	3	Fixed – Frame	Water	5.2	19	23
	4	Movable – Insert	Water	5.6	85	90
	5	Movable – Distributor	Water	5.2	19	23

The actual examination of Langmutter castings for the evaluation of the influence of manufacturing parameters was carried out using computed tomography on a Werth TomoScope XL machine. WinWerth software was used to evaluate the acquired data and reconstruct the cavity distribution. This software allows the cavities to be visualised in a three-dimensional model of the casting and colour-coded according to size. The 3D model can also be rotated to observe the structure from different views or to add labels with information about the individual cavities. For each casting under investigation, an image was created with a description of the largest cavities. Next, the volume of the casting and the total volume of the internal cavities were determined, from which percentage of the internal porosity was obtained. Finally, the total number of detected cavities was determined. In this way, the internal quality of the castings can also be assessed quantitatively and compared with each other.

3. RESULTS

Eight castings produced with the original set of parameters and eight castings made with modified parameters were evaluated. **Figure 2** shows an example of the 3D model obtained using CT of casting 12 made with the modified parameters. The distribution of the cavities in the model is shown along with a colour scale representing their volume.

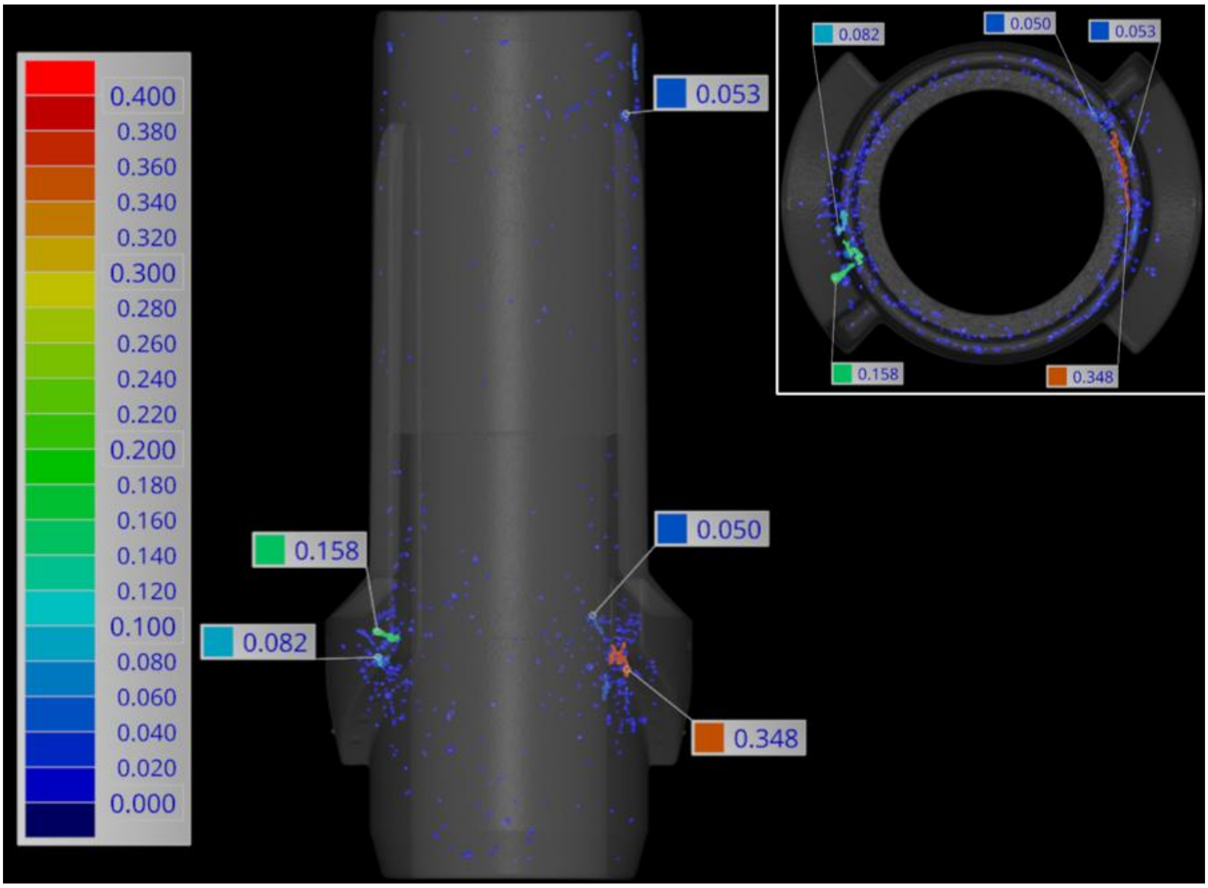

Figure 2 CT scan of casting 12 made with modified parameters, numbers indicate volume of cavities in mm^3

In general, it can be said that the larger cavities in all castings occurred mainly in the thick areas at the inlet and overflow and in the upper part of the casting. Microporosity (blue colour in the picture) is present throughout the entire volume of the castings.

