INFLUENCE OF THE AIR VOIDS DISTRIBUTION IN CONCRETE ON THE RATE OF WATER ABSORPTION

Mariusz DĄBROWSKI*, Kinga DZIEDZIC, Aneta ANTOLIK, Michał A. GLINICKI
Institute of Fundamental Technological Research Polish Academy of Sciences
5B, Pawińskiego Str., 02-106 Warszawa, Poland, *e-mail: mdabrow@ippt.pan.pl

ABSTRACT

Prolonged durability of concrete structures is closely related to the minimization of the transport of liquids in cement matrix. Capillary suction is a dominant mechanism of liquid transport, especially in moderate climate, where cyclic wetting-drying and freeze-thawing cycles occur. Air-entraining of concrete is the efficient way to prevent deterioration impact from environment. However, the influence of air voids distribution on the capillary suction is not well known. The purpose of the research was to assess the water absorption properties of the air entrained concrete. The concrete mixes with the air content from 1% to 16% and similar proportion of micropores to large air voids (A_{300}/A) were prepared. The water absorption tests were performed using ASTM C1585 procedure. The following parameters were determined: S_i – initial rate of water absorption, S_s – secondary rate of water absorption, t_n – time of nick point, I_n - water absorption for t_n, I_{60} – initial 60 seconds of water absorption. The results were compared with the air content in concrete. Additionally the compressive strength, porosity accessible to water and concrete resistivity were measured.

The linear relationships between initial and secondary rate of water absorption and the air content in concrete were found. A significant changes of rate of water absorption in concrete when the air content change more than 6% were observed.

Keywords
water absorption, air-entrained concrete, nick point, concrete resistivity, porosity accessible to water.

INTRODUCTION

The application of air-entraining admixtures is the most common method to ensure frost and scaling resistance of concrete. Deterioration of durability during freezing and thawing cycles takes place when the moisture from outside penetrates into microstructure of concrete and fills connected capillary pores and air voids. There are three major mechanisms of fluid transport in concrete such as permeation, capillary suction and diffusion. The capillary suction is the most important one in terms of frost resistance [1-4]]. Furthermore, the measurement of the rate of water absorption is one of the easiest and most efficient method of assessing transport properties in cement-based composites and gives reliable information about potential durability of concrete [6, 7]. The water absorption is related to microstructure and initial moisture content and is therefore influenced by mix composition, degree of hydration and exposure conditions of concrete [4, 8]. The pore network in a cement based matrix provides a path for the transport of fluid into concrete. For cement-based materials, the water absorption mainly occurs in the connected capillary pores between 10 nm and 10 μm. The larger the capillary pore diameter, the faster the water absorption rate increases [9]. Currently, there are many varieties of the capillary suction procedure [10-15], but the most consistent and widespread method is presented in ASTM C1585. Using capillary suction measurements and still developing the water absorption models we could calculate many factors connected to liquid ingress into concrete, e.g. profile of liquid penetration [16]. Water absorption strongly depends on the initial water content of the sample [17]. The correct determination of the water absorption rate is possible when the initial moisture content distribution is uniform. Hence, according to ASTM C1585, specimens before water absorption measurement are subjected to gentle conditioning procedure, ensuring an uniform distribution of moisture in tested concrete without deterioration of cement matrix [18]. Despite the uniform conditioning procedure, the final moisture content of specimen depends on the porosity of concrete and is generally unknown. The initial rate of water absorption, determined up after 6 h of testing, strongly depends on moisture content on surface of the specimen [19]. Additionally, increase of the initial and secondary (24-168 h) rates of water absorption is observed while increasing the air voids content in concrete [2]. The presence of air voids in concrete modifies the mechanism of water uptake, after 24h of testing, from capillary suction to diffusion [20]. Increase of air void content in concrete results in the increase of the rate of water absorption [2], however the quantitative aspect of that process is unknown.

