# ANALYSIS OF ALUMINIUM FOAM PORE SIZE BY COMPUTED TOMOGRAPHY

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**Abstract**

Aluminium foams are highly porous material whose properties are highly dependent on the shape and size of the pores. Production processes are still not perfected, resulting in pores of uneven shape and size, which worsens their mechanical properties. In order to gain insight into the internal structure of foamed aluminium, i.e. to find out the arrangement of the shape and size of the pores, the sample needs to be cut, which actually leads to its destruction and the impossibility of conducting further mechanical tests. To avoid this, analysis of the arrangement and size of the pores is performed using computed tomography (CT), which involves scanning the sample using X-rays to obtain a three-dimensional model of the foam. This paper describes the procedure of scanning aluminium foam by computed tomography as well as cross-sectional analysis of a three-dimensional model.



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## 1. INTRODUCTION

Although computed tomography (CT) is most often associated with medical examinations, it is also widely used in industry, where it is applied as one of the methods for non-destructive testing. The application of industrial CT is focused on comparisons of finished objects and CAD models, measurement of wall thickness and detection of unwanted pores or cracks in objects.

Metal foams are highly porous materials that mostly consist of pores between metal walls. Due to the still imperfect methods of production of these foams, the pores are mostly of different and unpredictable shapes and sizes, which affects their mechanical properties. As a method that allows insight into the morphology of foams, computed tomography is ideal for analyzing the shape and size of metal foam cells [1, 2] in order to determine correlations with mechanical properties and mechanisms of cell wall deformation [3, 4]. From the scanned model, it is possible to develop a numerical model using finite element methods (FEM) that can describe and predict mechanical, thermal and acoustic properties, without the need for complex experimental tests [4, 5].

An ex-situ compressive testing and CT scanning can be performed to gain insight into the foam structure during mechanical testing. In this case the sample is compressed in several stages, for example every 10 % of the deformation, and after each stage it is placed in a CT device to scan the newly formed morphological condition [4, 6, 7]. The problem with such ex-situ process is that the sample is plastically deformed again with each subsequent loading until the previous stage is reached, and gradually hardens by the compressive deformation. A more accurate relation between foam morphology and mechanical properties is achieved by in-situ compressive testing, when the mechanical loading test set is an integral part of the CT device, and the sample is constantly scanned during the test. In such a way the entire course of the test can be reconstructed and analysis of all stages of deformation can be performed [8, 9].



## 2. MATERIALS AND METHODS

A sample of aluminium foam, made by powder metallurgy method, was used for CT scanning. AlSi10 aluminium alloy powder was mixed with 0.4 wt. % foaming agent (titanium hydride, $TiH_2$), and mixture was compacted and extruded into a strip precursor. The weight of the precursor in the foaming mold was determined on the basis of the required degree of porosity 70 %, i.e. a relative density 0.3. The sample was made for a three-point bending test, and was reinforced with glass fibers extending through the middle. The strip was cut from the fiberglass mat with the surface mass 300 g/m$^2$. The lenght of the fiberglass strip was the same as the lenght of the mold and the width was 7 mm. A mold filled with a precursor and a fiberglass was placed in an electric resistance furnace at 750 °C and held for about fifteen minutes to dissolve the foaming agent into a solid component Ti and a gas $H_2$ that foams the metal and forms pores in it. Mold is taken out of the furnace in the moment the foam started to leak out through the hole in the mold and then cooled in water to keep the gas bubbles trapped inside the aluminium melt. The foamed sample was Ø25 x 212 mm in size.

CT scan was performed on the ZEISS Metrotom 6 Scout device in the company Topomatika d.o.o., Croatia. The device consists of three main elements, the radiation source, detector and the rotating table, as shown in Figure 1. The radiation source generates X-rays that pass through the scanning object and they reach the detector. Depending on the material density and the thickness of the scanning object, X-rays are more or less attenuated. The sample was recorded at a distance of 350 mm from the radiation source, and the pixel binning command was used in the software, resulting in a voxel size of 90 µm. The object rotates continuously and when it is rotated for a 360°, the scanning process is finished. After scanning, the reconstruction algorithm merges the obtained images and generates volume data, which is the first result of CT scanning. This volume can then be polygonized, and the final result is a polygonal mesh. The control of the CT scanning device is fully integrated through the GOM Volume Inspect Pro software which also enables direct measurement and analysis of the results of the scanned sample.

