

Study of porosity measurement using the computer tomograph

Tomasz Kowaluk, Adam Woźniak

Institute of Metrology and Biomedical Engineering, Warsaw University of Technology

Abstract: This paper is concerned with performance of measurement of pore volume in aluminum cast. The experiments were carried out on a METROTOM 800 Carl Zeiss computer tomograph. Results coming from algorithm of automatic detection were compared against to the manual detection according to the ISO surface. Results have been analyzed using the VGStudio MAX software.

Keywords: computer tomograph, porosity

Introduction

The idea of measurements consists of assembling three-dimensional spatial object from multiple flat images resulting from the scanning of measured element in the selected angular position. The measured element is set on a rotary table that allows the movement, linear and angular positioning of the component. While the measured object is illuminated by an X-ray beam generated in the tube, the image detection is done at certain angular positions of rotary table on the detector array. Acquired images are processed by specialized software, producing a three-dimensional model of the measured element.

While the measured objects absorb energy of X-rays during the measurements, the X-ray beam is therefore weakened and the difference in the intensity of radiation passing through the object is registered on the detector. The change of the intensity of the parallel beam of radiation of the same energy, during the transition through the measuring object is described by the dependency:

$$I = I_0 e^{-\mu g} [1],$$

where:

I – intensity of radiation after passing through the object,

I_0 – initial intensity of radiation,

μ – linear absorption coefficient of radiation,

g – thickness of the material.

X-ray absorption of the tested object is proportional to the density and to the atomic structure of the material and wall thickness of the element [1].

The study was performed on a METROTOM 800 Carl Zeiss (fig. 1) computer tomograph. To the main assembly of computer tomographs the X-ray tube, the radiation detector and a system for positioning the measured element consisting of a rotary table and the linear guideways are included. The data obtained are processed by a separate computer. The computer tomograph METROTOM 800 is equipped with a constant X-ray tube with a power of 39 W (at maximum parameters – 130 kV voltage and 300 μ A current) and a detector with a resolution of 1536 \times 1920 pixels. Main metrological parameters of the CT are summarized in tab. 1.



Fig. 1. Computer tomograph METROTOM 800

Rys. 1. Tomograf komputerowy METROTOM 800

Tab. 1. Metrological parameters of the CT METROTOM 800 [2, 3]

Tab. 1. Parametry metrologiczne tomografu komputerowego METROTOM 800 [2, 3]

Measuring range: x-y plane: z	170 mm, 190 mm
Workpiece weight, max.	4 kg
Focal spot size, min.	5 μ m
Geometric magnification (2D), max.	45
Geometric magnification (3D), max.	40
X-ray detector resolution	1536 \times 1920 pixels
X-ray detector Pixel size	127 \times 127 μ m
MPE _E – Maximum Permissible Error <small>Error of Indication</small>	4.5 + L/100 μ m (L – length of the measured distance mm)

2. The influence of the shape of the histogram on results

The study consisted of checking the obtained values of pore volume in aluminum cast. Theoretically, by measuring the elements which are made of one material in the histogram two peaks should be obtained, one for the air and second for the material. „Ideal histogram” is shown in fig. 2.

Obtaining the ideal histogram allows the use of algorithms for automatic detection of the ISO surface (threshold between background and material).

The effect of ISO surface settings are shown in fig. 3. On the left (fig. 3a) is visible noise in the central part of the element – aluminum casting (automatic algorithm). The settings change will remove noise (manual algorithm) which is shown in the fig. 3b. Changing the ISO value affects not only the removal of the outside noises in the measured element but also of the inside.