Table 3 shows the results of the quantitative evaluation of the cavities in the castings made with the original parameters.

Table 3 Cavities in castings produced with original parameters

Casting #	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Casting volume (mm^3)	3279.98	3287.53	3288.11	3287.76	3286.26	3291.73	3286.35	3291.51
Cavities volume (mm^3)	4.01	2.92	3.31	3.53	3.23	3.78	3.66	3.88
Porosity (%)	0.12	0.09	0.10	0.11	0.10	0.11	0.11	0.12
Number of cavities (1)	771	653	476	788	760	730	530	722

Results in **Table 3** show that highest porosity, 0.12%, was detected in castings 5 and 12. Average porosity in castings produced with original parameters was 0.108%. Highest number of cavities, 788, was in casting 8. Average amount of cavities in castings produced with original parameters was 679.

Table 4 shows the results of the quantitative evaluation of the cavities in the castings made with the modified parameters.

Table 4 Cavities in castings produced with modified parameters

Casting #	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Casting volume (mm³)	3164.42	3167.71	3165.19	3158.90	3156.15	3164.26	3165.92	3163.34
Cavities volume (mm³)	1.53	3.09	2.02	2.14	3.27	2.22	2.41	2.92
Porosity (%)	0.05	0.10	0.06	0.07	0.10	0.07	0.08	0.09
Number of cavities (1)	154	692	406	456	592	417	455	457

Results in **Table 4** show that highest porosity, 0.10%, was detected in castings 6 and 9. Average porosity in castings produced with modified parameters was 0.077%. Highest number of cavities, 692, was in casting 6. Average amount of cavities in castings produced with modified parameters was 454.

Figure 3 shows a chart comparing porosity in castings produced with original and modified parameters.

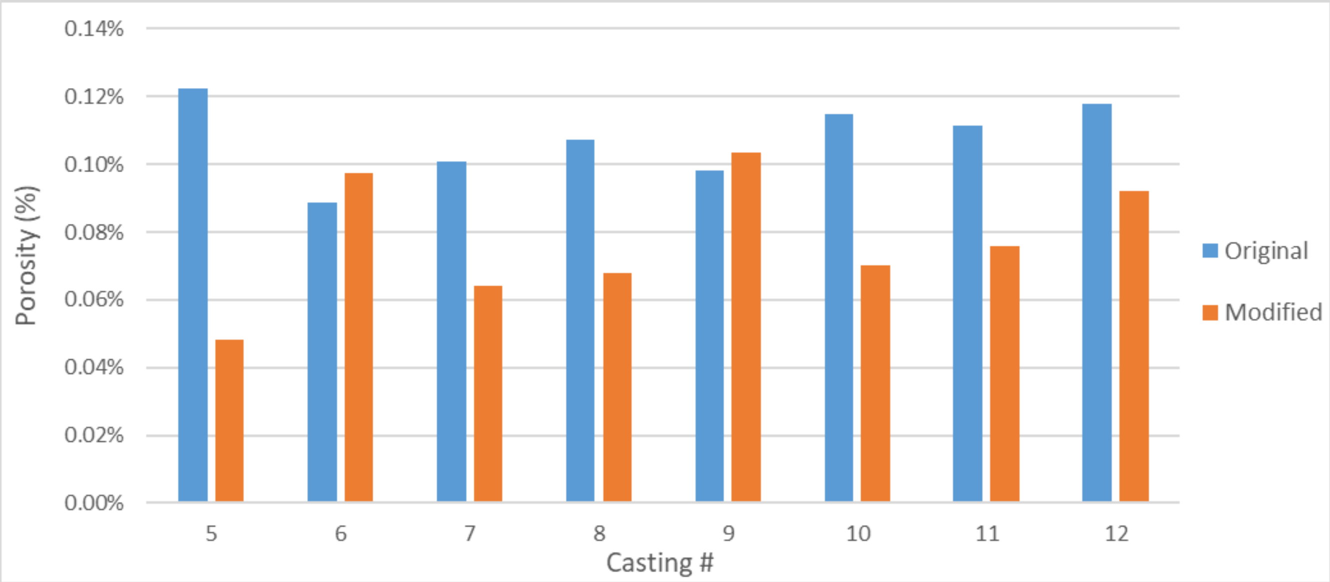

Figure 3 Comparison of porosity found in castings made with original and modified parameters

