Assessment of pore size distribution using image analysis

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ABSTRACT. Article deals with pore size distribution assessment of porous materials using image analysis. Test samples used in the study were prepared from metal foams and porcine trabecular bone. Two- and three-dimensional images were obtained by SEM (scanning electron microscopy) and a high resolution flatbed scanner. For the pore size distribution assessment various methods were used, depending on input data properties (method of obtainig image data) and on pores characteristics (different approach should be used for closed or opened pores). For pore size evaluation using 2D images 25F Association method [5] was used. For verification of the developed algorithms MIP (mercury intrusion porosimetry) [6] measurements were performed, but only in case of trabecular bone samples, because opened pores are necessary for these measurements. Presented algorithms were verified using artificial data structures (binary images with controlled pore- size distribution).

KEYWORDS. Pore size distribution; Image analysis; micro-CT.

INTRODUCTION

Porous material can be understood as a particular composite with discrete phase represented by voids. Porosity (a ratio between the volume of voids and the total volume) and pore-size distribution (frequences of various sized voids) can have an influence on the thermo-mechanical properties of the material, e.g. Young modulus, thermal capacity or thermal conductivity [1]. For estimation of relations between mentioned characteristics pore size distribution measurements are required. This article deals with pore size distributions measurements using image analysis.

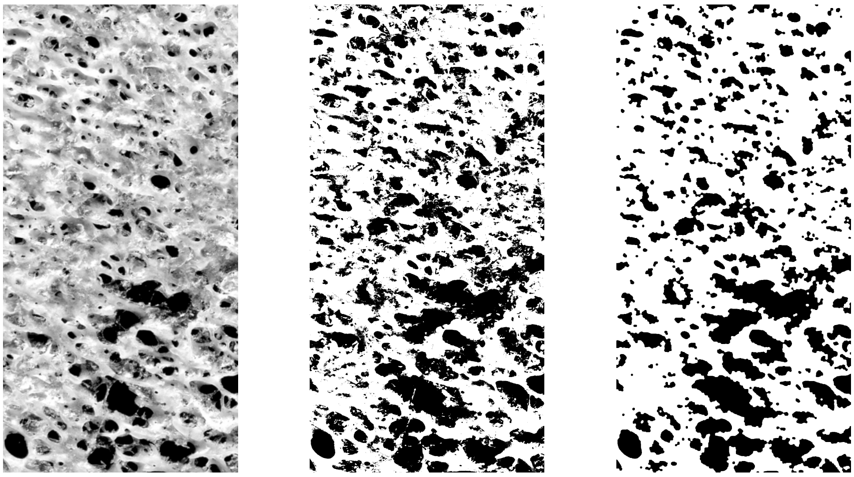
MATERIALS AND METHODS

Image data obtaining

Three different methods for image data obtaining were tested depending on the size of voids. For void- size in range of microns SEM (scanning electrone microscopy) or optical microscopy were used. In case of optical microscopy (using a trinocular microscope with a camera) studied samples had to be thin enough. The obtained images are exactly two-dimensional. In case of SEM the samples could be thick, but obtained images showed partly the inner structure of the samples and therefore they cannot be considered completely as sections. In the third case, the images of the samples were obtained by a high resolution flatbed scanner (EPSON Perfection V350 Photo). Resolution 4800 dpi was used (1 px corresponds to 5 μm). This method is suitable also for materials with larger pores, because samples with dimensions corresponding to representative area were required to register enough wide population of voids.

Pore-size assessment

Before the pore-size assessment the image data have to be preprocessed. In case of closed pores thresholding procedures had to be done to obtain binary images. For opened (connected) pores it is necessary to the find boudaries between pores (separate connected voids) using suitable segmentation algorithm. The used algorithm consists of morphological operations (closing, opening) and thresholding [2].



(a) scanned (b) thresholded (c) segmented

Figure 1: Section of trabecular bone sample

Described image analysis was performed in computational environment Matlab [3] and therefore it was possible to use functions of Image Processing Toolbox. To find vector of all voids rated by their size (number of pixels) two pass algorithm for Connected Component Analysis [4] was used. A function was developed for conversion of the size-distribution vector into a suitable format (2-by-N matrix with all ascertained pore-sizes and corresponding number of pores).