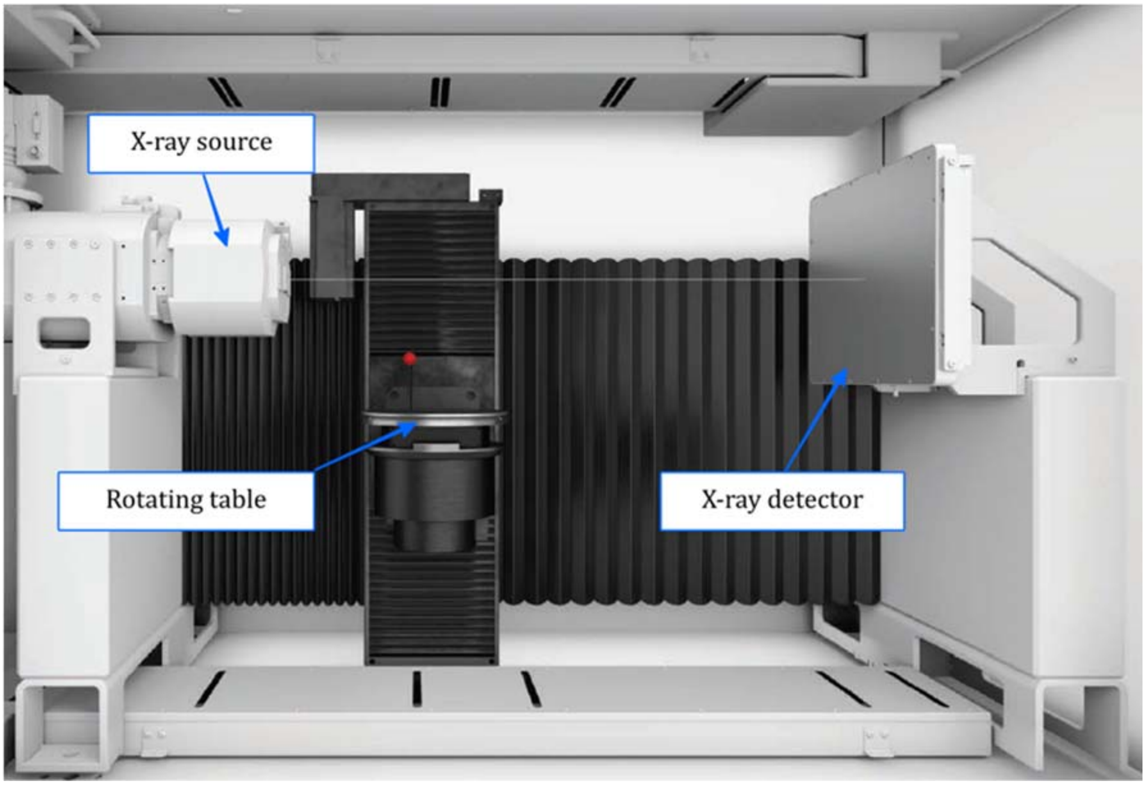


**Fig. 1: Parts of the ZEISS Metrotom 6 Scout CT device [10]**



Measurements of the size and number of pores in the sample cross section was performed by ImageJ software using the Analyze Particles command, and the pore size distribution was processed in MS Excel.

## 3. RESULTS AND DISCUSSION

The formatting process of a polygonal mesh of a scanned object is shown in Figure 2. By scanning the aluminium foam, two-dimensional images were obtained, which were connected and generated into the volume data of the object with the help of a reconstruction algorithm, and finally into a polygonal mesh.