It can be seen that in most castings the porosity decreased with the adjustment of casting parameters. The exceptions are castings 6 and 9, which showed a slight increase in porosity. The largest decrease in porosity was in casting 5.

Figure 4 shows a chart comparing number of cavities in castings produced with original and modified parameters.

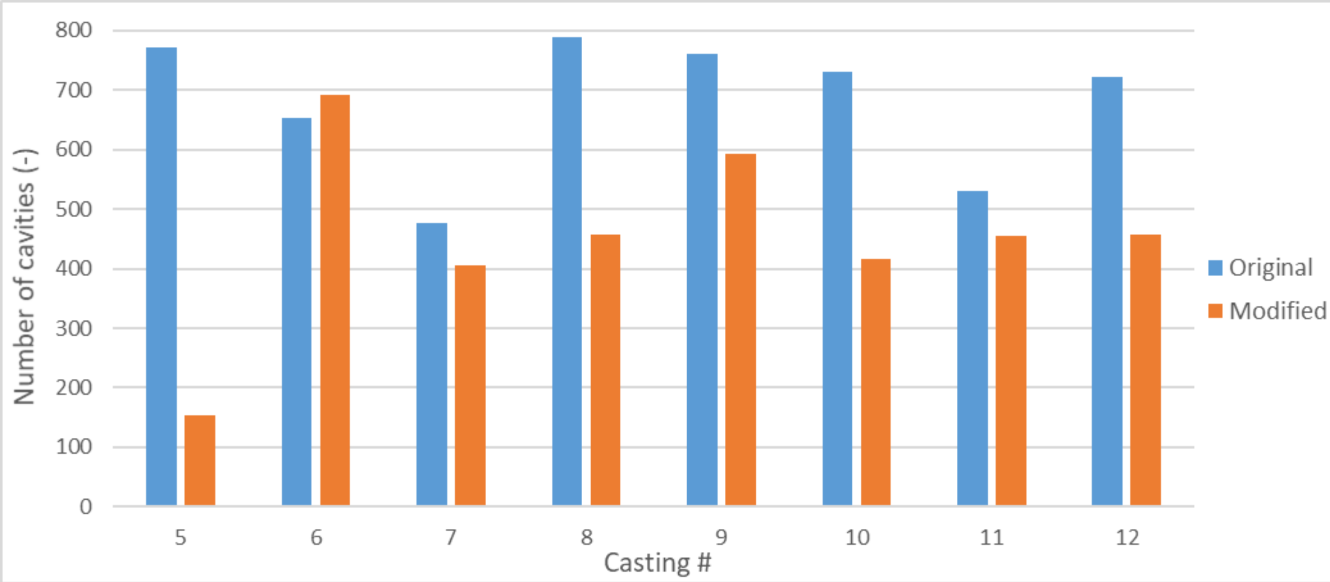

Figure 4 Comparison of number of cavities found in castings made with original and modified parameters

It can be seen that in most castings the number of cavities decreased with the adjustment of casting parameters. The exception is casting 6, which showed a slight increase. The largest decrease of cavities was in casting 5.

4. CONCLUSION

The influence of casting parameters on the production of ZP0430 zinc alloy castings was evaluated by computed tomography. Based on the information obtained by numerical simulations of the die casting process, the cycling and cooling of the die were adjusted. An average of 679 voids and 0.108% internal porosity were found in castings produced using the original casting parameters. An average of 454 voids and 0.077% internal porosity were found in castings produced using the modified casting parameters. The results thus indicate a positive effect of the modified casting parameters on the internal quality of the castings. Further work will focus on validating the results on other types of castings and metallography, in order to complement and/or verify the accuracy of computed tomography. This is because CT is based on the numerical interpretation of X-ray detections, and is not the ultimate result for more demanding tasks, such as those involving zinc alloys with high density and an unsymmetrical design, as presented in this paper.

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