Stereologic calculation method

Because two-dimensional images were used, only transection-size distribution was obtained. To estimate the pore size distribution in the three-dimensional space a stereological method had to be used. For this purpose, 25F association method [5] was chosen. This method requires transection- size distribution to be converted into a special form (vector of 25 values, corresponding to frequency of transections in 25 size classes).

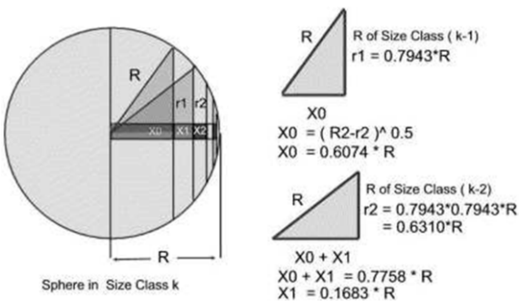
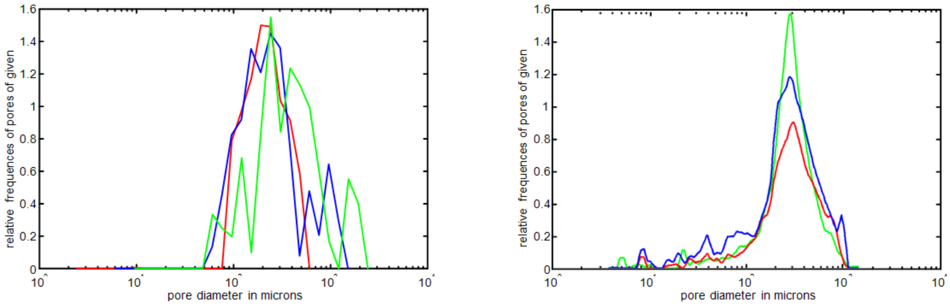


Figure 2: Chances to obtain various sized transections of a sphere [5].

Using the same ratio between size classes as in [5] a function to order transection size values into size classes a Matlab-function was developed. The 25F Association method uses geometrical properties of a sphere to calculate the probability of affiliation of transection in the given size-class to a sphere in the same or larger size-class. This method was implemented as an Matlab-function and used for the pore-size distribution assessment.

Results

Curves of pore size distribution of three samples of porcine trabecular bone were obtained by image analysis. These curves are shown on Fig. 3. For the verification of the described methods two distinct approaches were used, an experimental (MIP measurements were performed) and a computational one (artificial image data were used).



(a) obtained by image analysis (b) obtained by MIP

Figure 3: Pore size distribution curves of porcine trabecular bone.

MIP [6] measurements were performed on three samples of porcine trabecular bone. The comparison of obtained results with the results of image analysis is shown on Fig. 3. A special Matlab function was developed for three-dimensional binary matrices acquisition with ellipsoidical voids labeled by regions of symbolic ones. Selected planes of these matrices represented sections and enabled to compare the results obtained by the known properties of the whole matrix.

Conclusions

Pore size distribution curves of trabecular bone and metal foam samples were obtained using image analysis and stereological calculation. A satisfactory agreement with MIP measurements was observed. The method was verified using artificial image data with controled distribution of voids. Described algorithms are suitable for pore size distribution assessment of materials with wide range of pore size, if suitable method is used to obtain the image data.

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References

[1] L. J. Gibson, M. F. Ashby, Cellular Solids: Structure and Properties, Cambridge University Press, (1999).
[2] R. C. Gonzales, Digital image processing using MATLAB, Upper Saddle River, Pearson (2004).
[3] MATLAB version 7.8.0.347, The MathWorks Inc. (2009).
[4] L. Shapiro, G. Stockman: Computer Vision, Prentice Hall (2001).
[5] Y. H. Xu, H. C. Pitot, Computer Methods and Programs in Biomedicine (2003).
[6] A. B. Abell, K. L. Willis, D. A. Lange, Journal of Colloid and Interface Science, (1999).