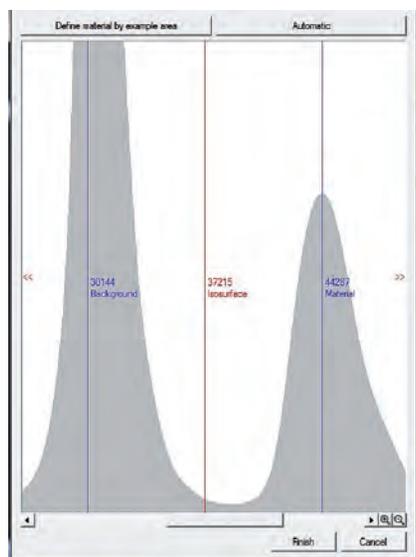


Fig. 2. „Ideal histogram” of grayscale value
Rys. 2. „Idealny histogram” skali odcieni szarości

Algorithms for calculation the volume of defects that occur inside of the elements are based on three levels of gray scale values (ISO surface, material and background). The most important is the value of the ISO surface. The software treats this value as a „threshold” between air and material. Voxels which values are less than ISO are treated as the air, while the values above the ISO are treated as the material. Changing the ISO value influence on the volume of the whole element as well as on detected defects that occur in the element. Table 2 shows the results of measurement of pore size for automatic as well as manual method of determining the ISO value.

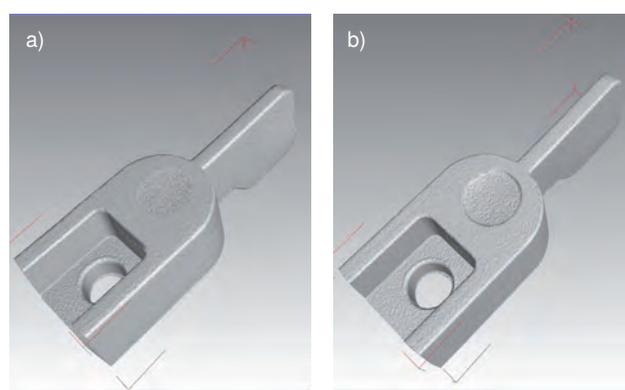


Fig. 3. 3D view of measuring element with the use: a) automatic algorithm, b) manual algorithm
Rys. 3. Widok 3D elementu pomiarowego z zastosowaniem: a) algorytmu automatycznego, b) algorytmu ręcznego

3. Comparison of pore-detection algorithms

The study compared two available in the VGStudio MAX software algorithms of pores detection. The first of available algorithms “Only threshold” based on the “threshold” and “background” value. The second algorithm “default” based on the “void max” and “background” value.

Tab. 2. The influence of the ISO value settings on results (automatic algorithm and manual setting)

Tab. 2. Wpływ ustawienia wartości ISO na wyniki (algorytm automatyczny, ustawienia manualne)

pore size	Above 0.000 mm ³		Above 0.010 mm ³	
	automatic	manual	automatic	manual
ISO value				
volume of element mm ³	1016.776	1006.671	1016.877	1006.671
volume of pores mm ³	0.775	0.797	0.250	0.252
percentage of pores	0.0761	0.0791	0.0246	0.025
number of analyzed cross-sections	1455	1540	8	8

The user can decide what size of pores should be detected (by setting minimum and maximum volume of pores). It is possible to find the pores from 0 μm³ to the entire volume of the CT measurement. The effect of the pores size settings are shown in fig. 4.

Result of pore detection algorithm (only threshold) is shown in fig. 4 – cross section of the aluminum cast with the defined ISO surface (white line which is a border of the material).

As it was shown in the magnification, not all pores (black points on the screen) were correctly interpreted. Detected pores do not fill the entire surface determined by ISO line. Additionally, not all detected pores are included in the calculations. This is due to the fact that the algorithm cuts the entire volume of the object with a certain step then analyzes

