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New Method for Diagnostic of Heat Engineering and Mechanical Properties of Cellular Concrete

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Annotation.The article presents the results of studies assessing the structure of cellular concrete using a photo-optical method based on the use of a modern approach from the standpoint of information technology. Based on the photo-optical method, a reverse formulation of the problem is also possible: on the basis of a given percentage of porosity of the material, obtain the most optimal pore arrangement (type of packaging) that meets the specified strength and thermal conductivity of aerated concrete. Having a specific type of image of aerated concrete obtained as a result of modeling, otherwise, a specific type of packing of pores of certain sizes that meets the required (specified) characteristics, then, we can set the technological task of obtaining it.

Key words: modeling, structure, cellular concrete, fractal dimension, photo-optical method, porosity, strength, thermal conductivity, type of concrete laying.

I. INTRODUCTION

Obtaining on an industrial scale energy-efficient, inexpensive and environmentally friendly heat-insulating building materials is one of the urgent problems in construction science. A striking representative of such materials is cellular concrete - an artificial porous building material with a characteristic evenly distributed fine-grained cellular macrostructure resulting from the porous and hydration hardening of a rationally selected mortar mixture consisting of a cementation, siliceous component, blowing agents and additives [1-3].

Aerated concrete, having almost a century of experience in production and use, has established itself as one of the most effective building materials for multifunctional purposes, with high strength and heat-shielding properties. A characteristic feature of cellular concrete is its porous structure, represented by various types of pores - cellular, capillary and helium. Therefore, in the task of studying the properties of cellular concrete, the main objects are a quasi-homogeneous medium, as a combination of many packed particles, and its physical characteristics. Theoretically, any set of particles can be quite fully represented by the corresponding matrix, consisting of elements in the form of descriptions of all the individual properties of each of the particles. The defining elements of such a matrix are the parameters of the macrostructure of cellular concrete, characterizing the relationship of the macrostructure with their strength and thermal properties. However, a theoretical solution to this practical problem involves a number of difficulties associated with its multi-functionality [3,6-10].

Since the macrostructure of aerated concrete is determined by a number of geometric parameters and the mutual orientation of the pores, it would be convenient to describe it to obtain some integral characteristic, including, on the one hand, geometric parameters, and on the other hand, characterizing the physical properties of aerated concrete.

The geometric features of aerated concrete, characterized by a porous structure, suggested that the theory of fractal geometry be used as a mathematical tool to obtain some integral characteristics of the macrostructure [1, 11-14].

To calculate the fractal dimension of the porous structure of aerated concrete, the modified Peano algorithm, known as the Box Counting method, was used [2]. According to this method of calculating the fractal dimension D, it is performed by the formula

$$D = \frac{\ln N}{\ln\left(\frac{1}{\delta}\right)}, \qquad (1)$$

Where □ is a square grid cell of size □×□ covering the studied structure (Fig. 1), presented in the form of an image (the technology of the method will be discussed in detail below.) In (1) N is the number of square cells at which points (with coordinates x_i, y_j, i=1, m, j=1, k) images belonging to the material – pore boundary.

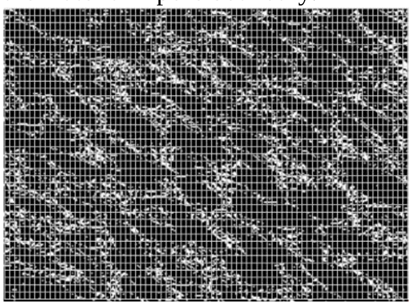

Fig. 1. The macrostructure image of cellular concrete covered with a grid of square cells, inside which the number of boundary points (material - pores) that fell into the i-th square was calculated

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According to the Box Counting algorithm implemented in a specially developed program, the studied structure of cellular concrete must be entered into the computer. For this purpose, it is proposed to fix the test sample using a Neophot-21 electron microscope equipped with a special interface that connects the microscope to a computer via a USB port (Fig. 2). A digital camera is built into the microscope, which provides an enlarged image in the "* BMP" format with the recording of an image not a hard disk in a given directory. The resulting image using the specially developed program "Converter" converts the image in the specified format into a digital matrix with 256 brightness levels (from 0 to 255), size $m \times n$ pixels (image elements). This procedure is called quantization of the image for a given number of brightness levels.

