ASSESSMENT OF THE INTERNAL QUALITY OF ZINC CASTINGS DURING MOULD LIFE USING COMPUTED TOMOGRAPHY

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Abstract

The research deals with the evaluation of internal quality of zinc castings in terms of porosity. The castings were produced by high-pressure die casting from ZP0410 alloy, which is an alloy of zinc with addition of aluminium and copper. For the evaluation, a computed tomography was used on a Werth Tomoscope XL, which allows for a non-destructive analysis of the internal structure of the casting and the creation of a 3D model of the porosity distribution inside of the casting. It also allows the number of cavities and the proportion of porosity in the casting volume to be determined. Castings from a two-cavity mould were evaluated. The mould is made of H11 steel. The investigation of the internal structure was carried out on castings from both cavities of the mould during its service life. Three samples of castings from each cavity were taken from a new mould and then after approximately every 100,000 shots up to 700,000 shots. Evaluation by computed tomography revealed that microporosity was present inside the whole casting. Larger cavities are generally found around the central hole in the area of the highest wall thickness. The number of cavities was different for the two positions of the castings up to 400,000 shots, with the number increasing for K3 castings and varying between increasing and decreasing for K4 castings. After reaching 400,000 shots the number of cavities in castings matched and a decrease to approximately 2,000 occurred. The volume of porosity at 700,000 shots was 0.4%.

Keywords: Die casting, zinc alloy, computed tomography, porosity, mould wear

1. INTRODUCTION

High pressure die casting (HPDC) is a high-volume manufacturing process, producing geometrically complex castings with high dimensional accuracy, excellent surface quality and low scrap rate. Other advantages are minimal machining and production of castings with thin walls. Castings are used in automobiles, motorcycles, as functional parts of mechanisms or in electronics, but they are also used as aesthetic parts in various products, including lighting fixtures, furniture, home appliances and fashion accessories. All major alloys can be processed by HPDC, and approximately half of the world's production of light metal castings is produced by this technology [1-6].

Zinc alloys have a low melting point, high solidification rate and good fluidity. They have high resistance to oxidation during melting, low thermochemical aggressiveness and adhesion to mould materials. Zinc castings have a low shrinkage rate, good mechanical properties and high wear resistance. These properties make it possible to produce castings with thin walls and fine details with high surface quality while maintaining low cost [1, 7].

The combination of mould temperature, fluidity, geometric complexity of the castings and cooling rate affects the quality of the castings. If these parameters are not properly controlled, defects are expected. Surface defects include blow, scar, blister, drop, scab, penetration or buckle. Internal defects are gas pores, shrinkage porosity, inclusions, dross, etc. Defects adversely affect mechanical properties such as ductility, toughness and fatigue resistance. Entrapped air impairs heat treatment suitability. The most common defect in zinc castings is air entrapment caused by highly turbulent flow of metal in the mould cavity. The trapped air remains in the castings in the form of bubbles and distorts the structure of the casting and deteriorates the electrical conductivity and strength [2, 4, 7, 8].

Castings are typically inspected in raw state or after machining. However, internal defects cannot be detected by the naked eye or even during general quality control. Many methods can be used to determine the amount of porosity in castings. The Archimedes test is commonly used non-destructive method of density determination. Average density is a good indicator of pore volume fraction, but it does not visualise the defects. Detection of internal defects is possible by metallography. The disadvantage of metallography is the high labour intensity of sample preparation involving several stages of grinding and polishing. As metallography can only image one plane, it does not perfectly show the structure and morphology of the porosity in the casting and biased results are expected when assessing the pore size. While macropores can be identified by X-ray, microporosity and bifilms are undetectable. Because internal porosity is a complex 3D structure and simple X-ray image is 2D, the method is inaccurate. Advanced methods such as 3D pore virtualization using X-ray microscopy and image processing technology, or computed tomography provide detailed information to describe the porosity in a casting [2, 4, 6, 9-13].

The use of computed tomography allows accurate and non-destructive 3D reconstruction of the porosity in the casting volume. It uses the passage of X-rays through the sample. A large number of X-ray images (radiographs) of the sample from different angles are taken. These images show the absorption coefficient of the material in each pixel and are used to reconstruct the internal structure of the object. In the case of porosity, a 3D reconstruction of the pores in the casting volume is made using a computational algorithm [6, 10, 11, 13].

Computed tomography was used by the authors of this article in previous works to evaluate porosity of aluminium castings [14]. The aim of current work is use of computed tomography to study porosity in zinc castings. One significant difference between zinc and aluminium alloys is their density with zinc having density approximately 2.6 times higher. Higher density limits passage of X-rays and therefore maximal size of samples. In collaboration with zinc casting company GD Druckguss s.r.o. experimental castings were produced to analyse by computed tomography both the porosity in the castings and the possible changes in porosity during long-term use of the die casting mould.

