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Some Aspects of the Photo-Optical Method of Estimation Composition of Light Concrete

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Abstract— The article is devoted to the determination of the fractal dimension of the porous surface and further finding the relationship of the fractal dimension with the porosity of cellular concrete. A numerical experiment was carried out aimed at determining the fractal dimension of the structure of cellular concrete in order to clarify the relationship of the latter with its porous structure. An approach has been developed to assess the properties of cellular concrete based on the analysis of its image.

Key words: fractal dimension, cellular concrete, structural simulation, porosity.

I. INTRODUCTION

Improving energy efficiency and energy saving of buildings and structures is a priority in the energy policy of Uzbekistan. In this regard, the production on an industrial scale of energy-efficient, inexpensive and environmentally friendly structurally-insulating building materials is one of the urgent problems of construction science [1-3].

Successful implementation of such tasks in the field of civil engineering urgently requires the development of a new methodological approach to the creation of building materials for external enclosing structures with specified sets of properties. To develop a technique for modeling properties, a material was chosen that has a developed porous structure - cellular concrete, represented by various types of pores: capillary, large, conditionally closed, and gel. When implementing this task, an assumption was introduced that cellular concrete is represented as a quasi-homogeneous medium, as a set of packed particles and with integral physical characteristics [4-6, 20-21].

The properties of building materials, including heat insulating materials, are determined both by the state of the structure of substances from which they are produced and by the macrostructure formed as a result of technological conversion. According to [7], the optimal structure corresponds to the complex of the most favorable indicators of the building and operational properties of the conglomerate. On this basis, the optimal structures of cellular concrete include those that are characterized by maximum values of porosity with a uniform distribution of pores and aggregate by volume [8-9, 22-23].

In the study of the properties of cellular concrete being developed, the main objects are a quasi-homogeneous medium, as an aggregate of a multitude of packed particles and its integral physical characteristics [10-11]. Theoretically, any set of particles can be quite fully described by the corresponding matrix consisting of elements in the form of descriptions of the individual properties of each of the particles, including their individual phase coordinates — the physical parameters of the state. The defining elements of such a matrix are the parameters of the macrostructure of cellular concrete, which characterize the connection with their strength and heat engineering properties.

The search for the optimal structure of thermal insulation materials was carried out by A.P. Merkin, Yu.P. Gorlov, A. A. Brushkov [15]. Questions of complex studies of the structure of materials are considered in the fundamental and fundamental works of V. A. Pinsker, as well as A. N. Kharkhardin, in which the main focus was on studying the mechanism of formation of the diameter of cellular pores and the formation of interpore partitions.

The theoretical rationale for the relationship between the macrostructure of cellular concrete and their strength was studied by G. I. Loginov and A. P. Filin. The researchers, on the basis of mathematical models characterizing the occupancy of a unit of volume by spherical bodies, derived fairly strict regularities describing the "ideal" structure of cellular concrete.

Analysis of research materials [1-17] showed that for the formation of the necessary strength and thermal characteristics of aerated concrete, it is necessary to implement a multifunctional task by varying a large number of variable factors.

II. EXPERIMENTAL STUDIES OF THE CELLULAR CONCRETE MACROSTRUCTURE

Taking into account the geometric features of the structure of cellular concrete, which is distinguished by high porosity, the theory of fractal geometry was adopted as a mathematical tool for the analytical description of the structure of cellular concrete [11,18].

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The methodology for the formation of fractal objects, a numerical experiment was carried out aimed at determining the fractal dimension of the structure of cellular concrete to determine the relationship of the latter with its porous structure. For this, the first step was to build a physical model of cellular concrete with hexagonal, cubic and rhombic packages [1, 7-8].

Image processing was carried out according to a specially developed algorithm, on the basis of which a software package was built, including image input, determining the type of packaging (its proximity to one of three types - hexagonal, cubic or rhombic), searching for boundaries between the pore space and the material (matrix, various types of inclusions, etc.). In addition, one of the main blocks in the program is a block of "quantizing" an image into a given number of levels with the construction for each level of a histogram of the sample's probability density distribution by brightness levels. The last level represents the binary distribution (black - material, white - porosity). To clearly represent the objects subjected to machine image analysis in

III. RESULTS AND DISCUSSIONS

Fig. 1 shows a micrograph of a fragment of the structure of cellular concrete [9-10].

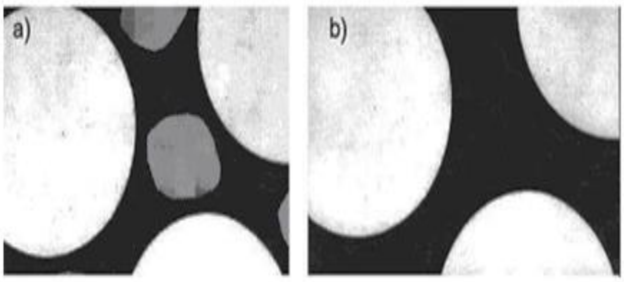

Fig. 1. Micrograph of cellular concrete (a - light color - air bubbles; black color - matrix; gray color – placeholder; b- the same image in binary form (quantized into two levels).

