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Quality Analysis of Mould Insert Produced by Additive Technology

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Abstract

The paper deals with monitoring the quality of a shaped part of a mould made from H13 tool steel using additive manufacturing. The shaped part of the mould is a key element in the casting of aluminium alloys by high pressure die casting (HPDC) technology and has a major influence on achieving the desired quality of the casting. This paper presents an evaluation methodology which includes the results of surface quality analysis and dimensional accuracy and stability of additively manufactured parts. These analyses were carried out from the production of the mould part to its application in the foundry operating conditions. The comprehensive analyses offer an overall view of the changes caused by individual technological operations. These operations are additive manufacturing, heat treatment, machining, and final coating before implementation into the operating conditions of the foundry. The paper also describes monitoring the quality of the mould part in regular cycles during the production of aluminium castings. This methodology and the results provide new insights in the field of engineering metallurgy.

Keywords: Dimensional analysis, 3D scanning, 3D CNC CMM, Roughness measurement, High-pressure die casting (HPDC)

1. Introduction

3D printing is used extensively in industrial manufacturing, specifically in the automotive, aerospace, and electronics industries [1]. Additive manufacturing, specifically 3D printing, can be used to great advantage over conventional manufacturing. A major advantage of 3D printing is the ability to create complex geometries and internal features that traditional technologies cannot produce [2]. CNC machining technology is used for finishing to improve the surface quality of 3D printed parts [3].

Measuring on a 3D scanner allows contactless digitization of objects. Optical, laser, and touch scanners are currently available. 3D scanning is used in reverse engineering to digitize existing parts for implementation into digital models, as well as for quality control to compare the scanned data with the CAD model [4] and, last but not least, in rapid prototyping for fast manufacturing of prototypes using additive manufacturing [5].

A coordinate measuring machine is used to check the dimensions and shapes of components with high accuracy. Furthermore, the method is used for calibrating tools used, for instance, in machining or engineering. This technology has a very important role in advanced industries [6].

Surface roughness measurements are used for surface inspection of components and for tribology, which studies friction, and surface wear under the influence of e.g. a metal in the liquid state [7]. An important variable in surface roughness measurement is the orientation of the component after printing [8]. Measuring printed components is challenging using this measurement technology due to difficult-to-measure features such as narrow channels and pores [9].

Experimental findings illustrate that the production of metal parts using 3D printing is a move in the right direction for advanced technology, thus contributing to the automation of the production of complex and specific components [10].

2. Experimental part

This paper describes the application of the methodology to monitor the quality and durability of the shaped parts of a mould for high-pressure die casting of aluminium castings. With this methodology, the shaped parts are measured after a certain number of cycles, usually based on the operational capabilities of the foundry. The results of this methodology are mapped and presented in colour maps and graphs.

Due to the multitude of results, the component selected for this paper was made using additive manufacturing from H13 tool steel. An overall idea of the lifetime of the shaped mould parts can be obtained from the results. The monitoring was carried out in cooperation with the die-casting division of MOTOR JIKOV Slévárna a.s. (Die-Casting Division).

2.1. Component characteristics

In this paper, the focus is on an additively manufactured component made from H13 tool steel that was operationally tested in a die foundry. This component is the shaped part of a mould. The tool forms the final shape of the hexagonal hole on the casting. The hexagon, or ‘crown’, forms the working surface on the top of the component that comes into contact with the liquid aluminium alloy. A total of 4 pieces were produced using conventional technology and 4 pieces using additive manufacturing. In this paper, the operational life of the selected component is analysed. Figure 1a shows the component in the form of a 3D CAD model to be made by additive manufacturing. In Figure 1b and 1c a real component can be seen which is ready to be deployed in the foundry operating conditions.

Component manufacturing: additive manufacturing, specifically SLM (Selective Laser Melting) technology, was used to produce the component. After converting the component to the stl. format, it is possible to proceed to the actual printing, during which the laser melts and then fuses the deposited powder in layers. The component can then be subjected to further technological operations. These operations are summarised below.

Fig. 1. Example of the analysed component: a) CAD model for additive manufacturing, b) additively manufactured component, c) detail of the working part of the crown

Component heat treatment: during SLM manufacturing, the material is heated and cooled rapidly, which can cause internal stresses. Heat treatment allows the material to cool down gradually, minimising internal stresses and improving the structure of the component. It is also necessary to achieve strength and durability at high temperatures and a prescribed hardness of 46 +2 HRC.

