INTRODUCTION TO THE METHODOLOGY OF THE STUDY OF OPERATIONAL WEAR OF EXPERIMENTAL SHAPED PARTS OF MOULDS FOR HPDC OF ZINC ALLOYS

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Abstract

This research article introduces a methodology for studying the operational wear of experimental shaped parts of moulds for high-pressure die casting (HPDC) of zinc alloys. The study includes roughness analysis and geometric dimensioning and tolerancing (GD&T) based on a coordinate measuring machine (CMM) and 3D scanning to quantify the wear of the mould parts due to contact with the zinc alloy melt and solidifying castings during the HPDC process cycles. The research aims to improve the understanding of the mechanisms of mould wear in HPDC of zinc alloys if different types of steel grades and their production technologies are applied during a hundred thousand casting cycles. The results show roughness and geometrical changes on the surface of shaped parts of moulds made from H11 steel grade conventionally, respectively additively manufactured by selective laser melting (SLM).

The results so far have shown that the shaped parts of the mould made of conventional H11 steel after 500,000 or additively manufactured H11 steels show the good shape and surface stability after 100,000 casting cycles. Until now, it has not been possible to determine the negative effect of the given HPDC process on the wear of the studied shape parts of the moulds using the above methods; the analyses will continue until their final wear. In parallel with evaluating the shape and surface of the shaped parts, these parameters are also assessed for the zinc alloy castings. However, the evaluation can't be squeezed into the required scope of this contribution. In the following research phase, also metallographic methods will be applied to study the quality parameters of both shaped mould inserts (after their wear) and castings (after different numbers of casting cycles) too. The final and tested methodology, in connection with other extensive outputs of the research and development carried out within the framework of the solved project, should be helpful for designers and manufacturers of shaped parts of moulds and for the own HPDC of zinc alloys.

Keywords: H11 steel, additive manufacturing, mould parts, wear, 3D scanning, CMM, roughness, zinc alloy, die casting

1. INTRODUCTION

High-pressure die casting (HPDC) of metals is a modern technology that allows mass production of even very complex parts with thin walls, depending on the casting machines used, the types of alloys and customer requirements. Compared to other foundry processes, the nature of HPDC allows a high degree of automated production with casting weights ranging from a few grams to tens of kilograms. This makes production via HPDC economical [1,2]. The process is extremely fast and since die casting is precise and repeatable, the castings are almost in their final state, requiring relatively small or no finishing operations [3]. The mould is one of the most important parts of the HPDC process. It is in the shaped mould part where liquid metal solidifies and the casting gets its shape [4]. The temperature of the mould along with other factors affects the final surface quality of the castings, the development of some internal defects and the final dimensions [5]. The production of die-casting moulds and their shaped parts is primarily carried out using conventional machining methods. However, these machining methods have limited capabilities and thus are not always able to provide optimal mould geometries, be it for venting or cooling. Therefore, the focus is directed towards additive manufacturing (AM) technologies, which provide considerable freedom in mould design, i.e., for conformal cooling [6]. In additive manufacturing, three-dimensional objects are created by successively adding layers of material according to a digital model. This process allows the production of complex parts directly from the design, without the need for additional tooling and reduces the number of manufacturing steps. Apart from the production of the die casting moulds, the use of AM is being explored in the medical, aerospace, energy or automotive industries [7,8]. AM also enables the processing of materials that are difficult to machine conventionally, such as hard metals, ceramics or composites [9]. One limitation of AM is the long production times, which can reach hundreds of hours. Possible solution is the use of AM only for the creation of a part with a unique geometry on a conventionally manufactured base [10,11]. Various methods are used to evaluate the lifetime and wear of the moulds. These include light and electron microscopy for microstructure and defect evaluation, surface roughness and hardness measurements or tribometers for wear assessment [12-14].

The company GD Druckguss specialises in HPDC of zinc alloy castings. Moulds with conventionally produced shaped parts made mostly of H11 tool steel are used for production. Experiments are currently underway with the use of mould shaped parts produced by AM from H11 powder steel. The surface evaluation of these shaped parts is carried out through roughness measurements. 3D scanner and a coordinate measuring machine are used to determine dimensional consistency during use of the mould.

The aim of the work presented in this paper is to describe the design of the experimental mould and to present the methods used to assess wear during use and to determine the service life. Comparisons are made between shaped mould parts produced by conventional machining methods and by AM.

2. MATERIALS AND METHODS

The examined mould is designed as a two-plate without slides. Two shaped parts intended to test the geometries subjected to the most stress and thus prone to developing defects during die casting are fitted into the mould plates. The mould shaped parts are designed as interchangeable. **Figure 1** shows the mould model and the investigated mould shaped part itself.