Before proceeding directly to the definition of the fractal dimension of the structure of cellular concrete, consider the possibilities of studying its properties based on image processing. For this we turn to fig. 2, which shows the results of quantization of the original image of the structure of cellular concrete into 8 levels and the corresponding histograms. Let's start with the original image (Fig. 2a) and its histograms.

As can be seen from the histogram, which shows the features of the structure of cellular concrete, the frequency distribution of brightness levels has a two-modal character: the first mode is associated with the matrix and various inclusions (material), the second mode - with porosity. Based on the presented histogram, we estimate the degree of sample porosity using the formula:

$$P_м + P_{tn} + P_п^{/} = 1 \qquad (1)$$

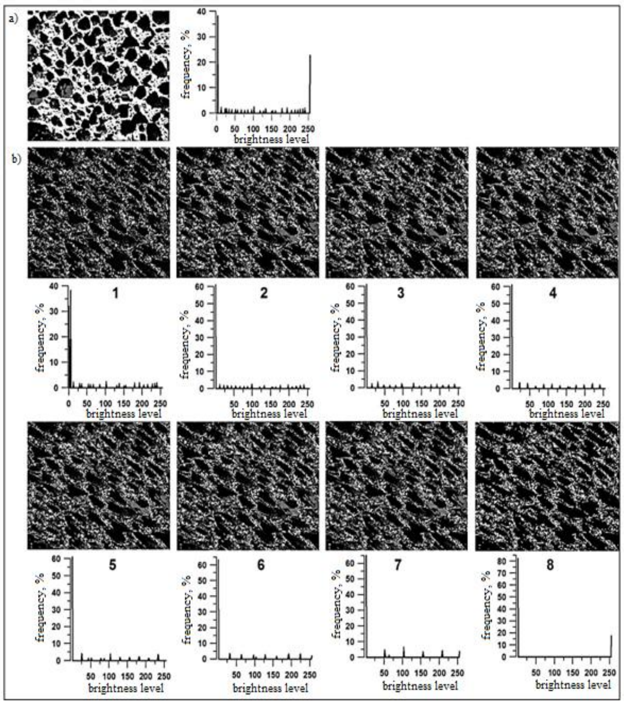

Fig. 2. Results of processing the image of the structure of cellular concrete (a - the original image of cellular concrete and its histogram (right); b - quantized images from the 1st to the 8th levels and their histograms (bottom) for the corresponding level (numbers from 1 to 8)

where is the probability (empirical frequency) of the image tone of the sample matrix material (image brightness level around the black area), is the image tone probability associated with inclusions (image brightness level near the gray area), is the tone probability of the image of partitions (borders) material - porous structure (brightness level around the neighborhood of white).

From (1) we determine the percentage of porosity of cellular concrete:

$$P_п(\%) = 100\% - (1 - P_м + P_{tn}) \cdot 100\% = 100\% - P_п^{/} \qquad (2)$$

For our sample on the basis of the histogram (Fig. 2a), we have . This estimate is made to within 2.54% of the sample documentation.

Since the technology of obtaining the image is not unambiguous, the image is characterized by noise (noise), distorting the true picture of the sample structure. Therefore, in order to filter out this kind of interference, a quantization procedure is included in the image processing software package - averaging the gradation levels in specified ranges over gradations.

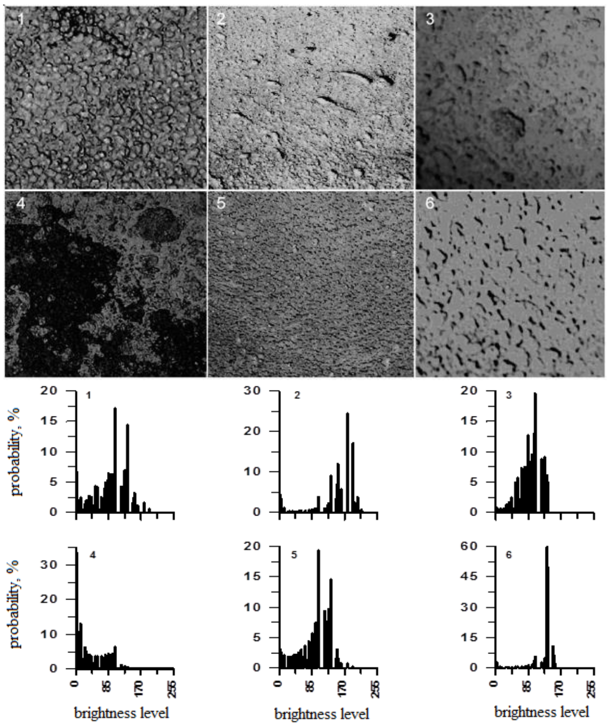

Fig. 3. Test samples of cellular concrete with different volume mass W, strength R_b , and porosity P (table 1) - top panel and their image histograms - bottom panel

In other words, this procedure allows you to bring the image to some average standard conditions. In essence, the number of task levels can be arbitrary, but a necessary condition is the task of the last level, as a binary one. This condition is necessary because, ultimately, we are interested in two objects — the material and the pores. In the language of image processing, these are two gradations (in our case, black and white). In Fig.2b shows the results of quantization of the image shown in Fig. 2a.