Component machining: in the next technological operation, the component is machined using conventional turning and milling technology. During these operations, the component is modified to the final dimensions according to the drawing.

Component coating: the last preparatory technological operation before the die casting is put into operation is coating. The coating is a high chromium ALWIN nanocomposite coating made up of CrAlSiN. This coating is characterised by a high heat resistance of over 1000 °C which makes it suitable for use on tools in high-pressure die casting of aluminium alloys.

Measurement methods: the following measurement devices were used:

- A 3D measuring laser scanner on the ROMER ABSOLUTE ARM 7525SI,
- Measurements on a THOME PRÄZISION GmbH coordinate measuring machine,
- Surface roughness measurements with the MITUTOYO SURFTEST SJ – 410.

2.2. Measurement on a 3D measuring scanner

The first method used for monitoring the quality is the 3D measuring scanner. This was used primarily because of the principle of the ROMER ABSOLUTE ARM scanner, which combines touch measurement and optical scanning of the component. The scanner is equipped with an optical sensor that enables the measurement of components using a laser beam. Using this beam, it quickly and accurately scans the component surface, generating a number of points from which a polygonal model is subsequently created.

The 3D measuring laser scanner is used to measure complex shapes. A colour map was obtained using this method, which gives the dimensions of the component with an accuracy of 0.05 mm. The device is shown in Figure 2.

Fig. 2. Example of measurement on the ROMER ABSOLUTE ARM 7525SI laser scanner: a) 3D laser scanner, b) component measurement

2.3. Measurement on a THOME PRÄZISION GmbH coordinate measuring machine

The second method used in the study of dimensional accuracy is the measurement on a coordinate measuring machine from THOME PRÄZISION GmbH. The main component of this machine is an arm that is equipped with movable axes that allow it to move in different directions. The measurement itself is carried out by means of a touch probe, which is located at the end of the arm and directly touches the surface of the component. The evaluation of the measurements is carried out in Polyworks software. Another advantage of using this equipment in our research is the possibility of accurate and repeatable measurement of the component. Using this device, precise geometric characteristics are measured at selected points on the component with a measurement accuracy of 0.005 mm. The device is shown in Figure 3.

Fig. 3. Example of measurement on the THOME PRÄZISION GmbH coordinate measuring machine: a) coordinate measuring machine, b) component measurement

2.4. Surface roughness measurement on the MITUTOYO SURFTEST SJ – 410

The third method used is to monitor the surface roughness of the component. This method is used because of the contact of the working part of the component with the molten alloy, where there is a risk of small metal particles penetrating below the surface which may cause deterioration of the surface quality, which would be reflected in the final casting. For this reason, it is necessary to check the surface roughness and detect any deviations from the ideal shape. The equipment is shown in Figure 4.

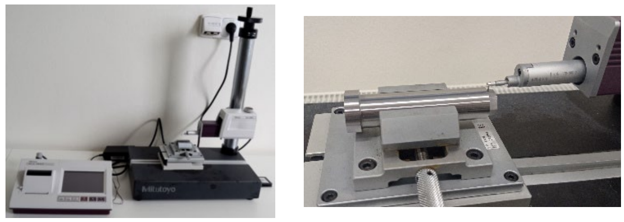

Fig. 4. Example of roughness measurement on the MITUTOYO SURFTEST SJ – 410 devices: a) Mitutoyo rough gauge, b) component clamping

3. Application in practise

The component quality analysis was performed after a certain number of operating cycles. In this paper the focus was on measurements in defined cycles during the operational testing at the pressure foundry of MOTOR JIKOV Slévárna a.s. (Die-Casting Division). Dimensional analysis was performed during all operating cycles. The component after deployment in operational testing and pictures are shown in Figure 5. During the operational testing, a repair was performed after 61 000 cycles.

For this paper, a single component A was selected, which was 3D printed, processed, and then operationally tested.

Fig. 5. Example of component A during operational testing

The analysis of the additively manufactured shaped mould parts aimed to map the lifetime of the additively manufactured components. From this perspective, continuous monitoring of the dimensional and shape accuracy of the body and crown was designed. The measurement of the components was carried out after a certain number of cycles according to the operating conditions of the foundry, with a component lifetime of 130 000 cycles.

