POROSITY MEASUREMENT METHOD BY X-RAY COMPUTED TOMOGRAPHY

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Abstract

This paper describes a new non-destructive approach for porosity measurement developed in response to a need for a more accurate porosity measurement method for solid samples. The conventional methods in X-ray CT imaging are based on image segmentation where a threshold is applied at a user-defined value. As a result the uncertainty in the porosity measurement is introduced.

Therefore, the new method, called the grey level method, which reflects the phenomenon of image processing and computation of ration between the volume of voids and the total volume of the entire sample, was considered and improved in term of image noise and artifacts. The volumes of 2D CT image as a surface are achieved by means of integrating the surface with operations relating to image histogram. The porosity value is given form the curve of a porosity distribution. Subsequently, the properties of individual pores were measured and comparison with conventional destructive method of porosity computation was carried out. Data analysis and image processing were realized in Matlab.

1 Introduction

Porosity occurrence is related to many solid samples. The term is used in multiple fields including ceramics, metallurgy, materials, manufacturing, earth sciences and construction. Porosity is a measure of the void spaces in material, and is measured as a fraction, between 0 - 1, or as a percentage between 0 - 100 %.

Whereas the metallurgical measuring method represents the destructive methods, the new approach based on X-ray CT application brings the way how the samples are examined for their porosity amount without destructive consequences. As well the verification with metallurgical measuring is conducted.

2 Principle of Method

The computed tomography is based upon measuring of attenuated X-rays passed through a tested object along the set of defined paths followed by the reconstruction of an acquired dataset with the aid of mathematical reconstruction algorithms. The result represents the distribution of the attenuation coefficient μ(x, y) for individual pixels in each cross-section.

The individual pixels are represented by CT numbers where the lowest CT number is set to black and the highest one to white.

The simple technique to segment image into solid and voids parts utilizes thresholding. The optimal threshold is selected by visual interpretation. However, it is very difficult to find this threshold because there are errors caused by human perception. Therefore, the automatic or semi automatic methods are required where thresholding would be more efficient.

In this study, the method suggested by H. Taud et al. [1] was considered.

The measurement of empty space and the total volume can be expressed as the function. Taking into account the gray levels of CT image, so called a Digital terrain model could be created where the grey levels are related to the altitude or elevation.

The volume of terrain between two altitudes r_{min} and r_{max} is expressed as:

$$V = s^2 a \sum_{r_i = r_{min}}^{r_{max}} (r_i - r_{min}) H(r_i) \qquad (1)$$

Where s is the pixel size in the horizontal plane and a is the pixel size in the vertical plane, $H(r_i)$ represents the proportion of the number of pixels with that grey level to the total number of pixels in the image.

The volume of the empty space, V_E corresponds to the complement to the volume of solid space. Therefore, porosity can be computed as a relation between empty space, V_E and the total volume, V_T:

$$\varphi = \frac{V_E}{V_T} = \frac{\sum_{r_i=r_{min}}^{r_{max}} (r_{max} - r_i) H(r_i)}{\sum_{r_i=r_{min}}^{r_{max}} r_{max} H(r_i)} \qquad (2)$$

The porosity calculation is better determined by porosity distribution when there are a few isolated pixels with a high CT number:

$$\varphi(l) = \frac{\sum_{r_i=r_{min}}^{l} (l - r_i) H(r_i)}{\sum_{r_i=r_{min}}^{l} l H(r_i)} \qquad (3)$$

3 CT Image Processing

The above mentioned method would not bring the right results if the image processing is not considered. The CT image obtained as a cross-section through the sample is a noisy image with enhanced edges due to beam hardening. The consecutive process has to be carried out: firstly, the background segmentation, eroding and retroactively dilatation of the edge, followed by the computation of image noise to denoising. The algorithm calculating porosity may be addressed to this corrected denoised image. Fig. 1 illustrates the descriptive image processing. The porosity estimation refers to the minimum of the distribution curve.