2. MATERIALS AND METHODS

The investigated castings are produced by HPDC from zinc alloy ZP0410, which contains 4% Al and 1% Cu. The mould is made of AISI H11 steel and is constructed with two cavities. The castings are referred to as K3 and K4 according to the cavity designation. For the analysis of the internal structure, samples were taken during the lifetime of the mould, both from the new mould and then after approximately every 100,000 shots. Every time, 3 samples of K3 castings and 3 samples of K4 castings were taken.

The samples were analysed by computed tomography on a Werth TomoScope XL. WinWerth software was used to create a reconstruction of the cavity distribution in the castings. This software allows for a colour visualisation of the cavities in the casting volume. It is also possible to rotate the 3D model and observe the structure from different angles or add labels with information about the individual cavities. Each casting was analysed in this way and a picture of it was created to study the distribution of the cavities. From the volume of the casting and the sum of the volume of the cavities, the proportion of porosity in the casting was determined. Furthermore, the total number of cavities was counted.

3. RESULTS AND DISCUSSION

A total of 48 castings were analysed by computed tomography. To give an idea of the porosity structures obtained, selected castings K3 and K4 from the new mould, after 400,000 and 700,000 shots, are shown in **Figure 1**.

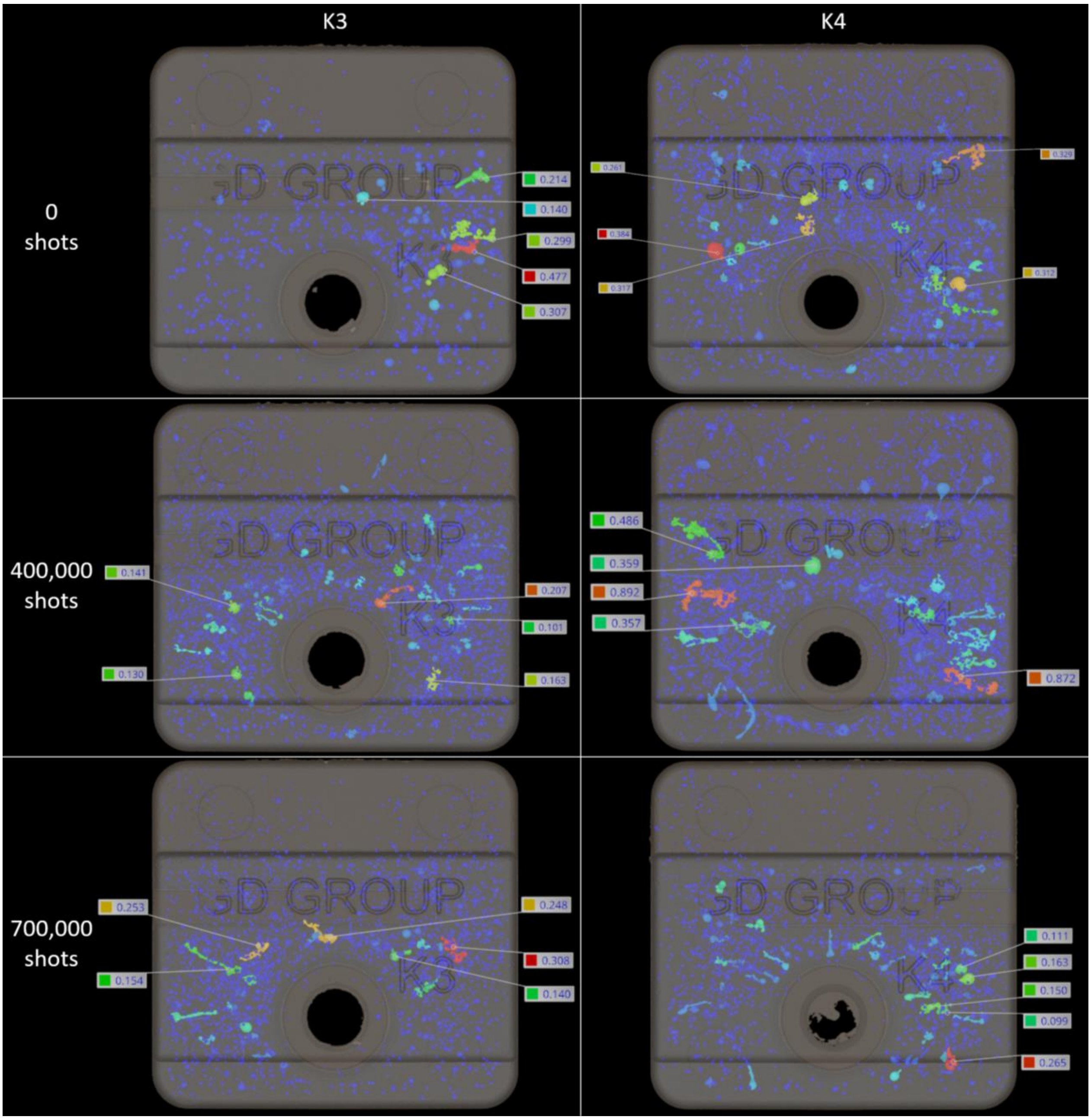

Figure 1 CT images of selected K3 (left) and K4 (right) castings from new mould (top row), after 400,000 shots (middle row) and after 700,000 shots (bottom row). Volume of five biggest cavities in mm^3 is indicated