3.1. Evaluation of dimensional stability of the component – scanner

Part of the 3D scanning evaluation involved the creation of colour maps to show the dimensional accuracy of the component after each cycle (see Figure 6). Scanning the component provides data on dimensional accuracy and stability. These scans provide information on how the component behaves during operational testing and whether the dimensional accuracy can withstand the specified lifetime of 130 000 cycles.

The colour maps show that the component is still within the required tolerance of ±0.200 mm. The deviation of the measured values on the component body is within ±0.050 mm. On the crown, the deviation was within ±0.100 mm.

Furthermore, in the evaluation of the component after 127 850 operating cycles, due to the higher number of operating cycles, the full wear of the component occurred. The deviation in this case increased to a range of ±0.130 mm and a deviation of ±0.080 mm was determined on the crown.

Since the component is still within the required tolerance, the part can continue to be deployed under operating conditions based on the scan.

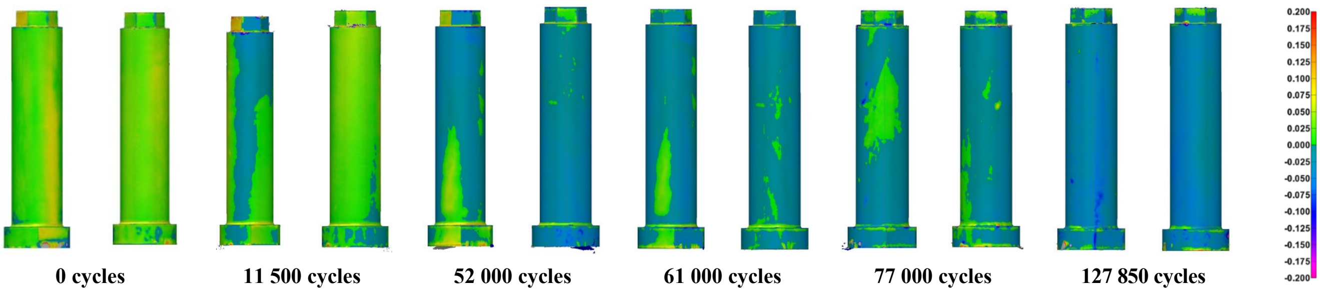

Fig. 6. Colour maps of 3D scanning of component A during operational testing

3.2. Evaluation of the dimensional stability of the component – 3D CNC CMM

Part of the evaluation of the measurements on the 3D coordinate measuring machine involved the creation of a graphical representation of the dimensional stability of the component. By measuring using the 3D CNC CMM method, a comprehensive graphical overview of the behaviour of the component in terms of operational testing was achieved. The body and crown were both measured up to 52 000 cycles. According to an agreement with the industrial partner, the body measurement was abandoned because the working part is only the crown, so the body was measured only up to 52 000 cycles. During the operational testing of the components, it was necessary to correct 61 000 cycles due to damage to the components during removal from the mould.

The graphs in Figures 7 and 8 show the evolution of the values within the tolerance of ± 0.200 mm. After this repair, the variation improved substantially as the deviation was minimal. Measurements using a higher precision CNC CMM were performed on the crown after 77000 cycles. This monitoring found a deviation of +0.400 mm to -0.015 mm. Further, after 127,850 cycles, the deviation ranged from +0.004 mm to -0.029 mm.