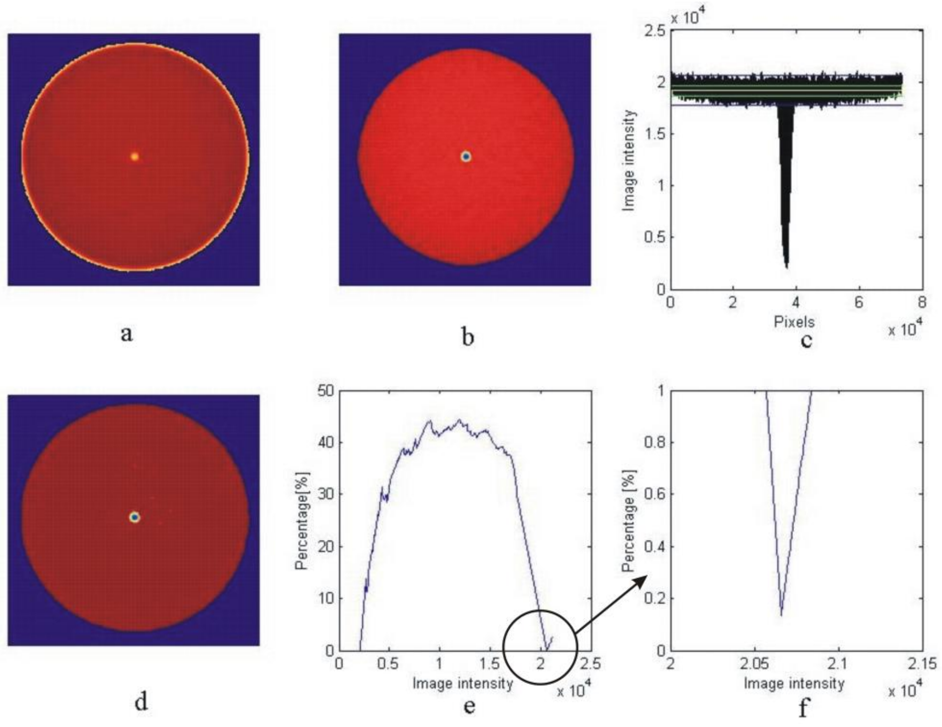

Figure 1: Image processing in individual steps
[a) raw image, b) raw image after removal of beam hardening (erosion and dilatation processes), c) image profile – noisy surface with hole depth, d) denoised image, e) porosity distribution, f) minimal point corresponding to the porosity estimation]

4 Results and Their Verification

Firstly, the examination was realized on the samples with the known dimensions of the hole(s) (pore). Specifically, the specimen diameter measured 32 mm related to 1,2 mm of the hole diameter that means the estimation porosity should be close to a value of 0.141%. As you can see in Fig. 2, the porosity estimation was very precise and based on a linear dependence for one, two, three, and four holes.

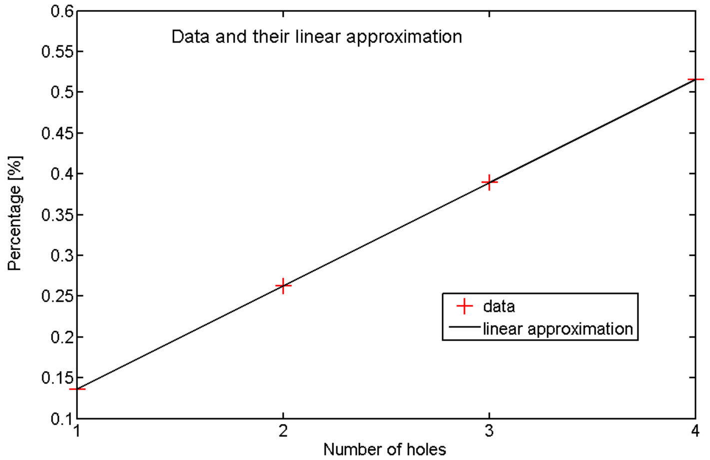

Figure 2: Linear approximation for one up to four holes

It is desirable to test this method on the sample with real porosity. The accuracy of method was approved on the aluminum castings samples. The close correlation between the results obtained by this method and metallurgical one is shown in Table 1.

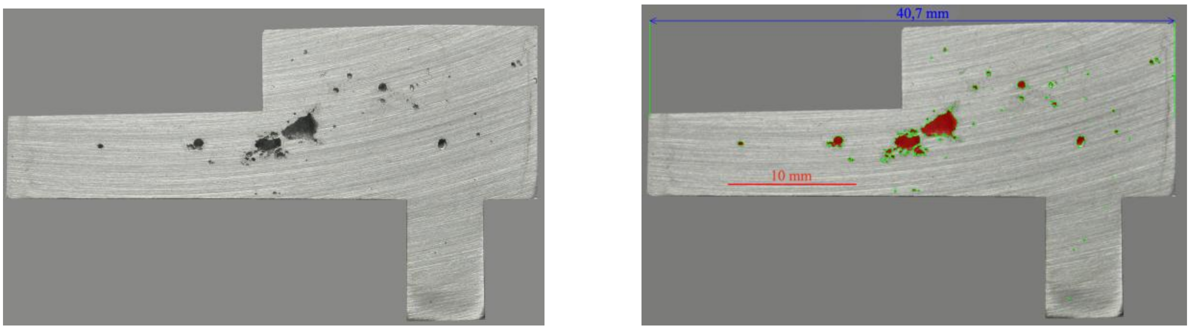

Figure 3: Optical image after metallographic cut of aluminum casting (left) and pores highlighted in NIS Elements BR 2.30 (right)

Table 1: POROSITY ESTIMATION BY THE GREY LEVEL METHOD AND METALLOGRAPHIC METHOD

Sample	A	B	C	D	E
Metallographic	1,88 %	1,21 %	0,88 %	0,50 %	2,23 %
Gray level	2,12 %	1,13 %	0,82 %	0,43 %	2,53 %

5 Summary

The porosity was calculated without using segmentation techniques and user-defined parameters. The original method [1] was improved by the image processing in term of image noise and artifacts in order to be more complex. It is necessary to realize that the differences come from the following reasons: it is never the exactly same slice in both tomographic and metallographic methods; the resolution of tomograms and slices from optical devices considerably differs.

The resolution of the CT image depends on the scanner used. The industrial VT 400 tomograph produces the 1024 x 1024 image matrix with a pixel size of 0.2 mm and spatial resolution of 1 LP/mm.

To sum up, the porosity estimation method documents it effectiveness and applicability in computed tomography as a nondestructive method.

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References

[1] Taud, H., Martinez-Angeles, R., Parrot, J. F., Hernandez-Escobedo, L. *Porosity estimation method by X-ray computed tomography*. Journal of Petroleum Technology, 2005.

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