Both microporosity and macroporosity are present in all castings. The microporosity is present uniformly throughout the volume of the castings. The larger cavities are distributed mainly around the central hole where the wall thickness is highest.

Graph on **Figure 2** shows number of cavities in castings K3 and K4 during mould lifetime.

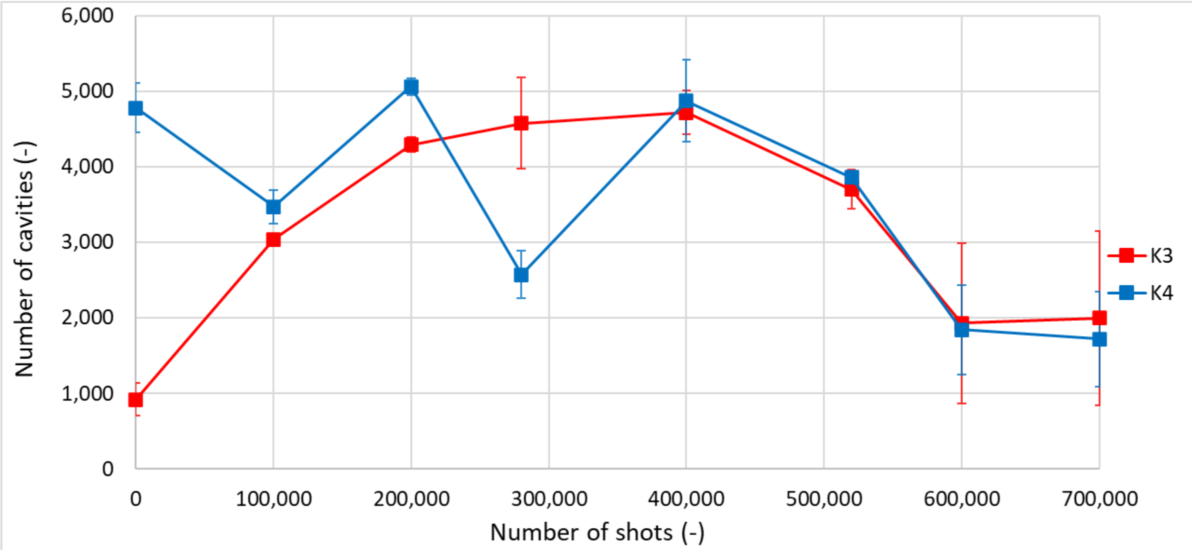

Figure 2 Number of cavities detected by CT in castings K3 and K4 during mould lifetime

The number of cavities found in the K3 and K4 castings differed up to 400,000 shots, after which they were evened. The K3 castings from the new mould contained an average of 921 cavities. After 100,000 and 200,000 shots there was a more significant increase to 3,043 and 4,295 cavities respectively. After 280,000 shots the increase was lower to 4,579 cavities and reached a maximum of 4,717 cavities after 400,000 shots. This was followed by a decline to 3,700 cavities after 520,000 shots and 1,930 cavities after 600,000 shots. After 700,000 shots the number of cavities increased slightly to 2000. The K4 castings from the new mould contained much more cavities than the K3 castings, namely 4,784. During the use of the mould, there were significant changes, first a decrease to 3,471 cavities after 100,000 shots, an increase to a maximum of 5,062 cavities after 200,000 shots, a significant decrease to 2,575 cavities after 280,000 shots and finally an increase to 4,875 cavities after 400,000 shots, where the K3 and K4 castings were evened. This was followed by a similar decline to that of the K3 castings to 3,863 cavities after 520,000 shots, 1,843 cavities after 600,000 shots and a slight decline to 1,718 cavities after 700,000 shots.