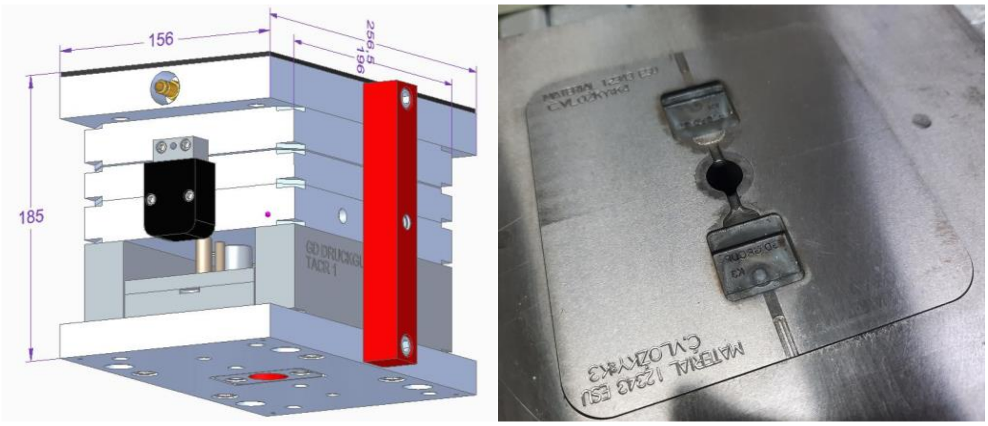


Figure 1 Model of mould assembly (left) and interchangeable shaped parts K3 and K4 (right)

To assess wear, the shaped parts are tested as new before being put into service and then after approximately every 100,000 shots. Currently, a shaped part made by conventional machining from H11 steel has been evaluated up to 520,000 shots. A shaped part made by AM from H11 powder steel has been evaluated prior to commissioning and after 100,000 shots so far and is further deployed for more wear testing. The mould consists of a fixed and a movable plate and two interchangeable shaped parts are located in each plate. Thus, the working section of the mould under examination consists of four shaped parts, designated K1-K4. Due to the limited scope of this paper, only the results of the shaped part K3, which is located on the fixed plate of the mould, will be presented.

Three methods were used to investigate the shaped parts: 3D scanning using a ROMER Absolute Arm 7525SI laser scanner (hereafter 3D Scanning). A coordinate measuring machine Thome Präzision GmbH (hereafter CMM) and a roughness measurement using a Mitutoyo Surftest SJ-410 Surface Roughness Tester (hereafter Roughness Tester).

In the 3D Scanning, the obtained point cloud was aligned using the method to the plane, axis and centre point on the CAD model of the mould. The colour range of the dimensional variations is 50 to -50 μm with a step of 5 μm. This range is outside the required dimensional tolerances of the shaped parts; however, the method provides an overview of the condition of the shaped part. For comparison, points were selected and then measured using a CMM.

The CMM provides suitable accuracy (5 μm) at individual measurement points, but it does not allow measurement of the whole object, so the measurement points were defined for the shaped parts. Alignment is performed using the same method as for 3D Scanning, i.e., on the plane, axis and centre point.

The Roughness Tester provides a direct roughness value to the nearest thousandth of a μm. The measurement is performed over a section of 80 μm. Thirteen positions in the shaped part of the mould were selected for measurement. Their position in part K3 is shown in **Figure 2** along with a detail of this mould part.

