Comparison of CT and metallographic method for evaluation of microporosities of dye cast aluminum parts

Tamás Bubonyi¹, Péter Barkóczy¹, Zoltán Gácsí¹

¹ University of Miskolc, 3515 Miskolc, Miskolc Egyetemváros, Hungary

E-mail: fembubo@uni-miskolc.hu

Abstract. Nowadays, the different material characterisation and testing methods are constantly evolving. With modern techniques, we have the ability to take a look inside the product without sample cutting, with modern CT systems. The modern techniques with their development become closer and closer to industrial applications. However, the testing protocols are sometimes 1 or 2 steps behind. This is mostly due to the cost or the complexity of the new testing methods. In this study we would like to take a quick look on the current standard industrial testing of porosities and microcracks and compare them with computer tomograph assisted testing.

1. Introduction

The die casting of aluminium products is a productive and cheap production process of complex shaped parts [1]. The enhanced cooling process is a common nature of this technology. Therefore, the crystallization process is also faster than in a gravitational sand-mould casting. During the fast crystallization gas inclusions and micropores forms in the solid metal [2]. These micropores and gas inclusions act as microcracks during the mechanical load of the parts. Therefore, an important qualification step is the total amount and the measure of the length of the microcracks [3]. According to a classical method the microcracks are evaluated on a metallographic specimen. The micropores are dark in an optical micrograph, so computational image analysis can be used during the evaluation of these [4]. There are two basic question related to this method: the position of the sample, and the interpretation of the measured values.

The position of the sample cannot be uniform, because the microporosity strongly depends on the cross section of the parts next to the process parameters [5]. So generally, it is described by the customer, and based on the description they try to define the worst case in the part.

During the interpolation of the result it must be taken into account that the metallographic sample shows only one section of the specimen instead of spatial information. The stereology helps to transform the measured values from section to spatial values, but this conversion is statistical, and it needs more sections or more micropores to give a stable and robust result [6]. In most cases just few pores can be found in the examined section, so this statistical evaluation is not possible. But the position of the sample can be determined based on the planned stress state, and simple acceptance rules can be deformed as the maximal pore length must be less than a limit [7].

But new samples are necessary from the same part for a detailed study of the pore structure. Additionally, the metallographic examination is a destructive testing method [8], so creating statistics about the processing technology is an expensive process.
The material characterisation went through some great improvements in the last decade. The keywords in today’s research field are the 3D, or non-destructive characterisation of the materials with as many details as possible, on the best resolution possible [9]. However, the industry still uses the old sample cutting method. In this case the biggest investment is some good optical microscope, and the sample preparing tools. This method could work, if the product is well known, and there are some specific failing points. But if the technology or the whole product changes, the porosities or cracks could be elsewhere. The only way to characterise the product with this method is to take a guess and try to find the worst case.

Today the 3D imaging devices like computer tomography [10] are more common and can help greatly during the investigation of the worst case in the product. Therefore, the result of a metallographic testing and a tomography is compared to show difference and parallelism of the two method through the evaluation of the microporosity of die cast aluminum part.

2. Materials and methods
An aluminum housing was chosen which was produced by die casting. The raw material of the casting is EN-AC47100. The nominal composition of the alloy is: 10.5-13.5w/w% Si, 0.7-1.2w/w% Cu and max. 1.3w/w% Fe, beside the aluminum. The housing and the typical microstructure are shown by Figure 1.

The pore structure is evaluated on the micrographs (Figure 2). Based on the tomographic image, the worst place and position of the metallographic samples are determined. The metallographic samples were cut by sawing. The examined surface of the sample was grinded mechanically by SiC particles, then polished by 3 and 1 µm diamond particles. The polished surface was etched by immersion to HF solution. Micrographs were taken by a Zeiss AxioImager M1m optical microscope. The micrographs were analyzed by computational image analysis with a self-developed Cprob software. The analysis algorithm is simple, because there is a big contrast difference between the pores and the aluminum material. The aluminum has a high contrast while the pores are dark. So, the segmentation was made based on the gray contrast on the images. Just the small digital noise was filtered by a binary open operator on the segmented image. Then the pores are indexed, and the distance of the outermost points is measured in the pores as the length. Additionally, the distance between the nearest pores also measured. The nearest pores are determined by a SKIZ operation [4], and the closest point of the nearest pores are measured as a distance. Some evaluations a distance limit is determined, and closest pores have to be handled as one big pore. In this case the length of the big pore is the sum of the pores and distances affected by this evaluation. The length of the pores and the images are compared.

