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2D Analysis of Concrete Composition in the Context of Determining Air Pore Structure Parameters

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2D Analysis of Concrete Composition in the Context of Determining Air Pore Structure Parameters

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Abstract. The concrete air pore structure quality evaluation is conducted according to the EN 480-11 standard. One of the basic parameters required for the concrete air pore structure quality evaluation is the P/A (paste/air) ratio. In practice, the paste's volume is determined based on the concrete mixture composition. In actual conditions, fluctuations in the air content can be observed, which directly affect the concrete composition and thus the P/A ratio, thereby ultimately affecting the results of the spacing factor $\bar{L}$. The aim of these studies was to determine the impact of various air contents and concrete mixture component proportions on the air pore structure parameters. The testing concerned surface concrete with the air content of approx. 5% and paste volume of P=26%. Standard tests for three samples with the air content fluctuating from 3.58 to 7.98% were conducted. The second stage of testing included 2D measurements of samples with the use of an innovative method of sample lighting, which allowed determining the contents of particular phases (aggregate, air, paste). The results of the standard tests were compared with the results obtained from the 2D analysis. It was found that the use of the 1D and 2D analyses leads to the determination of the values of the spacing factor amounting from 0.003 to 0.016 mm.

1. Introduction

The air pore structure parameter determination is conducted based on the EN 480-11 standard [1]. The tests include the use of two samples with the dimensions of 100x150x40 mm. One sample is measured across the traverse of 1,200 mm. Lines away from one another by 6 mm are distributed on the entire sample surface: 4 lines each on the sample's bottom and top part, and other ones in the middle. The determination of the air pore structure parameters requires the following data: total length of the measurement line (T_{tot}), total length of the measurement line passing through the air pores (T_a), paste volume fraction (P) and total number of measured chords (N). The quality of the testing methods and their impact on the evaluation of the air pore structure characteristics was the subject of many studies [2-13].

In practice, calculations often utilise the paste (P) volume based on the mixture composition obtained from preliminary testing. This approach can lead to erroneous calculations if the composition is not corrected depending on the change in the air content. The dependency between the composition and density of the concrete mixture can be presented as follows:

$$g_b = 10 \cdot g_k \cdot (100 - zp) + C\,[1 - \frac{g_k}{g_c} - \frac{W}{C} \cdot (g_k - 1)] \tag{1}$$

Assuming that the W/C ratio = const. and the aggregate granulation (g_k = const.) are not changing, the concrete density g_b depends on the air content zp. Changing the air content zp changes the concrete density g_b and thus the cement content (paste volume). For example, let us assume that in a mixture with the bulk density g_{b1} = 2490 kg/m^3 the cement content amounts to C = 360 kg/m^3 and the air content zp is_1 = 4%. If the W/C ratio = 0.45 and aggregate granulation do not change, the change in the mixture's bulk density results directly from the change in the air content. If the air content increases to zp_2 = 8%, then the density will amount to g_{b2} = 2375 kg/m^3. In effect, the paste density and air content ratio will decrease from $(P/A)_1 = 6.95$ to $(P/A)_2 = 3.325$. The above values affect the results of the spacing factor calculations.

If the paste/air ratio amounts to P/A > 4.342, then the spacing factor $\bar{L}$ is calculated according to the following formula:

$$\bar{L} = \frac{3}{\alpha}[1{,}4(\frac{P}{A} + 1)^{1/3} - 1] \tag{2}$$

If the paste/air ratio amounts to P/A > 4.342, then the spacing factor $\bar{L}$ is calculated according to the following formula:

$$\bar{L} = \frac{P}{\alpha \cdot A} \tag{3}$$

The determination of the actual content of paste in the concrete will be possible thanks to 2D measurements. The test results of the paste (P) volume based on microscopic measurements should however be treated with reservation. Then can lead to an erroneous estimation of the concrete's air content. According to Pleau, et al. [11], measurements often lead to underestimation of the concrete's air content. Based on own research, they point out that the calculated paste density is approx. 12% higher than demonstrated from microscopic measurements according to ASTM C457 [14].

