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3D image multifractal analysis and pore detection on a stereometric measurement file of a ceramic coating

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Abstract

Intensive work is carried out both on improving the existing test equipment as well as on developing new methods of surface modelling and analysis. Modern methods of surface topography analysis enable to obtain high-quality three-dimensional images of a surface. The analysis of spatial images is an important issue applied, inter alia, in materials science, robotics, medicine or in the development of satellite images. For people dealing with fractal description, it means computer calculations with the aim of obtaining fractal dimensions from the record representing the studied processes. The resulting dimensions are designed to detect the characteristics of the analysed object. In the paper, multifractal analysis of stereometric files was carried out, whose aim was to determine the locations of the most likely presence of pores on alumina ceramic coating surfaces.
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Keywords: Detection; 3D segmentation; Image analysis; Pores; Surface stereometry

1. Introduction

Bioceramic implant materials with an appropriately designed microstructure, and especially those with a particular pore size and shape, can serve as potential drug carriers. A ceramic biomaterial is considered a brittle material with low flexural strength. However, owing to the surface porosity, it has been used in implantology. On the ceramic implant surface, there are pores which enable faster bonding of an implant with a tissue by its ingrowth into the pores, thus obtaining a durable connection which has appropriate biomechanical properties. The final material porosity is defined in a technological process.[1]

Image analysis is an important issue applied, inter alia, in materials science, robotics, medicine, in the development of satellite images, etc. For people dealing with fractal description, it means computer calculations with the aim of obtaining fractal dimensions from the record representing the studied processes. The resulting dimensions are designed to detect the characteristics of the analysed object. Multifractal image analysis[2–6] consists of two stages. The first one, described in detail in Refs. [3,4], involves pre-treating the test image, e.g. by using filters applied in conventional analysis, whereas the latter one involves its segmentation.

Image segmentation is the process of dividing the analysed image into parts defined as areas (sets of pixels), which are homogeneous in terms of certain selected properties. The properties which are most often selected are homogeneity criteria such as texture, colour and grey level. The resulting segmented image is simplified with respect to the image subjected to segmentation, it does not contain much detailed information present in the original image. A similar situation also occurs in the case of edge detection in an image. Segmentation methods can be divided into: segmentation based on areas (neighbourhood in terms of pixel homogeneity) and segmentation based on edge extraction (determination of boundaries and contours of objects).[7,8] Similarity measures defined on a group of features (feature vector) that characterize a given area are most commonly used as a criterion of homogeneity. Examples of similarity measures are (Fig. 1).

In the case of multifractal analysis, the task of segmentation is to determine, on the basis of the Hausdorff dimension spectrum, locations with a similar Hölder exponent.[4]

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(a)

√2	1	√2
1	(x1,y1)	1
√2	1	√2

(b)

2	1	2
1	(x1,y1)	1
2	1	2

(c)

2	2	2	2	2
2	1	1	1	2
2	1	(x1,y1)	1	2
2	1	1	1	2
2	2	2	2	2

Fig. 1. Schema for determining similarity measures based upon: (a) Euclidean distances, (b) 4-neighbourhood distances, and (c) 8-neighbourhood distances.

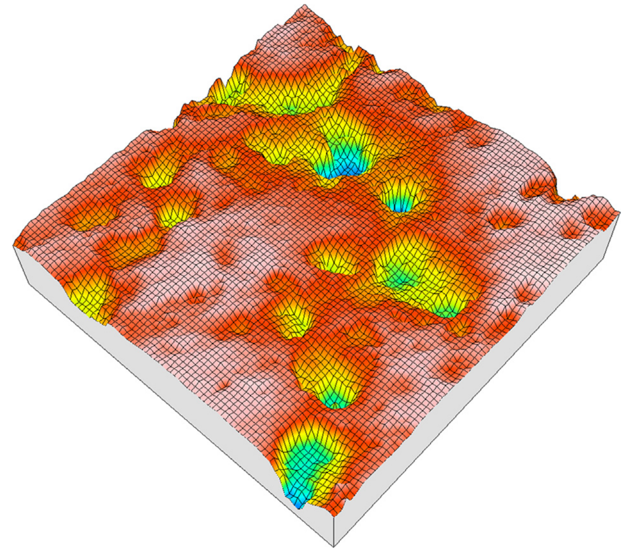

Fig. 2. Example of a porous surface fragment showing measuring points (intersection of lines) obtained from microscopic examination (every 20th measuring point was presented in order to simplify the figure).

