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DETERMINATION OF 3-D AIR VOID CHARACTERISTICS IN HARDENED CONCRETE BY MEANS OF IMAGE ANALYSIS

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ABSTRACT

For concrete to have excellent frost durability it is effective to control the void distribution in the material. To rebuild the three-dimensional void distribution, there are only two methods that are described in a norm. Image analysis provides a powerful tool to ameliorate and fasten these methods. There has been considerable research activity at our institute in these areas over the last two years.
The existing methods, described in the norm ASTM C457-71, have been implemented on an automated image analysis system. It concerns the modified point counting and linear traverse techniques. Two-dimensional data resulting from simple plane sections measurements on hardened concrete specimens are worked out to reconstruct the three-dimensional void-distribution. Current thoughts and approaches are emphasized.

Key words: air voids, image analysis, three-dimensional reconstruction.

INTRODUCTION

For determining the air bubble characteristics of homogeneously distributed air voids in hardened concrete, there exist at present only two methods. The preparation of the samples and the execution of the measurements are established in the standards.

- Modified point counting (ASTM C457-71)
- Linear traverse (ASTM C457-71).

These two methods are described for manual operation, with an operator looking through a microscope. These measurements provide the following results

- modified point counting: air content, specific surface and spacing factor
- linear traverse: air content, specific surface and chord distribution. When the cement content is known the spacing factor can be calculated. By means of existing methods the 3-D air bubble distribution can be reconstructed.

In a first step these two existing methods were simulated by means of an image analysis system for a manual execution and for an automatic one, whereby the instructions of the standard were carefully followed.
Automating the measurements means first of all establishing a contrast between the phase which will be measured, and the rest of the sample. Then the grey value interval of the selected phase is transferred to the system as a parameter, so that the computer is able to select the air bubbles as a seperate phase by discriminating these grey values.

EXISTING METHODS SIMULATED ON AN IMAGE ANALYSIS SYSTEM

EQUIPMENT

The following equipment is being used at the BBRI:

Optical research microscope
Type: ZEISS Axioplan
Transmitted or reflected light; normal/polarized/fluorescent light
Scanning stage and Microscope Control Processor (MCP)
Type: MARZHAUSER- KONTRON ELEKTRONIK
range 215 * 102 mm; 1 micron step size
control of 2 axes (scanning stage) and focus motor; joystick for interactive control
Camera
Type: MTI precision 81 (Vidicon type camera tube)
resolution 1600 TV lines; shading correction; builded in colour filters
Image analysis system
Type: IBAS system; Kontron Elektronik
Real-colour image processing; 16 Mbyte of image memory;
HDD-display processor; Integrated Bernoulli 44 Mbyte

MODIFIED POINT COUNTING

MANUAL EXECUTION

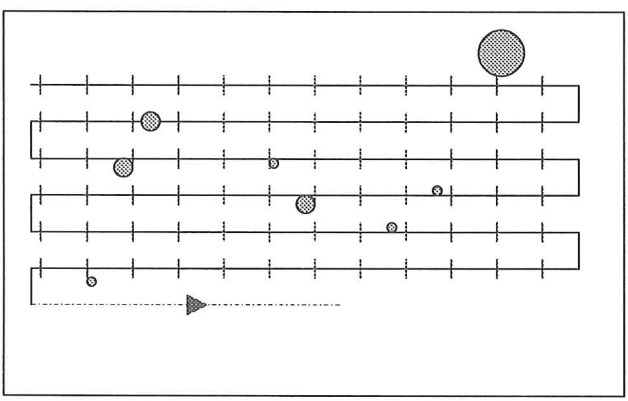

Fig.1. Modified pount counting method executed with an image analysis system.

The implementation of the modified point counting technique on an image analysis system consists in evaluating the sample along one line, during which the motor, that moves the sample, is stopped after a certain distance is covered. At each stop the point is evaluated under 2 vertical vectors (evaluation points) by the operator. The number of times the motor stops at an air bubble S_V or on the cement paste S_p, is counted accurately. Between two stops one also measures how many times the evaluation point passes an air bubble. This is demonstrated in Fig 1.
In this way the following parameters are known :

S_t :total number of stops
S_V :number of stops at an air bubble
S_p :number of stops at the cement paste

N :total number of air bubbles passed by in between the stops
T :total length of scan line.

The following parameters can be calculated (ASTM C457-71) : air content, A (Eq.1), mean chord length, $\bar{l}$ (Eq.2), specific surface area, α (Eq.3) and spacing factor, $\bar{L}$ (Eq.4, Eq.5).

$$A = \frac{S_V}{S_T} \tag{1}$$

$$\bar{l} = \frac{A * T}{100 * N} \tag{2}$$

$$\alpha = \frac{4}{\bar{l}} \tag{3}$$

$$\bar{L} = \frac{3}{\alpha} * (1.4 * (\frac{p}{A} + 1)^{1/3} - 1) \tag{4}$$

$$\bar{L} = \frac{p}{400 * n} \tag{5}$$

where p = paste content in volume percent of the concrete. Eq. 4 is to be used when p/A exceeds the value 4.33. Eq. 5 is to be used when p/A is less than 4.33.