The aim of these studies is to attempt to determine the impact of various air contents and concrete mixture component proportions on the air pore structure parameters results. These parameters were determined using the standard method (1D) and based on 2D analyses of the concrete sample surfaces.

2. Materials and Methods

The subject of the testing was surface concrete with the air content of approx. 5% and paste volume of P=26%. Standard tests for three samples with the air content fluctuating from 3.58 to 7.98% were conducted. The second stage of testing included 2D measurements of samples with the use of an innovative method of sample lighting, which allowed determining the contents of particular phases (aggregate, air, paste).

The scope of testing of hardened concrete included the determination of:

- air pore structure characteristics (A, A_{300}, $\bar{L}$, α) according to PN-EN 480–11:2008 [1],
- content of paste P^{2D}, air content A^{2D} and spacing factor $\bar{L}^{2D}$ in 2D measurements.

The automatic image analysis was conducted with the use of the set-up (Figure 1) composed of a stereo microscope, a CCD camera, the motorized stage and computer with Image-Pro Plus [15] software enabling determination of the tested parameters.

The first stage of testing featured preparation of the samples and determination of the air pore structure characteristics with the use of the chord count method according to the PN-EN 480-11:2008 standard. In the second stage, the samples were prepared for the 2D analysis. A fluorescent powder was applied to the sample surface prepared for testing (Figure 2). Then, a series of photographs were taken for each sample. The sample surface was photographed with two various types of lighting. The UV lighting was used to highlight the influence of the fluorescent powder and extract air pores (Figure 3a), whereas the LED lighting was used to capture aggregate grains (fine and coarse) (Figure 3b).

The air pore as well as fine and coarse aggregate images were subjected to processing, among others, in the form of removal of pores from aggregate grains, reproduction of air pores imprecisely filled out by the fluorescent powder, reconstruction of the shape of air pores or aggregate grains damaged during grinding or polishing, etc.

