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THE ANALYSIS OF PORE DISTRIBUTION AND PORE CONNECTIVITY IN CONCRETE SAMPLES USING X-RAY MICROTOMOGRAPHY

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1. Introduction

The durability of concrete in outdoor structures is closely related to its resistance against the aggressive gaseous actions coming from the environment and including influence of oxygen, nitrogen, carbon dioxide. The pore system and its interconnectivity in the concrete matrix directly influence the possibility of penetration of various aggressive gaseous media into concrete structure. The X-ray microtomography (micro-CT) is a modern, non-invasive technique enabling for determination of existing pores in the microstructure of concrete matrix. In the paper the results of investigation of two different concretes by the application of micro-CT method to micro-cores are presented. The quantitative information on the parameters of the analysed microstructure can improve the methods of material characterization available up to now.

2. Application of X-ray microtomography in concrete microstructure analysis

The micro-CT technique and the material testing systems employed with this technique are produced by a few companies only. They are capable to perform tests on the small specimens of a few millimetres size or on larger elements. They include the microfocal source of X-ray radiation, the movable table to place a specimen, and the flat panel with a radiation detector. The microstructure of concrete is visualized on the tomograms of the investigated specimen using grey scale convention related directly to the amount of local radiation absorption of the material. The grey scale is ordered from white related to maximum of absorption to black related to the minimum, respectively. Unhydrated cement particles and aggregate grains analysed in the micro-CT are objects of the greatest absorption. The hydration products as calcium silica hydrates that cover major part of the concrete matrix develop slightly lower absorption ability, then plates of calcium hydroxide and at the end of the scale are the regions of high porosity. The image resolution of tomograms is usually in the order of a few micrometers. The application of the micro-CT technique allows to reconstruct a real 3-dimensional image of investigated concrete micro cores and to determine the volumetric part of the material occupied by bulk matrix, aggregates, voids, pores, cracks, etc.

Slate and Olsefski [1] visualized the crack growth in compressed concrete specimens in early sixties of twentieth century. On their radiograms with resolution of 100 μm only large cracks, aggregate grains and matrix were visible. Landis *et. al.* [2] carried on compression tests of small mortar cylinders. During the experiments in compressed specimens the process of material decohesion was captured and rapid onset of the system of microcracks after exceeding the critical stress in tested mortar. On the basis of a qualitative analysis of the test results it was concluded that the area most affected by cracks appeared in the mortar of low density. Provis *et. al.* [3] tested concretes with addition of siliceous fly ash and ground granulated blast furnace slag in different proportions. The scanning was performed on small agglomerates of particles of approx. $1 \times 1 \times 1$ mm. The aim of investigation was to trace the volume evolution of pores and to determine the time changes of connectivity within the pore system. To characterise the connectivity of pores a diffusive tortuosity T was determined. The latter parameter is constructed on the basis of the measurements of the paths created by the traces of migrating abstract particles, called 'walkers' using the special algorithm. The authors have reported that the pore volume decreased in linear proportion to the hardening time of specimens made with all investigated concretes. The decrease of pore volume was accompanied by the increase of their tortuosity.

3. The details of a 'random walk' procedure

Random walk algorithm was intended to simulate the diffusion of gases and liquids in the interconnected network of pores. At the starting point of the action a certain number of walkers was distributed randomly across the space reconstructed by means of the micro-CT scanning procedure. The walkers migrated on discrete voxels obeying the information on voxels brightness (i.e. material density). The walkers executed jumps in randomly chosen direction but the jumps could be performed if the neighbouring voxel belonged to a pore and otherwise the jumps are discarded. After refreshing the position of all walkers one epoch of its action was completed by the algorithm. The nubber of epochs was measured by the dimensionless integer time τ. The output of the random walk procedure is the walkers mean-square displacement $\langle r(\tau)^2 \rangle$ as a function of time (x_i, y_i, z_i are the coordinates of a current walker position and n is a number of executed epochs):

$$\langle r(\tau)^2 \rangle = \frac{1}{n} \sum_{i=1}^{n} (x_i(\tau) - x_i(0))^2 + (y_i(\tau) - y_i(0))^2 + (z_i(\tau) - (z_i(0))^2. \tag{1}$$

The mean-square displacement is important because the diffusion coefficient D of the porous medium is related to the time-derivative of $\langle r(\tau)^2 \rangle$ and the key transport property called *tortuosity* T can be expressed as:

$$T = \frac{A}{d\langle r(\tau)^2 \rangle / d\tau} \qquad \text{as} \quad \tau \to \infty, \tag{2}$$

where A is a constant depended of image lattice parameters and when a tortuosity of the samples of the same dimensions are compared A can be assumed as 1.

4. Experimental Results

Two concrete specimens were tested using a micro-CT method and their analysed volume was appr. 410 mm^3. The total porosity of the first one was 7.1% and of the other – 4.9%, thus their porosity ratio equalled 1.41. The total number of pores found in the reconstructed micro-CT image of the first sample was 84684 and it was 1.36 times greater than that in the other one. The mean-square displacements ratio of determined for these samples was 1.38 what means that the diffusion parameter remained in good agreement with porosity of the samples reported in [3], however it was not possible to calculate the certain values of their tortuosity.

References

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