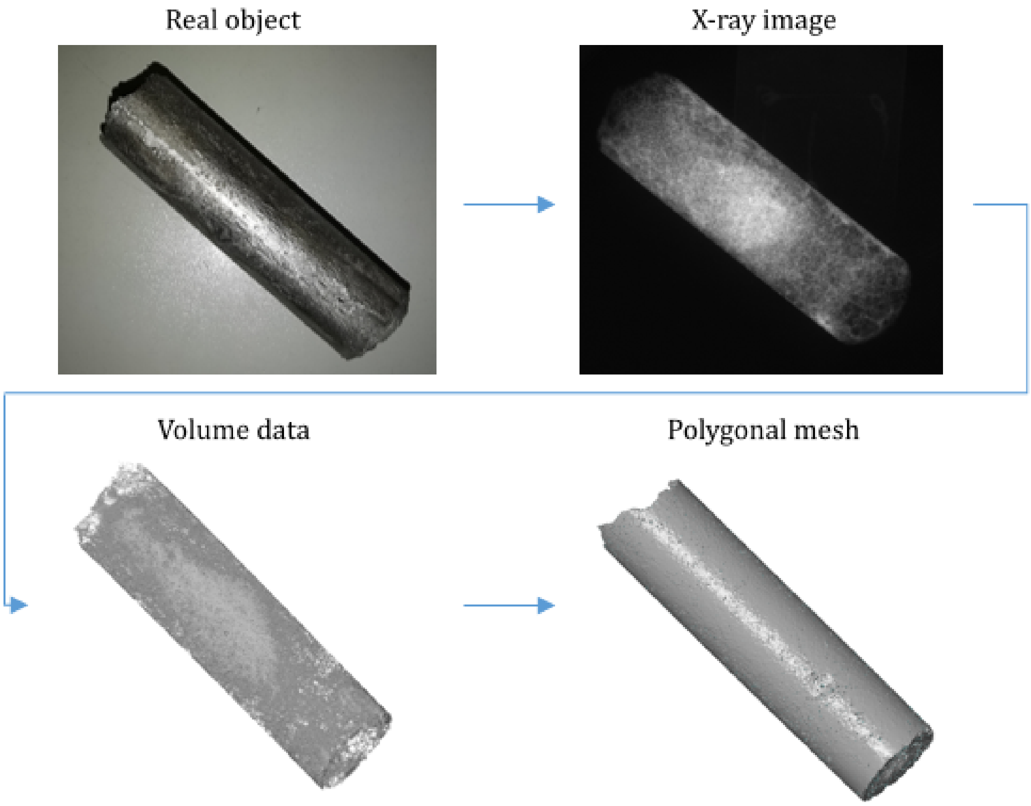


**Fig. 2: The formatting process of a polygonal mesh by CT scanning**



Any cross-section of the scanned sample can be viewed from the obtained volume in the GOM Volume Inspect Pro software. Figure 3 shows sample cross-sections at different places obtained by computed tomography.

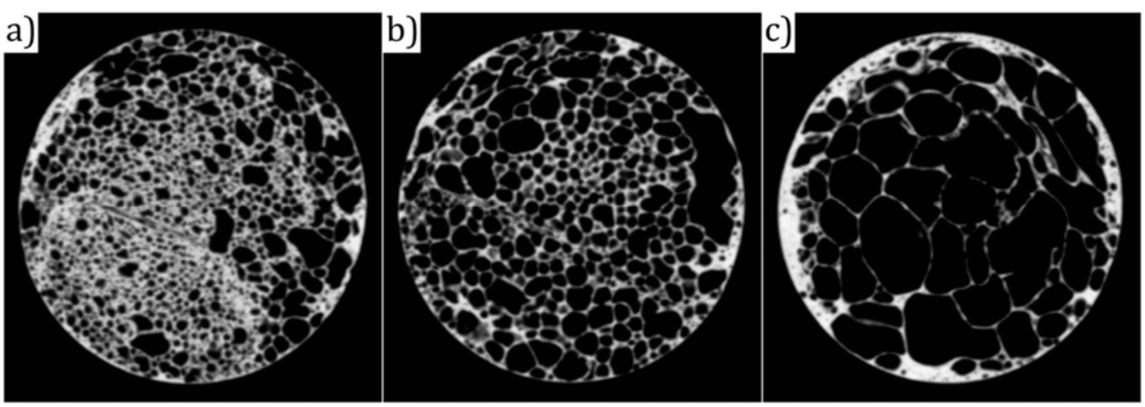


**Fig. 3: Cross-sections of the scanned sample at the distance of a) 50 mm, b) 30 mm and c) 5 mm from the sample edge**

From the sample cross-sections, the average pore size can be calculated. Figure 3 shows that the pore size varies between different cross-sections from which the anisotropy of mechanical properties can be concluded. In the part of the foam where the pores are smaller, Figure 3a, the mechanical properties are higher because there are numerous cell walls that resist mechanical stress. Larger pores are visible in the Figure 3b and the biggest ones are recorded in the Figure 3c, which is therefore characterized by significantly lower mechanical resistance. The outer crust of the foam has different thicknesses, which also affects the mechanical properties.