Figure 1. The setup for air pore structure testing

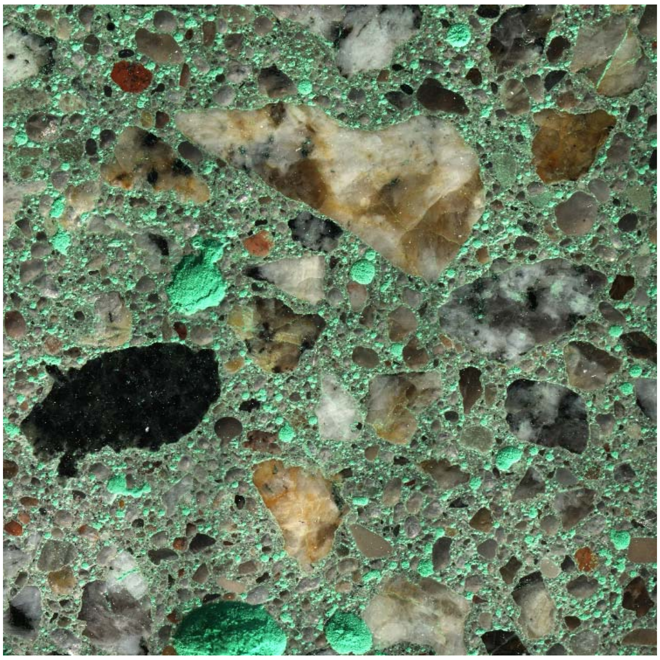


Figure 2. Image of a natural surface of sample fragment

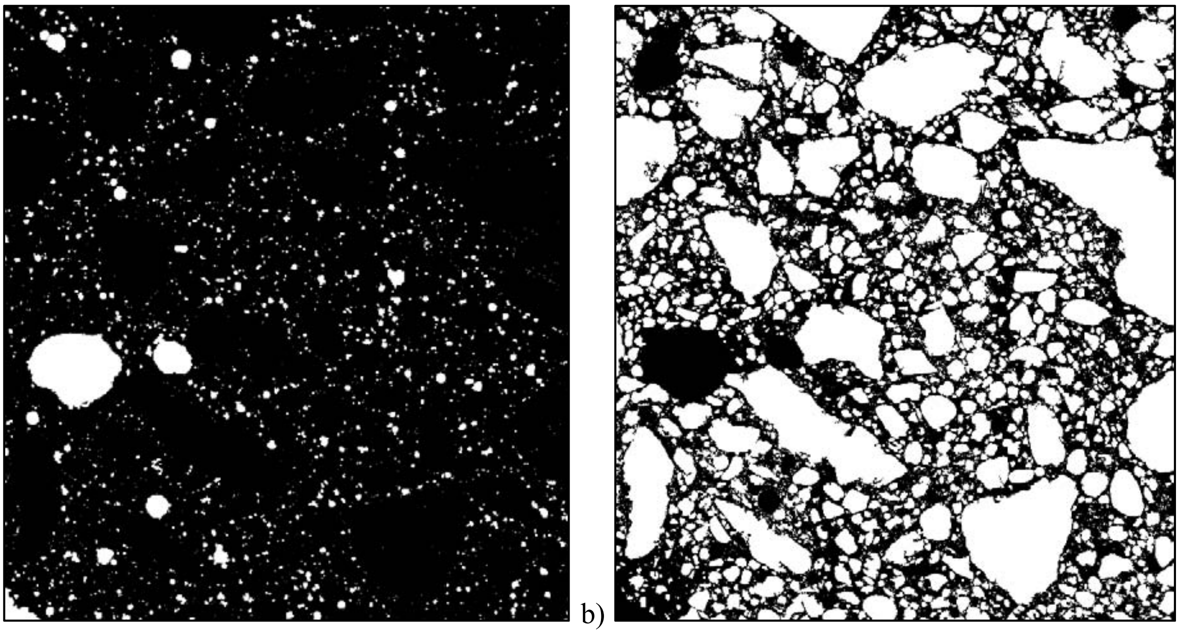
a)  b)

Figure 3. Binary image of a) air-pores b) aggregate

3. Results and discussions

Table 1 presents the test results of the air pore structure parameters obtained from the 1D analysis (standard method) and 2D analysis. For the standard calculations, paste density of P=26% determined based on the concrete mixture composition was assumed. The air content A in the tested samples amounted from 3.58 to 7.98% and the content of pores with the diameter of up to 300μm A_{300} - from 2.25 to 3.40%. The values of the spacing factor $\bar{L}$ amount to 0.139-0.218 mm.

Based on the 2D analyses of the tested sample surfaces, the content of aggregate, air A^{2D} and paste P^{2D} were determined. The actual paste volume P^{2D} determined in the 2D measurements amounts from 24.28 to 27.79% and the air content A^{2D} amounts from 3.69 to 9.74%. The values of the spacing factor $\bar{L}^{2D}$ amounted from 0.142 to 0.228 mm.

The difference in the obtained values of the spacing factor from 1D and 2D analysis amounts from 0.003 to 0.016 mm. The difference in the air content amounts from 0.05 to 1.76% and results, among others, from the presence of large air pores which are easy to extract in the 2D method. The volume of air pores with a diameter higher than 2 mm in the analysed concretes B1, B2, B3 (2D analysis) amounted to 0.26%, 1.68% and 3.59%, respectively. The biggest differences were observed in samples with the largest air content. In the standard method, air pores with diameter of up to 4 mm were taken into consideration. Pores larger than 4 mm present on the sample surfaces were also extracted in the 2D analysis. Figure 4 presents the comparison of the test results of air content obtained from the 1D and 2D analyses. Figure 5 presents the comparison of the test results of the spacing factor determined in the 1D analysis ($\bar{L}$) with spacing factor determined in the 2D analysis ($\bar{L}^{2D}$).