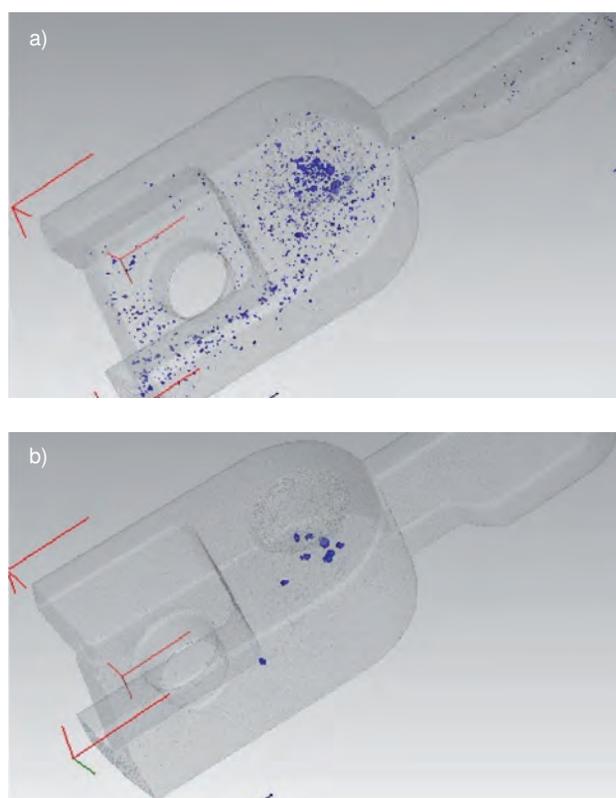


Fig. 4. Visualization of the occurrence of the pores in aluminum cast: a) with no limits of pore size, b) above 0.010 mm³

Rys. 4. Wizualizacja występowania porów w odlewie aluminiowym: a) bez ograniczeń wielkości porów, b) powyżej 0,010 mm³

the sections in which the „defects are detected” – a limited number of cross-sections results that not all pores are analyzed. This approach allows to detect only the largest pores, but reduces significantly the time necessary for calculations (single calculation takes 10 minutes).

To detect all pores occurring in the aluminum casting advanced algorithms (default and enhanced) must be used. Both algorithms are based on the same values (void max and background) and differ from each other in the number of „runs”. In the research “default” algorithms were used.

In fig. 5 cross section of the aluminum cast with the defined ISO surface is shown.

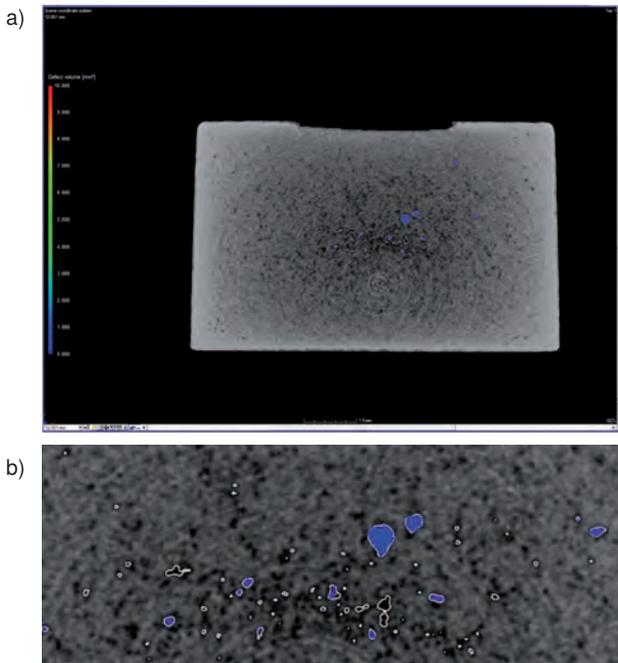


Fig. 5. Cross section view with marked errors of defects detection algorithm (pores – “only threshold” algorithm)
Rys. 5. Widok przekroju z zaznaczonymi błędami algorytmu wykrywania wad (porów – algorytm „only threshold”)

The same as it was previously shown in the magnification, not all pores (black points on the screen) are correctly interpreted. For this algorithm also not all detected pores are included in the calculations. This shows that even advanced algorithms do not detect all the pores. Although pores were closed by ISO surface, not all were analyzed.

Operations for calculating the pore volume are performed in the computer’s RAM. The advanced algorithm detects more pores but it needs much more time (8–12 hours).