AUTOMATIC EXECUTION

Instead of performing this point counting on a sample without contrast enhancing, the automation consists in establishing an unequivocal contrast between the air bubbles and the rest of the sample. At the moment this contrast is improved by colouring the sample with a dark marker, and by thereupon filling the empty spaces (air bubbles, pores) with a white zinc paste as earlier developed by Chatterji and Gudmundsson(1977). In this way the originally 3-phase sample, consisting of air, aggragate and cement paste is reduced to a 2-phase sample pore-matrix. At the start of the measurement the grey value interval of the air bubbles is

exactly determined, so that the computer can determine independently whether the grey value of a certain point belongs to this interval or not. In this way the system can independently cover the whole scanline while registering the number of air bubbles passing underneath the evaluation point and of the stops .
The sample is no longer continuously moved between the stops, but the surface is scanned picture by picture (512 pixels * 512 pixels) (in real dimensions these values have to be multiplied by the scale factor for the x- and y-direction).
Remark: A large part of the information will be discarded of the selected phase, only 1 dot per passing air void will be used.

LINEAR TRAVERSE

The linear traverse method consists in scanning the sample along a line, while not only registering whether there is an air bubble or not, but also recording the lenght of the intersection of the air bubble and the traverse line. In this way it is possible to determine not only the specific surface, the spacing factor and the air content, but also the 3-dimensional air bubble distribution by means of existing theories. According to the standard it is necessary for a correct execution, in order to take into account the heterogeneity of the sample, that the number of lines is evenly distributed over the field. This is demonstrated in Fig. 2.

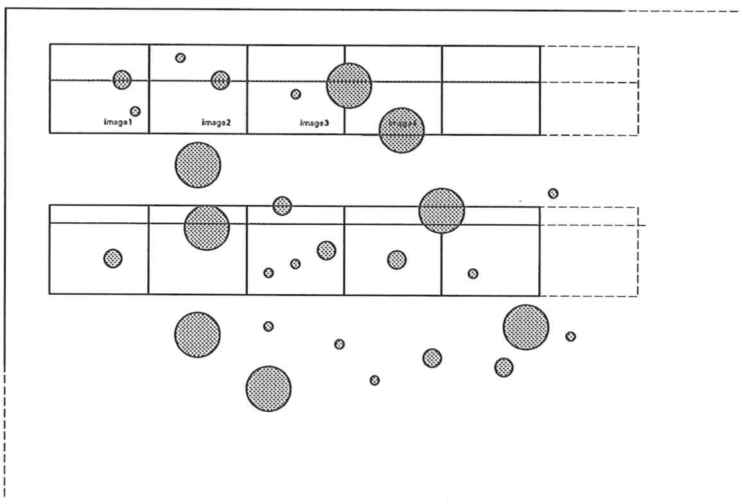

Fig. 2. Linear traverse method executed with an image analysis system.

MANUAL EXECUTION

With the manual execution the not contrast enhanced sample is scanned very slowely along a traverse line. Each time an air bubble passes underneath the evaluation point, this point is very carefully positioned on the edge of the air bubble and the length along the scan line of this chord till the end of this bubble is registered. For the exact execution of this measurement it is very important that the edges of the air bubbles are very neat and not disfigured by for instance a bad polishing technique.

AUTOMATIC EXECUTION

The automatic execution is performed on a contrast enhanced sample. The sample is contrasted as with the automatic point counting, the air bubbles distinguishing themselves as a separate phase from the rest of the sample.
The sample is no longer continously scanned but picture by picture, whereby the intersection of the scan line is registered each time. In this case it is very important that the successive images follow one another exactly, otherwise one misses each time some micrometer in the length of the section which crosses the boundaries of the picture .

As the complete image is composed of 512 potential scan lines, the possibility exists to cross the sample with more lines. Every scan line can be considered as an independent probe (the starting point of the measurement is a statistic variable) and in this way several measurements are simultaneously executed on the same sample. These results can later be processed statistically and provide an image of the accuracy which can be expected in relation with the heterogeneity of the concrete.

DISCUSSION

It is important to note that a large part of the information contained in each image is not used. The linear traverse method uses only a few of the 512 lines of the image. In the point counting method only one point out of a number of points of the complete image is registered. By means of the automatic image analysis techniques each point of the image can be evaluated. This provides the possibility of measuring the diameters of sections, the amount of cement paste, the surface of the granulates, etc.
In an ongoing Brite-Euram project possibilities are investigated to consider every pixel of the void section that is visible on the computer screen, and to derive in this way the diameter of the complete section, this derivation is also made for incomplete voids, thus voids being cut by the image borders. By using existing methods f.i. Schwartz-Saltykov and Saltykov (Underwood,1970) the three dimensional air void population can be reconstructed.
Instead of a reconstruction of the three-dimensional air void distribution, methods are examined measuring very quickly and rather easily only total air content and specific surface of the concrete, the two most relevant parameters for the frost resistance.

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REFERENCES

American Society for Testing and Materials, Standard recommended Practice for Microscopical determination of air-void content and parameters of the air-void system in hardened concrete, ASTM Annual Book of Standards. Part 14, 1979: 269-284

Chatterji S, Gudmundsson H. Characterization of entrained air bubble systems in concrete by means of an image analyzing microscope. Cement and Concrete Research. 1977;7;423-428.

Gudmundsson H, Chatterji S. The use of TAS for determination of air-voidsystem and cement paste content in hardened concrete. Microscopica Acta. 1980;Suppl 4:163-170.
Underwood EE. Quantitative stereology. Reading,Mass.:Adison Wesley, 1970: 149-199.