It turned out that the filtering, which leads to the image of some average shooting conditions, performs an extremely important function related to the characteristic of the structure of the sample as a whole (Fig. 2b). It is seen that the latter shows the geometry of the formation of the structure of the sample as a whole, which is anisotropic in nature, determined by the orientation of the macrostructure in the preferred direction. Moreover, with an increase in the level of quantization, this feature of the macrostructure is manifested to a greater degree. The above explains where the magnified image of the binary level is shown (Fig. 2b-8) with the predominant direction of the formed macrostructure as a whole (the direction is indicated by the arrow). To determine the apparent porosity in the test samples from the existing methods were used: the method of saturation of the sample pores with water during boiling and photo electronic method developed in the Moscow Engineering Construction Institute (MICI) [6,15-17].

The apparent porosity for the first method was calculated by the formula (%):

$$P_к = \left[\frac{m_2 - m_1}{m_2 - m_3}\right] \cdot 100, \qquad (3)$$

where m1 - mass of sample before saturation with water; m2 - mass of sample after saturation with water during air weighing; m3 - mass of sample after saturation during hydrostatic weighing.

Assessment of the accuracy of cellular concrete porosity determination by "image analysis" method

As estimates of the accuracy of the method are accepted:

- the difference Δ_i between the value of "truth" of porosity P_i^{uc}, for which the manufacturer's estimation is accepted, and the value of porosity obtained by the MICI method and the method of "image analysis".

$\Delta_i = P_i^{uc} - P_i^{/}$ .i = 1,2, . . ., 6 - sample numbers;

- average error in arithmetic

$$\bar{\Delta} = \frac{1}{N}\sum_{i=1}^{N}\Delta_i \ ;$$

- absolute maximum error

$$|\Delta_{max}| = \max|\{\Delta_i\}| \ ;$$

- mean square error;

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(P_i^{ис} - P_i^{/}\right)^2} \ .$$

The reason for the systematic error of the method, apparently, is related to the resolution of the levels of quantization of the original image and further recognition of the boundaries of the matrix (material) - pores. Further experiments with quantization levels of the initial image were not carried out, since the obtained RMS error (• =0,312) at 8 levels of quantization is acceptable in practical work. Images of 8 levels of quantization of the test sample No. 1 (W=420 kg/m3, P=80%) are given for a more visual representation of the above mentioned in Fig. 4. [6,17-18].

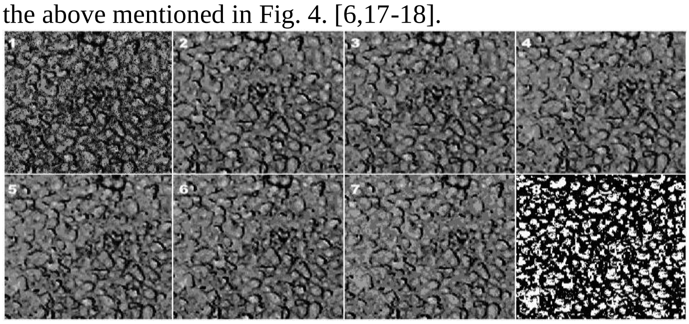

Fig. 4. Results of the original image quantization procedure of sample No. 1 (Fig. 2) of cellular concrete. Note: numbers - quantization levels.

In addition, in Fig. 5, the strength surface of cellular concrete is given as a function of fractal dimensionality and porosity. This figure clearly indicates the fact that the fractal dimension of the cellular concrete structure is an informative characteristic of the physical properties of the latter, describing all the major parameters: porosity, strength and thermal conductivity [6,17-19].

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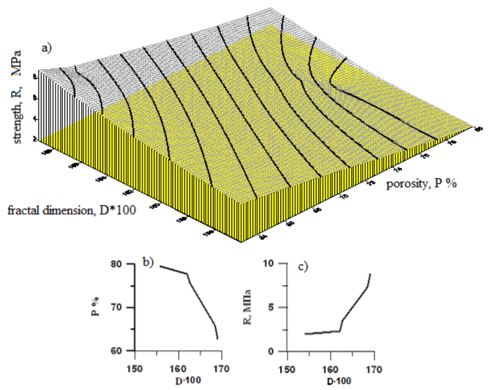

Fig. 5. Surface strength of cellular concrete (a) as a function of fractal dimension and porosity; b), c) the dependence of the porosity and strength of the test samples on the fractal dimension of the structure of cellular concrete.

IV. CONCLUSION

The conducted numerical experiment in the framework of the software implementation includes modules that provide input and matrix formation for the image of the structure of cellular concrete in the computer memory. Here, image processing procedures are performed, including quantizing the original image to a specified number of levels, of which the binary level is mandatory, material — pore boundaries recognition, calculation of the fractal dimension of the cellular concrete structure of a given porosity. This part of the software package provides the primary implementation of a numerical experiment. The second part of the software complex performs numerical experiments on model samples of cellular concrete of various porosities and studies related to the formation of its connection with the fractal dimension and, ultimately, with the strength and heat engineering properties.

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