3. Results and discussion
Figure 1. shows the examined housing with the position of the samples. Two samples were cut from the part for metallographic testing. The positions of the samples are selected by the tomographic image. Sections with large pores are chosen. The samples were prepared for optical microscopy, and micrographs were taken. Figure 1. also shows some micrographs where the typical microstructure also can be studied. The nominal composition is close to the eutectic composition of the Al-Si alloy system. According to it a fully eutectic microstructure can be seen on the micrograph. The eutectic structure is fine, and the silicon is not a plate like in the eutectic. The eutectic structure is modified to achieve a better mechanical property. The modification turns the silicon into small plates and globular particles. All micrograph contains micropores, which are the dark objects with different shapes. The globular objects like spherical shapes are probably gas inclusions. The others are micropores formed during the shrinkage in the solidification process.

Figure 2. shows typical sections of the tomographic reconstructed 3D images, measured with an YXLON FF35 MicroCT. The parameters of the test are summarized in Table 1. As it can be seen, the background of the images is dark while the aluminum material is bright, so the micropores – microcracks are visible also in dark color. The image shows a top-view section, and a section according to Figure 1.
On both sections the micropores are visible and can be measured by the software package of the tomography equipment.

The micropores on the sequence of optical micrographs are measured by the mentioned image analysis software. As it shown the pores are dark in the bright field illuminated images. The segmentation of the pores can be made by the intensity level of a grayscale image (Figure 1 and Figure 3). The segmented objects, the pores can be evaluated. The main measure of the pores is the length. The area, especially the area fraction of the pores on a section is also important as an impact to the static mechanical properties, but the fracture mechanics determines a maximal length based on the planned stress state of the part. This length basically the diameter of the plane section of the pores in case of a general single pore. But in a case of clustered pores the length is different. There are definition practices for the evaluation of this case. The common aspect of all method, that enumerate the clustered pores as a single large one. That pores belongs to the cluster which are closer that a critical distance. This critical distance can be derived from fracture mechanics and the stereology of the spatial pore and its plane sections. In current study we define this critical distance as 7µm, and the length of the clustered pore are measured as the distance of the farthest contour point of all pores in the cluster. There is possible descriptor based on the measured lengths: the average and the maximal length of the examined section. Therefore, the average, and the maximal length of the micropores are compared together. The values are reported in Table 2.

![Figure 1](image1.png)

**Figure 1.** The metallographic results. The tested part is in the middle, while the two sample is on its sides. Below the macro photos of the part, is the optical micrographs showing the worst cases in the vertical and horizontal sample, and the second worst case on the horizontal sample.
Figure 2. CT sections of the sample. a) is the top view, b) is the front view.

Table 1. Test parameters of the CT imaging.

| Test parameters               | Value 1 | Value 2 |
|------------------------------|---------|---------|
| number of projections        | 1080    | Voxel (mm) | 49.6 |
| focal-object distance (mm)   | 410     | accelerating voltage (kV) | 150  |
| focal-detector distance (mm) | 1150    | sample current (mA)       | 80   |
| magnification                | 2.80    |          |      |

Table 2. Length of the micropores measured by the different techniques.

|               | Metallography | CT     |
|---------------|---------------|--------|
| mean (mm)     | 0.175         | 3.9    |
| std. dev.     | 0.427         | 1.65   |
| maximum       | 2.56          | 6.94   |