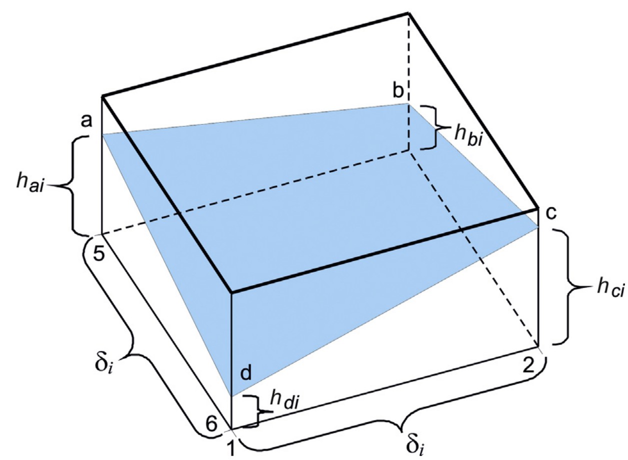

Fig. 3. Enlarged, isometric view of four adjacent measuring points (one measuring area).

In the paper, multifractal analyses of stereometric files were carried out, whose aim was to determine the locations of the most likely presence of pores on an alumina ceramic coating surface and present them in graphical form.

2. Materials and methods

Two samples of a material with Al_2O_3 coating deposited on an aluminium alloy disc were studied. Al_2O_3 layers were obtained from a multi-component electrolyte. The manufacturing process was carried out at 20 °C using constant anodic current density of 4 A/dm^2 and electric charge density of 240 A_{min}/dm^2. The coatings were applied to the disks with a diameter of 65 mm and thickness of 5 mm.

The Olympus LEXT OLS4000 confocal microscope was used to study the material surface structure. The samples did not require pre-treatment. The measurement was performed with 50× objective lenses dedicated to laser light with a wavelength of 405 nm. The size of the analysed area was 256 × 256 μm and the resolution of stereometric data was 1024 × 1024 measuring points.

3. Theory and calculation

A confocal microscope, being primarily a light microscopy, allows to obtain (2D) two-dimensional images, which can be stored in electronic form. These images are stored by means of pixels of specified coordinates X and Y with certain intensity, for example, in grayscale ranging from 0 to 255. The proper function of a laser confocal microscope is the ability to obtain images in three dimensions (3D). To do this, the electronic record of stereometric data is carried out using three-dimensional pixel counterparts – voxels. The resulting digital images can be processed and converted in order to: change the contrast, perform analysis, prepare a quantitative description or reduce noise.[9]

The principle of registering a three-dimensional image is relatively simple. A beam coming from a point source, after being reflected from the sample surface, is directed through a separating prism to the detector. Images are registered by the detector in two modes: point or line. These modes offer comparable research capabilities. The detector registers only the rays reflected from the sample components that are in the focal plane of the objective lens. The rays reflected from the test product components located above or below the focal plane of the object are suppressed at the aperture and are not subject to registration. In this case, no blurred image of these details is observed, unlike in a conventional light microscope. Registration of the surface height coordinates is performed by stepwise changing the position of the focal plane in the direction of the Z axis. After scanning one focal plane of the test surface in the direction of the X and Y axes, an image of scanning (confocal cutting) is stored in the memory (RAM) of the microscope. Then, the position of the focal plane is changed, and the procedure of scanning and recording confocal cutting is repeated. The change in the height of the focal plane position is done by shifting a

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