The aim of the research was to evaluate the water absorption properties of air entrained concrete mixtures with assumed target of air content within the limits 1-16%. Only single types of cement and of AEA were used to achieve the stable air voids system in concrete mixtures, ensuring similar proportion of micropores to air voids content in hardened concrete. Two variants of concrete mixtures with different proportions of cement paste and aggregates were investigated. Additionally, the effects of air content on resistivity (CR) and on volume fraction of porosity accessible to water (PAW) of concrete were analyzed.

MATERIALS AND METHODS

Materials

The effect of air voids characteristic on sorptivity of concrete with different air content with two cement paste to aggregate proportions was investigated. The Portland Cement CEM I 42.5 R (according with PN-EN 197-1 [21]) was used. The chemical composition of cement is given in Table 1. The specific surfaces of cement determined by Blain method was 4300 cm^2/kg, density of cement measured by the pycnometer method was 3.10 kg/m^3.

Table 1. Chemical composition of cement
(XRF analysis; LOI – up to 1000°C; SO_3 – elemental analysis method)

Component [%]								
CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	LOI
63.64	19.03	4.84	3.22	1.15	2.97	0.53	0.21	3.34

The mix proportions of the concrete mixtures are given in Table 2. The natural quartz sand as fine aggregate, gravel and amphibolite as coarse aggregate were used for concrete mix design. The content of sand is given as oven-dry mass and extra water was added to compensate for the absorption of sand (0.8% by mass). The gravel grains had a natural oval shape and smooth texture and the amphibolite was crushed before use. The first set of concrete mixes (series G) was characterized by the same volume of cement paste in cubic meter of concrete. Increased amount of air voids was compensated by reduction of aggregate volume, ensuring the same proportion of fine and coarse aggregate. Series A of concrete mixes was characterized by the same cement paste to aggregate volume ratio. The air content was intentionally modified by an adequate dose of AEA. The densities of dry ingredients were: quartz sand and gravel 2.65 kg/dm^3, crushed amphibolite aggregate 2.90 kg/dm^3.

Table 2. Concrete mix design – the series with variable air content (AEA – air entrainment agent, WR – water reducer)

Mixture	Cement [kg/m^3]	Water [kg/m^3]	Sand [kg/m^3]	Gravel [kg/m^3]		Amphibolite [kg/m^3]	Admixture [% cement mass]	
				2/16mm	16/32mm	2/8 mm	WR	AEA
G-1%	330	155	668	946	303	-	3.2	-
G-8%	330	155	604	854	273	-	3.2	0.16
G-16%	330	155	530	750	239	-	3.2	0.45
A-2%	448	179	522	-	-	1332	1.9	0.02
A-4%	438	175	510	-	-	1302	1.9	0.05
A-6%	434	173	504	-	-	1288	1.9	0.10
A-8%	425	170	495	-	-	1263	1.9	0.12
A-10%	420	168	489	-	-	1249	1.9	0.15
A-12%	411	164	478	-	-	1221	1.9	0.18

The selection of proper dosage of admixtures was an important part of the technological process. At first the water reducer agent (WR) was added to achieve slump 100-200 mm. The next step was addition of air-entrained agent (AEA) to achieve the target air entrainment in fresh mix verified by gravimetric measurement. The fresh mix properties are given in Table 3. These include air content measured by pressure method, density by the gravimetric method, and consistency by slump.

Table 3. Basic fresh and hardened concrete properties

Mixture	Fresh concrete properties			Cube compressive strength after 28 days of hardening [MPa]
	Slump [mm]	Apparent density [kg/m^3]	Air content [%]	
G-1%	190	2340	1.1	-
G-8%	190	2240	8.5	-
G-16%	160	2030	16.4	-
A-2%	110	2480	1.9	56.3
A-4%	80	2420	4.1	54.1
A-6%	100	2390	5.2	53.2
A-8%	110	2340	7.1	51.1
A-10%	120	2320	8.3	48.6
A-12%	100	2260	10.6	42.8

Concrete mixes were produced in the laboratory mixer of 50 litre capacity. Standard specimens were manufactured for determination of:

- compressive strength according to PN-EN 12390-3 [22] – 100 mm cubes,
- air void characteristics – 150 mm cubes,
- water absorption, CR and PAW – cylinders Ø=100 mm, h=200 mm.