Table 3 shows the results obtained from the analysis using two algorithms (“default” and “only threshold”), depending on the size of the pores (above 0.000 mm³ and above 0.010 mm³).

Depending on the selected algorithm, different values of volume of whole element and of pores in therein occurring are obtained. Changing the range (size) of detected pores in the algorithm parameters influences on changing of volume of the whole element in the case of algorithm “default”. For the algorithm “Only threshold” value of the volume of element remains the same.

Advanced algorithm detects two orders of magnitude higher volume of pores than the algorithm “Only threshold”

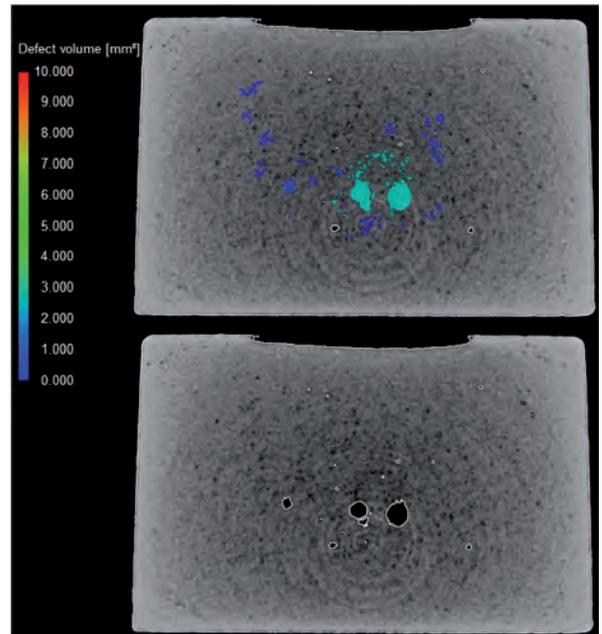


Fig. 6. Cross section view with marked errors of defects detection algorithm (“default” algorithm)
Rys. 6. Widok przekroju z zaznaczonymi błędami algorytmu wykrywania wad (algorytm „default”)

Tab. 3. The influence of the type of algorithm on the results
Tab. 3. Wpływ typu algorytmu na wynik

pore size	Above 0.000 mm ³		Above 0.010 mm ³	
	default	only threshold	default	only threshold
volume of element mm ³	964.653	1006.671	994.540	1006.671
volume of pores mm ³	42.924	0.797	13.165	0.252
percentage of pores	4.26	0.0791	1.31	0.025
number of analyzed cross-sections	70 358	1540	241	8

(for the tested aluminum casting). The number of analyzed cross sections is significantly dependent on the threshold of pores detection as well as of the type of algorithm. Advanced algorithm analyzes two orders of magnitude higher the number of cross sections than the basic algorithm.

4. The influence of magnification on the results

An important question which must be considered is the influence of used magnification on the obtained results. To be able to check the influence of magnification on results appropriate gauges should be used. Gauges should be possible to estimate the actual volume of pores for example by gravimetric method [4, 5], or using materials of known estimated pore sizes [6].