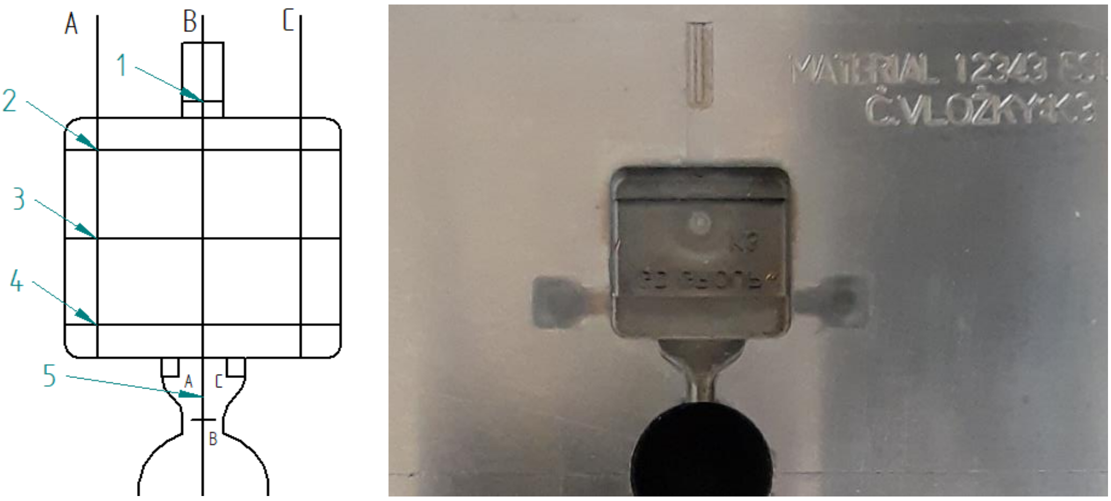
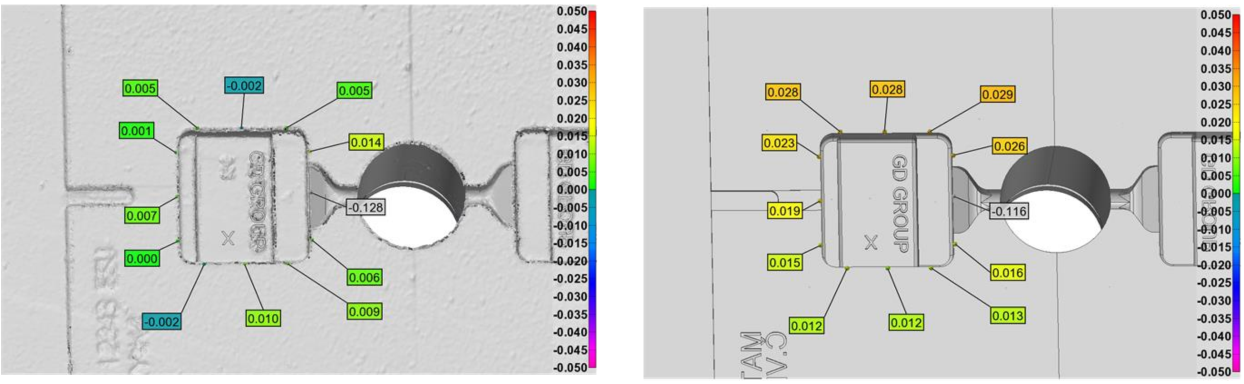


Figure 2 Positions of roughness measurement in the part K3 (left), detail of the shaped part K3 (right)

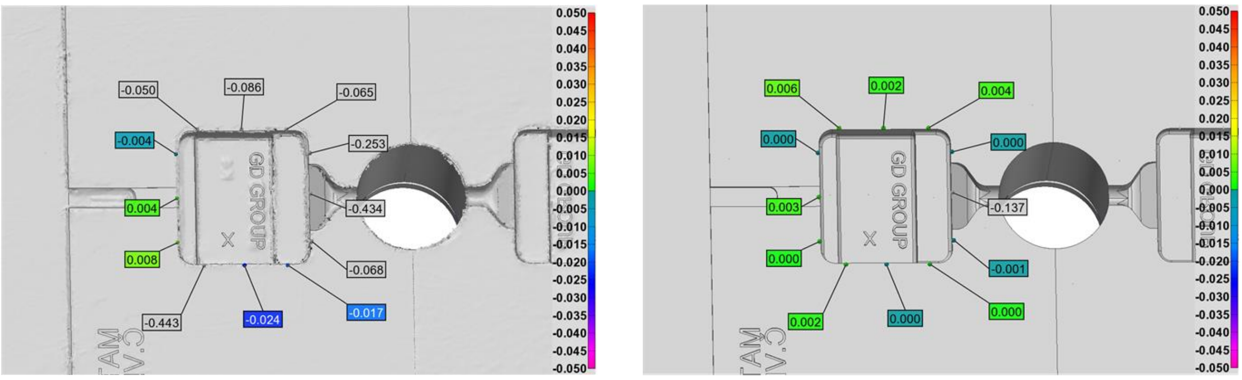
3. RESULTS AND DISCUSSION

Currently, an evaluation of a new shaped part made conventionally from H11 steel was carried out and then after 100, 200, 280, 400 and 520 thousand shots. The shaped part made by AM from H11 steel was evaluated as new and then after 100,000 shots so far. 3D Scanning, CMM and Roughness Testing were carried out at each stage. **Figure 3** shows the results and comparison of 3D Scanning and CMM for the conventionally manufactured shaped part as new and after 520,000 shots. **Figure 4** then shows the results for the AM shaped part as new and after 100,000 shots.