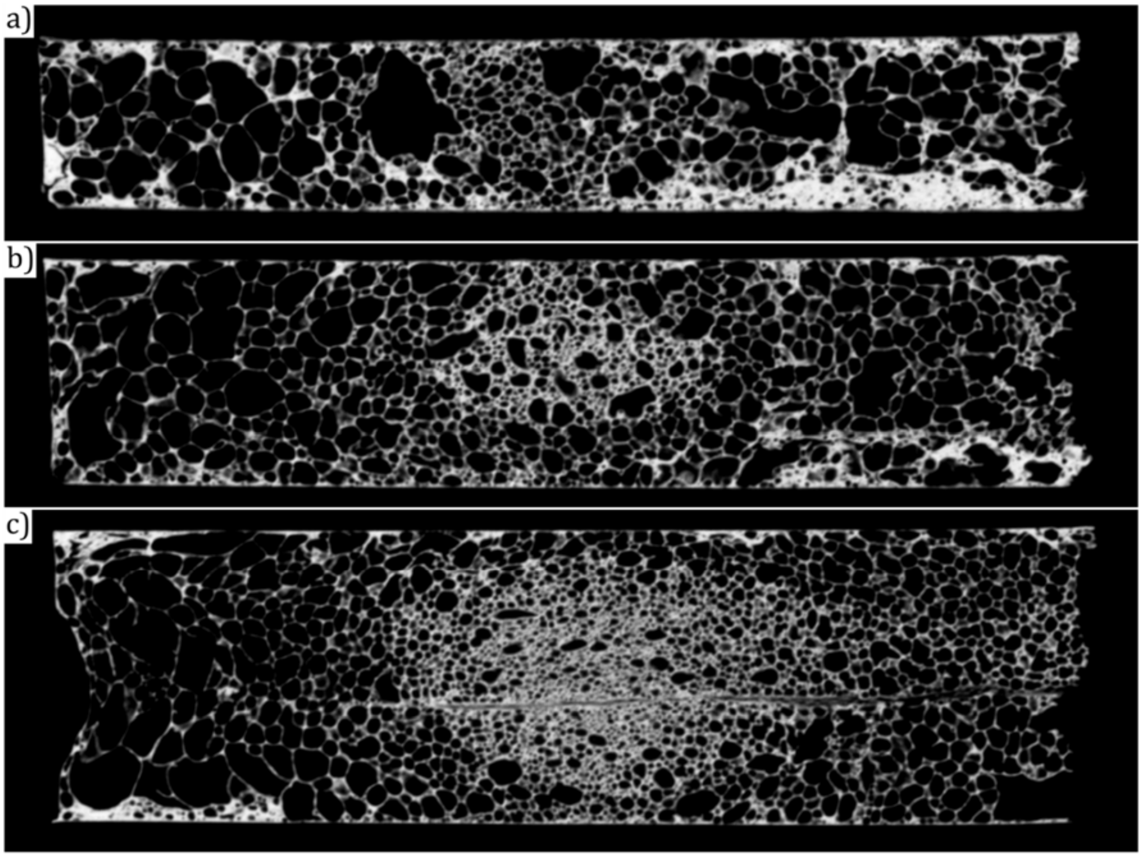


**Fig. 4: Longitudinal sections of the scanned sample at a distance from the edge of the sample of 3 mm (a), 6 mm (b) and 12.5 mm (c)**

Smaller pores in the central part compared to the outer parts of the sample can be seen on the longitudinal sections of the aluminium foam, Figure 4. The reason for this may be filling of the mold with a precursor. The precursor was not evenly distributed along the entire mold but was obviously accumulated in the middle so that there the pores are finer with a larger number and length of cell walls. There are less cell walls at the edges (smaller amount of precursor) and the pores are thus larger. Another reason for such a foam morphologies may be different temperature gradients in the mold during the heating and foaming process as well as during cooling.

By adjusting the parameters in the ImageJ software and using the Analyze Particles function, it is possible to identify individual pores, as illustrated in Figure 5.