The length of the pores can be measured directly on the tomographic image. Here also important the definition of the length. In current study also the so-called length, the diameter is used for the evaluation. The determination of this measure is a simple and easy process in the evaluation software of the equipment. The result of the measurement also a single value, but in the evaluation is necessary to take into account its spatial character. So the length of the micropores is larger on the CT image. A large deviation can be seen in the mean value the measured lengths. But there is a large difference in the resolution of the different images too. While the smallest object in this case in the CT images is ~50µm, the same in the optical images is around 1µm. The optical microscopic survey reveals much smaller objects than CT which causes this large deviation in the mean value. The standard deviation is in both cases so large, because there are large micropores next to small ones. The maximum value measured by CT is nearly 2.7 times larger than in optical microscopic tests. It is important when the evaluation of the part is made by the maximal length.

Plane sections of the CT image and the metallographic results are compared to evaluate the abovementioned difference in a so-called critical section. The position and the place of the examined metallographic section are chosen based on the analysis of CT images, but the metallographic is a section without depth in spatial coordinates. This can distort the section related to the CT image, and gives a smaller maximum. But the largest micropore was found and measured in the chosen section.
Figure 3. a) pore in 3D CT image, b) pore in 2D CT image, c) pore after sample cut and preparation, d) pore analysis on optical micrograph

To validate the results above, one object is identified on the tomographic and the same in the microscopic image (Figure 3.). The unique shape and the position of the pore was used to identified in both images. Additionally, it is found in the prepared section. The length was measured by both techniques. The CT measurement gives 1.87mm and the image analysis gives 1.64 mm. The two values are close together, which validates the two method, and the comparison. But in an automated testing the image analysis gives 2.08mm as the length of this object, because there are small pores next it, which are not present in the CT image, which is another difference between the two tested method.

4. Summary
CT and optical microscopy and image analysis are compared in the evaluation of micropores in a die cast aluminum housing. Two basic differences between the two different methods are that the CT is a nondestructive method while for optical microscopic testing a sampling is necessary. Therefore, first the CT imaging was made. Based on the CT examination, the worst position and the place for the sampling were chosen. Samples were cut from the housing and prepared to metallographic examination. Computational image analysis measured the length of the pores on the optical micrographs. Large difference was found between the means of the measured lengths. The resolution of the two type of images differs, smaller objects are identified and measured on the microscopic images. Therefore, a much larger mean of length is evaluated. Between the maximum lengths there is lower difference. The maximal length is 2.7 times larger in CT images. The metallography shows just a section of the housing; therefore, this difference can be found there. But the largest micropore is measured in the same position with both techniques. This large difference makes the validation necessary. A micropore is identified by
its unique shape and position, and the measured lengths are compared. The CT and the metallography give nearly the same result, so this measurement shows that the differences really originate from the sampling and the mentioned specialty of the tests. The advantage of the metallographic tests that these can reveal the microstructure, and the solidified structure can be evaluated next to the porosity. But this comparison shows the importance of the proper determination of the examined section in case of metallographic tests.

Acknowledgements
Supported by the únkp-19.3 new national excellence program of the ministry for innovation and technology.

References
[1] K. Anderson et al. 2018 Aluminum Science and Technology ASM Handbook Vol. 2A
[2] S. H. Davies 2001 Theory of Solidification, Cambridge University Press
[3] D. Sui et al. 2016 International Journal of Metalcasting, 10, pp. 32–42
[4] J.F. Friel 2000 Practical Guide to Image Analysis, ASM International
[5] R. Elliott 1983 Eutectic solidification processing : crystalline and glassy alloys
[6] M. Sumanasooriya, N. Neithalath 2009 Aci Materials Journal, pp. 428-38
[7] B. Zhang et al. 2005 Casting defects in low-pressure die-cast aluminum alloy wheels, JOM, 57 pp. 36–43
[8] G.F. Vander Voort et al. 2014 Metallographic Assessment of Al-12Si High-Pressure Die Casting Escalator Steps, Microscopy and Microanalysis, 20, pp. 1486-93
[9] N. Pears, et al. 2012 3D Imaging, Analysis and Applications, Springer
[10] J. Baruchel et al. 2000 X-Ray Tomography in Material Science, Hermes