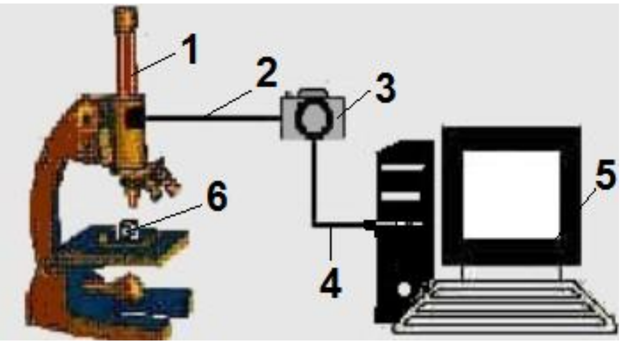

Fig. 2. Scheme of connecting a "Neophot-21" electron microscope to a computer using a special interface and a USB cable:1 - Neophot-21 electron microscope; 2 - interface; 3 - digital camera; 4 - USB cable; 5 - PC; 6 - test sample

Then, the procedures for quantizing the original image matrix (256 brightness levels) by a given number of levels and plotting a histogram at each step of the corresponding level are performed. The last level is a binary image, i.e. an image consisting of a black brightness level ("0") and a white brightness level ("255"). In this case, the "black" matrix of the sample is accepted, the "white" matrix is pores, that is, the pore-matrix boundary is uniquely determined.

II. RESULTS & DISCUSSIONS

Further, according to the Box Counting algorithm, a grid with square cells, □×□, where □ ≤ r, r – is the average pore radius of the sample is superimposed on the binary image. The binary image, in practice, provides automatic recognition of the "matrix-pore" boundaries, necessary for counting the squares of the grid in the image, including the pores in accordance with (1).

In our algorithm, the quantization procedure performs, in addition to dividing the image into two classes of "pores - not pores", the filter function — averaging the image over gradations of brightness levels.

When analyzing a series of quantized images of cellular concrete samples obtained by this technique, it was found that the geometry of the formation of the structure of the material of the sample as a whole is manifested in these images. In this case, the revealed structure was anisotropic in nature, determined by the orientation of the material – pore boundary in a separate preferred direction — the angle of inclination was 18 ° with a horizontal line [3].

Taking into account that the anisotropy of the macrostructure reduces the average strength of aerated concrete in the case of a directed load [4], then, having quantized images of a material sample, one can judge its strength characteristics.

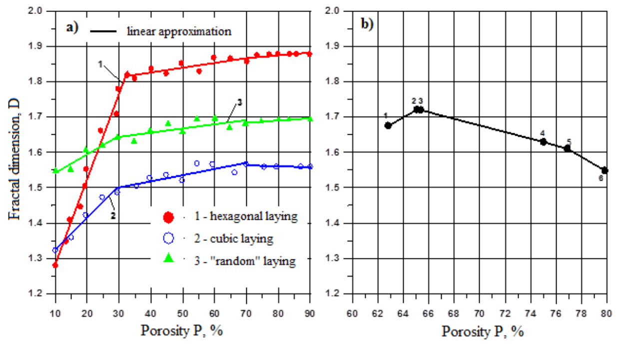

Fig. 3. The relationship between the fractal dimension D and porosity P (%) according to the model image of cellular concrete (a) with hexagonal (1), cubic (2) and "random" (random number generator) laying types (3) with a given percentage of porosity ; b) - the same dependence according to the data of real samples of cellular concrete (numbers - numbers of samples).

When quantizing the initial image of the cellular concrete sample, the corresponding histogram is built, based on which you can immediately give an estimate of the degree of porosity of the sample according to the formula:

$$P_M + Pinc + P'_п = 1 \qquad (2)$$

where $P_м$ -is the probability (empirical frequency) of the image tone of the sample matrix material (image brightness level near the black neighborhood), Pinc -is the probability of the image tone associated with inclusions (image brightness level near the gray neighborhood), $P'_п$ is the image tone probability of the partitions (borders) material - porous structure (brightness level near the neighborhood of white color).

From (2) it is possible to determine the percentage of porosity of aerated concrete:

$$P_п(\%) = 100\% - (1 - P_м + P_{вкл}) \cdot 100\% = 100\% - P'_п \qquad (3)$$

Studies performed on real samples showed that this method makes it possible to assess the porosity of aerated concrete with an accuracy of 2.5%.

Based on the developed software package, which includes all stages of modeling, numerical experiments were carried out, firstly, to identify the presence of a fractal nature in the structure of cellular concrete and, secondly, the features of the relationship of the fractal structure with its physical, mechanical and thermal characteristics. When modeling the structure of aerated concrete, the pore sizes were specified in the range of pore radii from 0.2 to 2 mm in 0.2 mm increments, and the porosity range was considered in the range from 10 to 90% [5].

In fig. Figure 3 shows the dependences of the fractal dimension of cellular concrete on its porosity with hexagonal and cubic types of pore stacking.

III. CONCLUSION

Thus, the fractal nature of cellular concrete, determined by its fractal dimension, which has a regular (in the statistical sense) connection with porosity, and hence with thermal conductivity, and with the strength of cellular concrete, is revealed. Therefore, the fractal dimension can act as an integral characteristic of the properties of aerated concrete, and the proposed photo-optical method can be used to diagnose the properties of aerated concrete.

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