a) 3D Scanning, conventional part, new

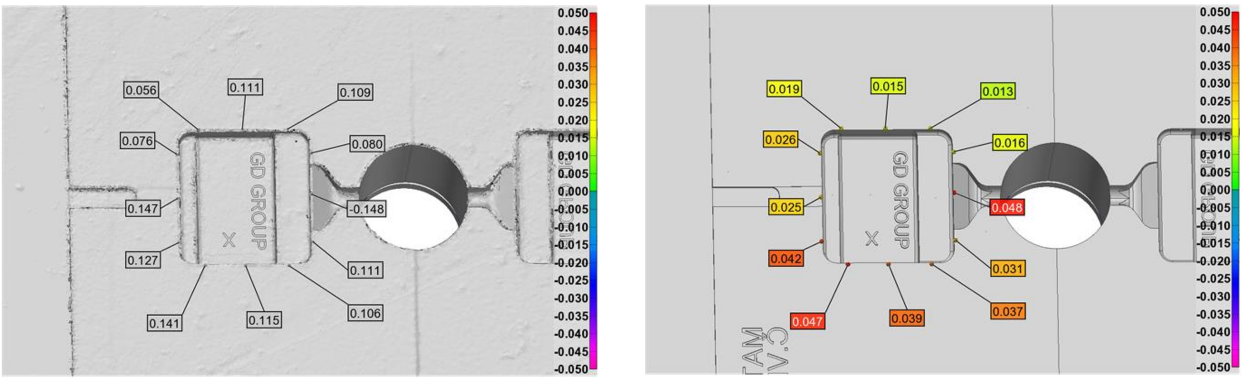
b) CMM, conventional part, new



c) 3D Scanning, conventional part, 520,000 shots

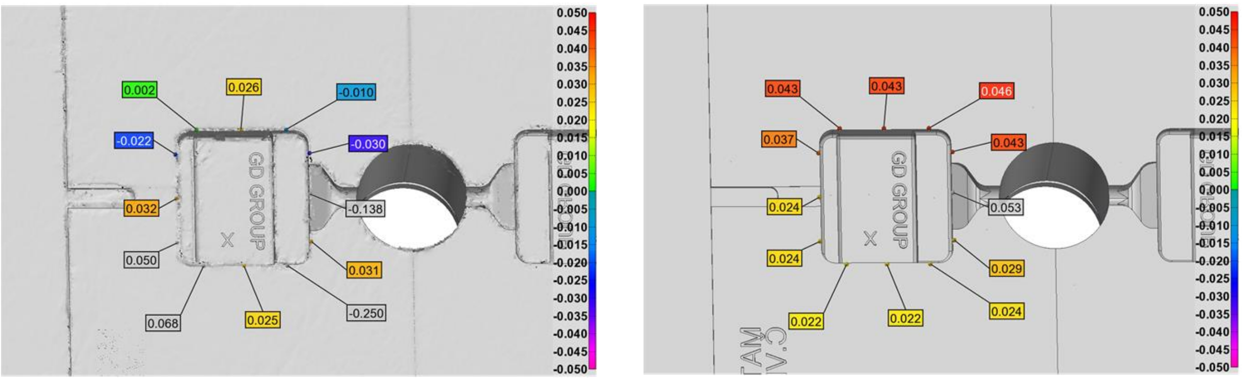
d) CMM, conventional part 520,000 shots

Figure 3 3D Scanning and CMM of a conventionally manufactured shaped part K3



a) 3D Scanning, AM part, new

b) CMM, AM part, new



c) 3D Scanning, AM part, 100,000 shots

d) CMM, AM part, 100,000 shots

Figure 4 3D Scanning and CMM of an AM shaped part K3

From **Figures 3** and **4** it can be seen that less accuracy is achieved in 3D Scanning than in CMM. The grey values are outside the 50 μm tolerance for the dimensions of the shaped parts. Comparison of the CMM of the new conventional (**Figure 3b**) and new AM (**Figure 4b**) shaped parts shows that higher dimensional accuracy was achieved with conventional manufacturing. In the case of the conventionally manufactured shaped part the range of dimensional deviations decreased with further use (520,000 shots, **Figure 3d**). This cannot be said for the AM shaped part, where after 100,000 shots some deviations have decreased, others have increased (**Figure 4d**). More thorough comparison will be possible when the same wear rate is achieved for both shaped parts.

Figure 5 shows changes of roughness during usage of the conventionally manufactured and AM shaped part K3. The individual measured points correspond to the schematic in **Figure 2**.