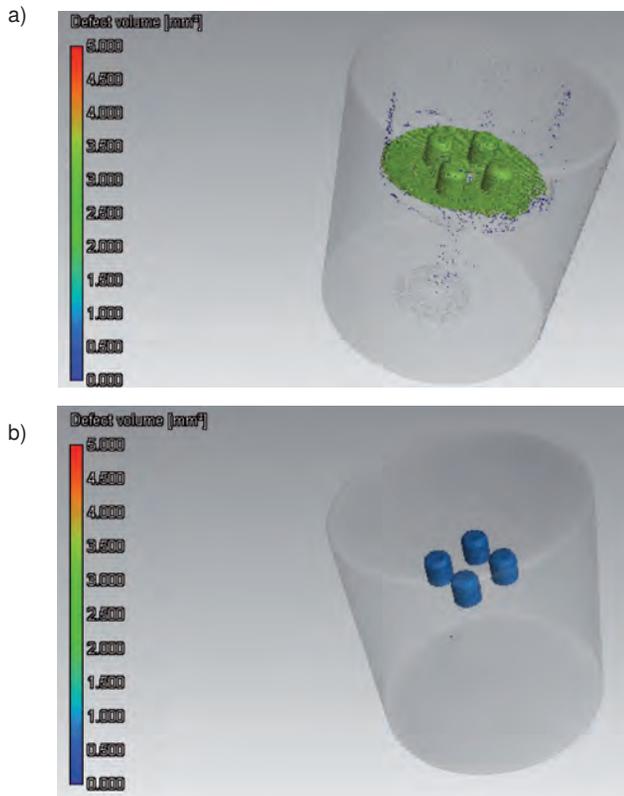


Fig. 7. 3D reconstruction of the gauge with marked pores: a) with the 8 μm magnification, b) with the 25 μm magnification (size of single voxel)

Rys. 7. Rekonstrukcja 3D wzorca z zaznaczonymi porami: a) przy powiększeniu 8 μm , b) przy powiększeniu 25 μm (rozmiar pojedynczego woksela)

The study used a different approach. It was constructed a gauge which consists of two cylinders. The first cylinder was created with hole so that the second cylinder with four smaller drilled cylinders can be molded. Theoretically, a gauge with the four pores should be obtained.

In fig. 7 results of reconstruction of pores which are in the gauge at different magnifications (8 μm (a) and 25 μm (b)) are shown.

As it was shown at a magnification of at 8 μm (fig. 7a) pores between the two cylinders are visible. While at a magnification of 25 μm (fig. 7b) only artificially produced in the gauge pores are visible. This is caused by the use of the basic algorithm “only threshold” based on the ISO surface. At lower magnifications, the algorithm does not detect the surface between two cylinders. A slot is visible but there is no possibility of closing slot by ISO surface. In fig. 8 the slot between surfaces is shown.

On the contact surface of both cylinders slot of 26 μm is formed (measured at a magnification of 8 μm (fig. 8a)). While size of the slot at a magnification of 25 μm (fig. 8b) is 49 μm . The phenomenon of apparent expansion of slot arises. This happens when the actual size of the slot is smaller than the pixel size.

5. Conclusions

Computer tomography allows to perform non-destructive testing of aluminum castings. The study of single cross sections allows detection of the existing pores and inclusions

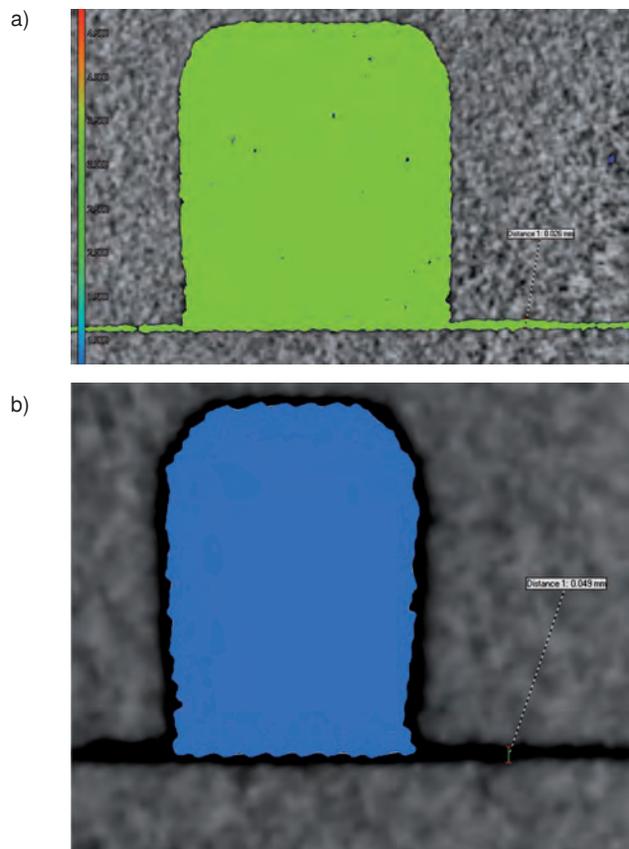


Fig. 8. A cross section view of the slot: a) with the 8 μm magnification, b) with the 25 μm magnification (size of single voxel)