The internal porosity of the castings K3 and K4, expressed as the percentage of the cavities volume from the casting volume, over the lifetime of the mould is shown in **Figure 3**.

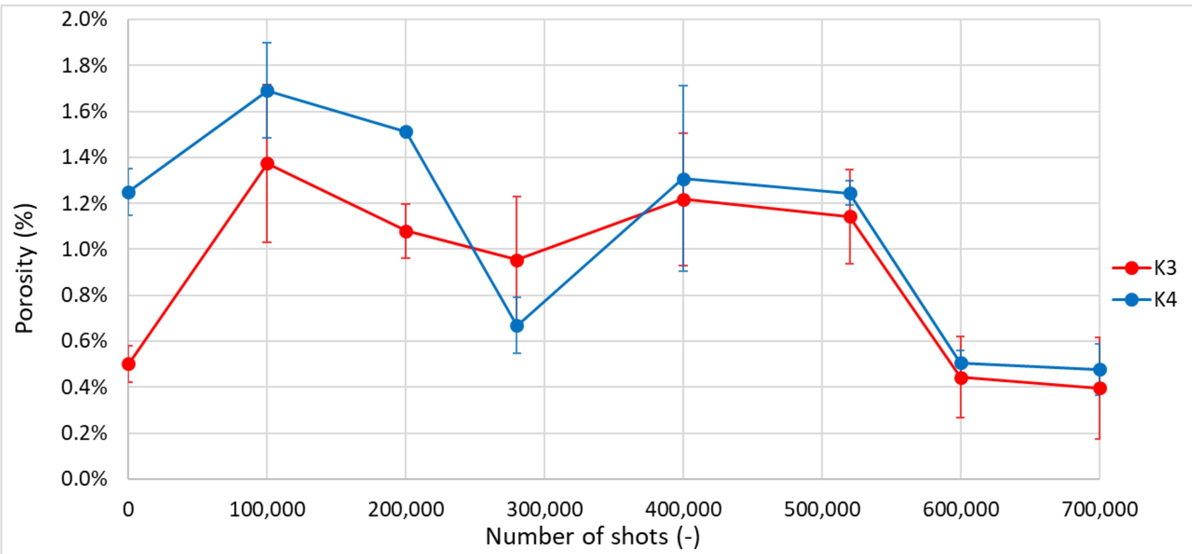

Figure 3 Porosity detected by CT in castings K3 and K4 during mould lifetime

The detected porosity was different in castings K3 and K4 up to 400,000 shots, then the trends were similar with the porosity in casting K3 being slightly lower. The porosity of K3 castings from the new mould was 0.50%, with an increase to a peak porosity of 1.38% after 100,000 shots followed by a decrease to 1.08% after 200,000 shots and 0.96% after 280,000 shots. After 400,000 shots, the porosity increased to 1.22%. After 520,000 shots, there was a slight decrease to 1.14%. After 600,000 shots, the decrease was more pronounced to 0.44%. After 700,000 shots, there was only a slight change to 0.40%. The porosity of the K4 castings from the new mould was 1.25%. After 100,000 shots the porosity increased to a maximum of 1.69%. This was followed by a decrease to 1.51 % after 200,000 shots and a more significant decrease to 0.67 % after 280,000 shots. After 400,000 shots, the porosity increased to 1.31%. Thereafter the behaviour was similar to castings K3. There was a slight decrease to 1.24% after 520,000 shots and a significant decrease to 0.51% after 600,000 shots followed by a slight change in porosity to 0.48% after 700,000 shots.

4. CONCLUSION

The presence of porosity in zinc alloy castings was evaluated using computed tomography. The castings were produced by HPDC from ZP0410 alloy. Castings collected during the deployment of the mould up to 700,000 shots were evaluated. By evaluating the 3D reconstruction of the cavity distribution in the casting, it was found that all castings exhibited microporosity throughout their volume. Larger cavities occur around the central hole where the wall thickness is highest. In terms of the number of cavities and porosity, it was found that castings K3 and K4 behave differently up to 400,000 shots. The number of cavities increases steadily for casting K3 and alternately increases and decreases for casting K4. After 400,000 shots, the number of cavities in both castings gradually decreases to values of around 2,000 at 700,000 shots. The porosity in casting K3 first increases significantly, then decreases slightly and then increases again slightly. The porosity in casting K4 first increases, then decreases significantly and then increases again. After a wear of 400,000 shots, both castings show a gradual decrease to 0.4% at 700,000 shots, similar trend as with the number of cavities.

Computed tomography has been shown to be a reliable method for the comprehensive assessment of porosity in zinc alloy castings. Further planned work includes comparison of computed tomography results with metallographic sections of castings and numerical simulations of porosity occurrence.

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