Table 1. Air pore structure parameters

Series	1D measurements						2D measurements				
	P %	N pcs.	A %	A_{300} %	α mm^{-1}	$\bar{L}$ mm	P^{2D} %	N^{2D} pcs.	A^{2D} %	$α^{2D}$ mm^{-1}	$\bar{L}^{2D}$ mm
B1	26.00	433	3.58	2.25	37.92	0.145	24.83	25278	3.69	37.32	0.142
B2	26.00	380	6.28	2.25	19.00	0.218	24.28	11238	6.33	16.80	0.228
B3	26.00	594	7.98	3.40	23.40	0.139	27.79	22842	9.74	18.40	0.155

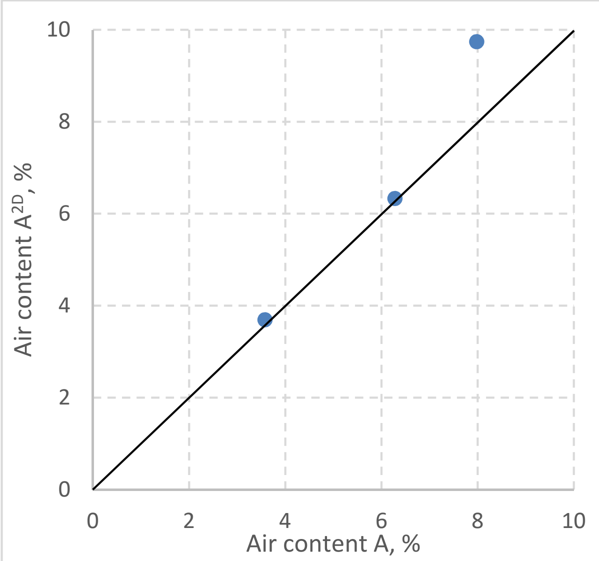


Figure 4. Comparison of the air content determined in the 1D analysis (A) with the air content determined in the 2D analysis (A^{2D})

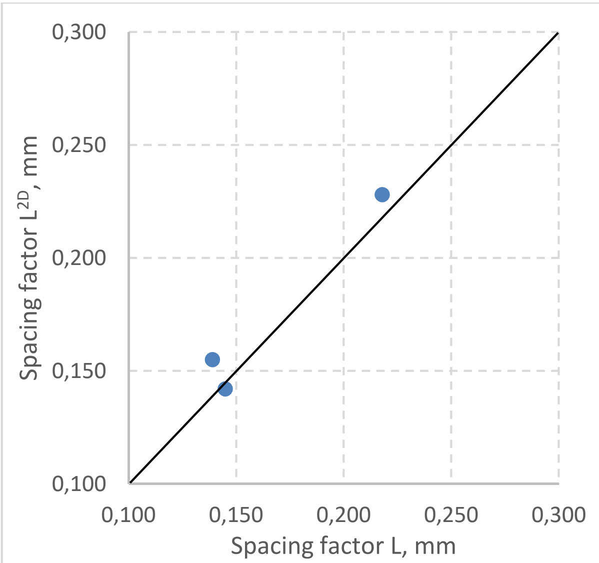


Figure 5. Comparison of the spacing factor determined in the 1D analysis ($\overline{L}$) with spacing factor determined in the 2D analysis ($\overline{L}^{2D}$).

4. Conclusions

Based on the analysis of the test results of three concrete samples with various air content it was found that the use of the 1D and 2D analyses leads to the determination of the values of the spacing factor $\overline{L}$ amounting from 0.003 to 0.016 mm. The difference in the air content amounts from 0.05 to 1.76% and can be explained by the presence of large air pores which are not considered in the standard method (1D). In the case of the standard method (1D), air pores with a diameter exceeding 4 mm are not taken into consideration. However, such pores exist in some areas of the tested samples and are easily extracted in the 2D method. The biggest difference is visible in samples with the largest air content.

The obtained test results the air pore structure using the 2D analysis are promising and worth being continued according to the authors. The remaining problem is the determination of the content of air pores with the diameter of up to 300μm A_{300}. It is very effective to use in the 2D analysis an innovative method of sample lighting, which allows determining the contents of particular phases (aggregate, air, paste).

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