Rys. 8. Widok przekroju szczeliny: a) przy powiększeniu 8 μm , b) przy powiększeniu 25 μm (rozmiar pojedynczego woksela)

of other materials. Algorithms used to calculate the volume of pores can detect correctly only the largest pores. For the verification correct operation of the algorithms is necessary to build appropriate gauges. Gauges should be constructed so that it is possible to estimate the actual volume of the pores. The study does not consider the influence of sub-pixel effects [7] of the automatically determined value and routes of ISO line. In addition, significant influence on the final result of the calculated pore volume has a value of used magnification.

Bibliography

1. Ratajczyk E., *Tomografia komputerowa CT w zastosowaniach przemysłowych*, „Mechanik”, nr 2/2011, 112–117; nr 3/2011, 226–231; nr 4/2011 326–331. (in Polish). [www.zeiss.pl].
2. METROTOM 800. *Operating Instructions*. Zeiss.
3. Niemelä T., Aydoğan D.B., Hannula M., Hyttinen J., Kellomäki M., *Determination of bioceramic filler distribution and porosity of self-reinforced bioabsorbable composites using micro-computed tomography*, Elsevier, “Composites”: Part A 42 (2011) 534–542.
4. Khalid A. Alshibili, Bashar A. Alramahi, Attia Mahmoud Attia, *Assessment of Spatial Distribution of Porosity in Synthetic Quartz Cores Using Microfocus Computed Tomography (CT)*, “Particulate Science and Technology”, 24: 369–380, 2006.

6. Hitoshi Nakayama, Douglas M. Burns, Tomoyuki Kawase, *Nondestructive Microstructural Analysis of Porous Bioceramics by Microfocus X-ray Computed Tomography (CT): A Proposed Protocol for Standardized Evaluation of Porosity and Interconnectivity Between Macro-pores*, "Journal of Nondestructive Evaluation" (2011) 30:71–80.
7. Weber E., Fernandez M., Wapner P., Hoffman W., *Comparison of X-ray micro-tomography measurements of densities and porosity principally to values measured by mercury porosimetry for carbon-carbon composites*, Elsevier, "Carbon", 48 (2010) 2151–2158. ■

Pomiary porowatości za pomocą tomografu komputerowego

Streszczenie: W artykule przedstawiono wyniki badań dotyczące pomiarów objętości porów w odlewach aluminiowych. Badania przeprowadzono na przemysłowym tomografie komputerowym METROTOM 800 firmy Carl Zeiss. Porównano wyniki algorytmów automatycznego i manualnego wykrywania porów w odniesieniu do powierzchni ISO. Do analizy wyników zastosowano oprogramowanie VGStudio MAX.

Słowa kluczowe: tomografia komputerowa, porowatość

Tomasz Kowaluk, MSc

He received the M.Sc. from Warsaw University of Technology in 2011. He is currently a PhD student in the Institute of Metrology and Biomedical Engineering, Faculty of Mechatronics, Warsaw University of Technology. Within the PhD he deals with the porosity of elements from computer tomography.

e-mail: t.kowaluk@mchtr.pw.edu.pl



Adam Wozniak, PhD, DSc, prof. of WUT

He received the MSc (1998), PhD (2002), and DSc (2011) degrees from Warsaw University of Technology, Poland. From 2005 to 2006 he was a Visiting Professor with the Department of Mechanical Engineering, École Polytechnique de Montréal, Canada. He is currently a Professor with the Institute of Metrology and Biomedical Engineering, Faculty of Mechatronics, Warsaw University of Technology. His current research interests include dimensional metrology, especially coordinate measuring technique. He is the author of more than 80 papers in these areas.

e-mail: a.wozniak@mchtr.pw.edu.pl