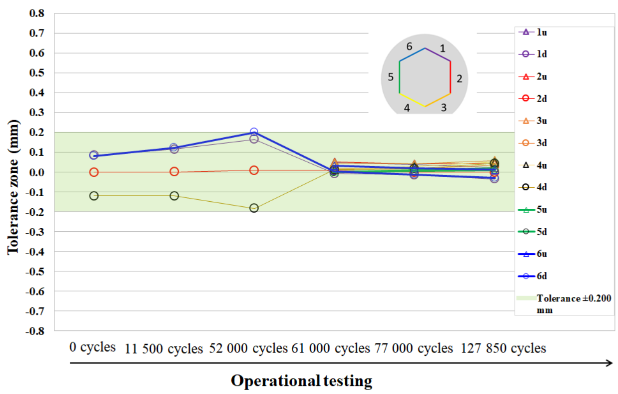

Fig. 7. Evolution of values during CNC CMM measurements on the component crown

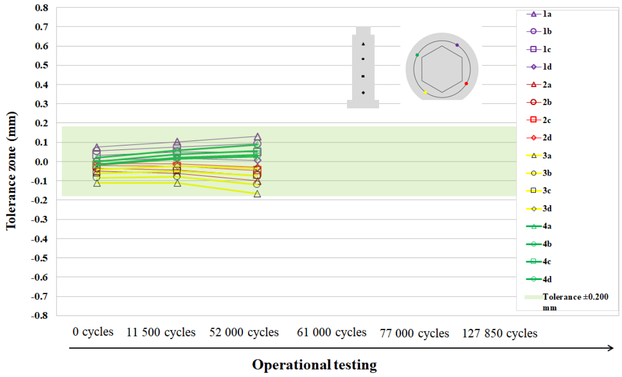

Fig. 8. Development of values during CNC CMM measurements on the component body

3.3. Surface roughness evaluation

The last part was the surface roughness evaluation, where the results were obtained as part of the operational testing of the component. This monitoring provides a comprehensive picture of the evolution of the surface roughness of the component during the operational testing.

As part of the evaluation of the surface roughness measurements, graphs were created from the measured data to show the evolution of surface roughness on the body and crown during the operational testing. Figure 9 shows the evolution of the surface roughness on the component body. The average value of the surface roughness measurements on the body ranged from 0.267 to 0.371 µm, with the value increasing to 0.568 µm after 127 850 cycles.

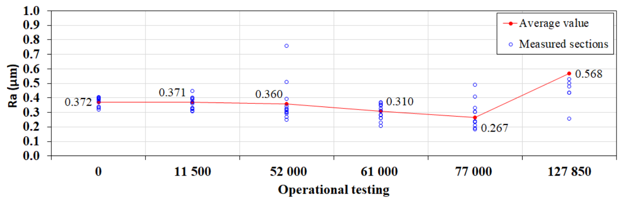

Fig. 9. Evaluation of roughness → body → component A → during individual technological operations

Figure 10 shows the evolution of the surface roughness of the component on the working part of the tool called the crown. The average value of the surface roughness measurement on the crown ranged from 0.256 to 0.421 µm, with an increase to 0.563 µm after 77,000 cycles. During further monitoring, the value decreased again, and it can be seen in Figure 10 that there was only a one-off fluctuation.

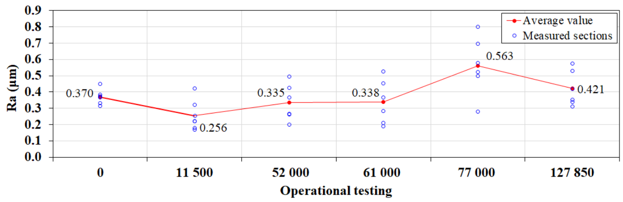

Fig. 10. Roughness evaluation → crown → component A → during individual technological operations

4. Conclusion

This paper described the analysis of an additively manufactured component, which is intended as a working tool in a foundry using high-pressure die casting technology of aluminium alloys. This component was measured at certain numbers of operating cycles usually according to the operating capabilities of the foundry.

- 3D laser scanner and CNC CMM measurement methods were introduced to measure the component. These methods were used because of the accuracy and objectivity of the measured results.
- The results on the 3D laser scanner and CNC CMM correspond to the required tolerance on the drawing, indicating the dimensional stability of the components.
- No effect of operating conditions was evident in the surface roughness measurements. Thus, the component was still of good quality. Continuous measurements showed that there was no significant wear on the component.
- It can be concluded that the proposed methodology enables assessing dimensional accuracy during service life. Using this procedure of lifetime monitoring, it was found that additively manufactured components can be used under operating conditions. It is important to note that continuous monitoring of component lifetime is still needed.
- It should be noted that the specified lifetime of 130,000 cycles was met for the additively manufactured components and the dimensional and shape stability of the components was maintained within the required tolerance.
- The monitoring of the shaped mould part having been carried out, the research team will subsequently focus on mapping the structure of the components using metallographic evaluation.

Acknowledgements

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