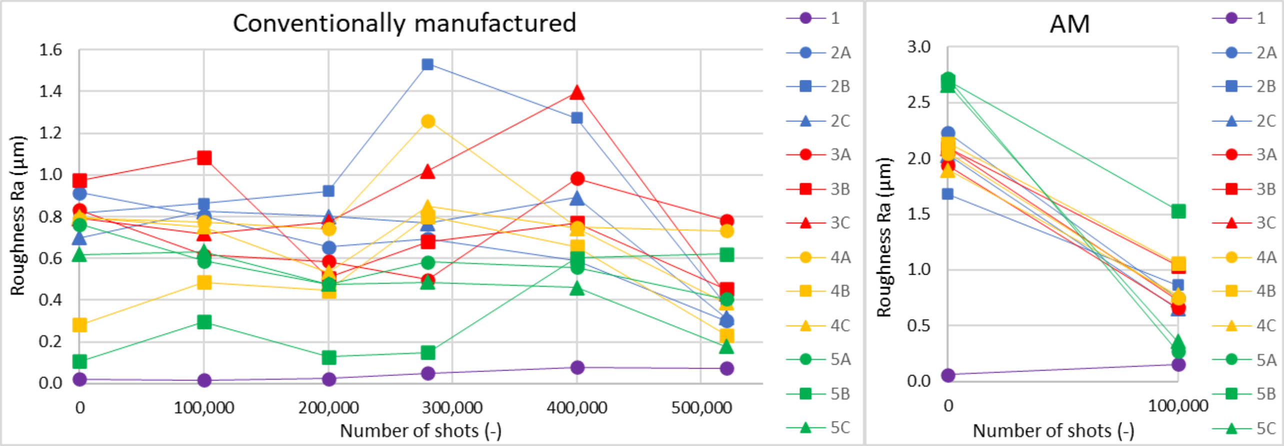


Figure 5 Evolution of the roughness of the shaped part K3. Left conventionally manufactured, right AM

From the graphs in **Figure 5** it can be seen that the conventionally manufactured shaped part has undergone significant changes in roughness during use, but it can be stated that after 520,000 shots the roughness is generally the same or lower than it was in a new part. This may be due to physical or physical-chemical factors related to the elevated working temperature in contact with the liquid and solidifying zinc alloy, during which partial smoothing may occur. However, these effects will only be analysed after the final wear of the shaped parts. Comparing the conventionally manufactured and AM shaped parts, it can be seen that the roughness of the new AM part is generally higher, but after 100,000 shots there is a decrease to values comparable to the conventionally manufactured part, except for position 5B. Generally, except for position 1, there is decrease in roughness of AM part, which does not occur in the conventional part after 100,000 shots. It is also interesting to note that the AM part, with few exceptions, experienced a uniform decrease in roughness.

4. CONCLUSION

Additive manufacturing technologies provide new possibilities in mould design for die casting. At company GD Druckguss AM is used to produce experimental shaped mould parts with conformal cooling for zinc die casting. For comparison, shaped parts of moulds were produced using conventional machining and AM. Steel H11 which is commonly used for die casting moulds was used. Dimensional accuracy was measured for both shaped parts using a 3D Scanner and a Coordinate Measuring Machine. Surface roughness tests were also performed. These measurements are repeated after every approximately 100,000 shots to evaluate the change in the condition of the shaped part during use. For the conventionally manufactured shaped part, 520,000 shots have already been achieved, for the AM part 100,000 shots have been reached so far. The 3D scanning is a contactless method with a lower accuracy, providing a general overview of the surface condition of the measured part. The Coordinate Measuring Machine provides sufficient accuracy for evaluating mould shaped parts, but only measures at individual points. For the conventionally manufactured part, the dimensional deviations have decreased during use, while for the AM part the deviations vary erratically. A relevant comparison will be possible when the same wear is achieved for both parts. The roughness measurements have so far shown that the conventionally manufactured part has lower roughness values than the AM part and that there are changes in roughness during use. The AM part has only shown a decrease in roughness as of yet.

The aim of the follow-up work is to further evaluate the shaped mould parts during continued use until comparable wear is achieved and relevant data can be compared. Attention will also be directed to the evaluation of castings from both mould parts by the presented methods. Those will be further complemented by metallographic analysis or computed tomography scanning. At the end of the service life of the shaped mould parts, it is intended to carry out comprehensive analyses in order to clarify the physical and physical-chemical factors affecting them when working at elevated temperatures in contact with solidifying zinc alloy melt.

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