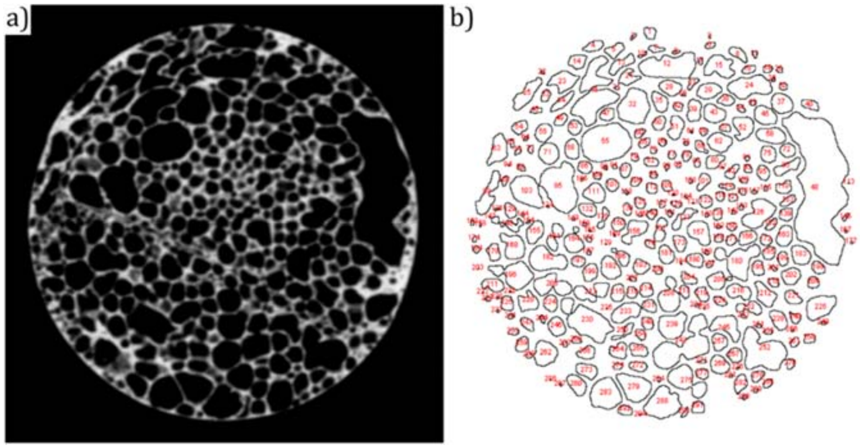


**Fig. 5: The cross-section of the sample at the distance of 30 mm from the sample edge after scanning (a) and the pore analysis in the ImageJ software (b)**

Numerous pores (294) of different sizes were observed by this analysis. The size of their cross section varied from 0.003 mm$^2$ up to 24.055 mm$^2$. The largest number of pores, 80% of them, having an area less than 1 mm$^2$. It is obvious that the pore size changes significantly, which is shown on the histogram of the pore size distribution, Figure 6. This diagram represents the pores with cross-section area up to 1 mm$^2$.



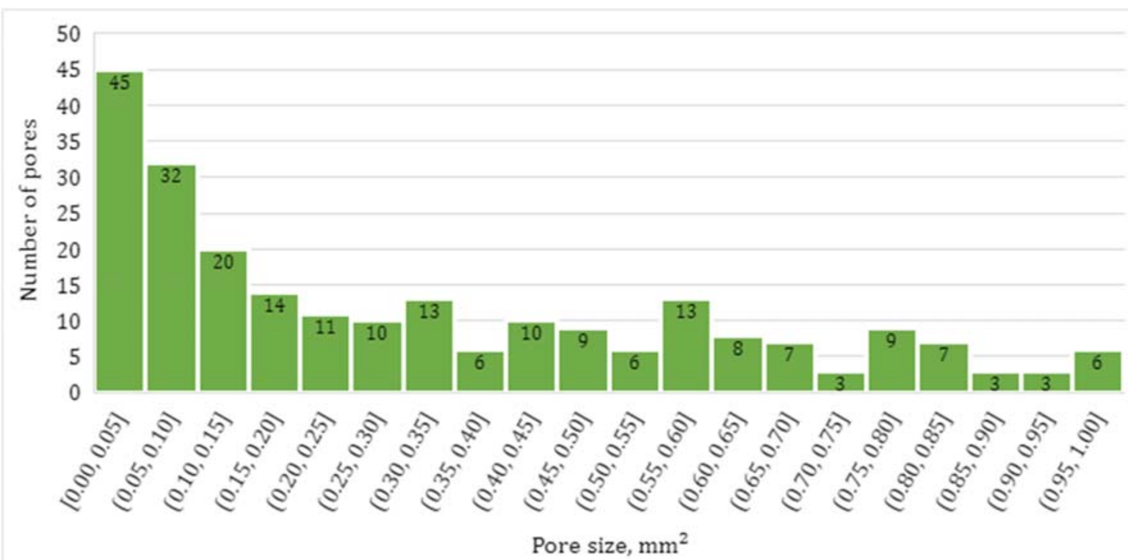


**Fig. 6: Pore size distribution**

The average pore size for analyzed cross-section is 0.774 mm$^2$. When the largest pore is eliminated the mean value is reduced to 0.695 mm$^2$. Considering only those pores with the cross-section area smaller than 1 mm$^2$, represented by 80 % of pores, the average pore size was halved (0.322 mm$^2$). In order to accurately determine the pore size, it is necessary to analyze a large number of cross-sections or use softwares that automatically recognize entire pore volumes from a three-dimensional model, which takes a long time, especially for larger samples.

## 4. CONCLUSION

Computed tomography of aluminium foam can provide insight into morphology, i.e. the size and arrangement of pores, without destruction of the sample. Observing the generated longitudinal and cross sections, diverse cell sizes in different parts of the foamed sample can be seen. One of the possible reasons for this can be that the precursor was not evenly distributed along the entire mold. Where the amount of precursor was higher, more cell walls were formed, making the pores smaller. The other reason can be different temperature distribution through the sample and the mold during the foaming of the precursor and cooling of the foamed sample. In order to achieve more homogeneous properties of the foam, it is necessary to pay attention to the placement of precursors, but also to balance the temperature gradients during heating and cooling. The pore size and its distribution in specific localities of metal foams is very important for its properties and behavior in certain exploitation conditions.

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