Specimens were maintained for 28 days in saturated curing conditions before testing or conditioning.

METHODOLOGY AND TESTS PERFORMED

Water absorption test was carried out in accordance with ASTM C 1585. Three concrete discs (thickness 50 mm and diameter 100 mm) were cut out from cylinder specimens of each concrete mixture and then placed in an environmental chamber at temperature of 50°C and RH of 80% for 3 days. After that, each specimen was stored in an individually sealed container for 15 days to achieve equilibration of internal humidity. The specimens were then covered with plastic water-proof sheets, completely sealed on their sides and bottom, leaving only the top surface exposed. The exposed surface of the specimen was placed face down on the support device (plastic rods) inside the container filled with water up to 3 ± 1 mm above the top of the device. The mass of the specimens were measured at regular intervals – more frequently for the first 6 h and less frequently afterwards – for 8 days. The initial sorptivity (S_i) was calculated based on mass intake during the first 6 h, and secondary sorptivity (S_s) based on the mass intake in the 24 h to 8 day exposure period. Both S_i and S_s were obtained for all concrete mixtures that were initially cured for 28 days in saturated curing conditions. The point of intersection of linear functions of initial and secondary sorptivity (the nick point) was recorded. Time of nick point (t_n) and water absorption value for t_n (I_n) was indicated. Additionally, the first measurement of water absorption after 60 seconds of capillary suction (I_{60}) was indicated. Average values of sorptivities for two specimens of each mixture are reported.

The air void characteristic in hardened concrete was determined using a computer-driven system of automatic image analysis. Tests were performed using polished surface of concrete specimens 100x100x25 mm cut out from cube specimens (150 mm). The automatic measurement procedure was designed to comply with the requirements imposed by PN-EN 480-11:2008 [23]. Results of measurements were available as a set of parameters for air void microstructure characterization: spacing factor – L [mm]; specific surface – α [1/mm]; air content in hardened concrete – A [%]; content of air voids with diameter less than 0.3 mm - A_{300} [%].

Concrete resistivity (CR) measurements, for specimens cured in water, were carried out using the Giatec RCON2 device. A cylindrical specimen of hardened concrete was placed between two parallel plates of the device (electrodes) connected to an alternate current source. The device calculates the bulk electrical resistivity of concrete based on the measured potential drop between the electrodes and predefined dimensions of the specimen. According to [24], resistivity is well correlated with porosity of cement matrix and water absorption rate. Average values of resistivities for the three specimens of each mixture are reported.

Porosity accessible to water (PAW) was measured according to French standard NF P18-459 [25]. Three cylindrical specimens (Ø=100 mm, h=50 mm) cut out from cast cylinder (Ø=100 mm, h=200 mm) have been vacuum saturated with water. Specimens were weighted in three states: full saturated on the hydrostatic weight, full saturated and dried to constant mass on laboratory weight. Based on the measurements (average of three specimens) the volume fraction of PAW was calculated.

RESULTS AND DISCUSSIONS

The air void characteristics of hardened concrete series A are given in Table 4. The loss of air voids content in hardened concrete compared to measurement of air content in fresh concrete was up to 20% for all concrete mixtures except A-2%. For concrete mixture A-2% loss of air voids reached 40%.

Table 4. Quantitative characteristics of air voids in hardened concrete

	A [%]	α [mm^{-1}]	$\bar{L}$ [mm]	A_{300} [%]	A_{300}/A [%]
A-2%	1.19	14.54	0.42	0.58	49
A-4%	3.21	35.38	0.19	1.78	55
A-6%	4.61	40.43	0.16	2.16	47
A-8%	6.22	31.81	0.15	3.26	52
A-10%	7.16	33.94	0.13	3.55	50
A-12%	9.52	25.63	0.14	3.29	35

Similar proportion of micropores to air voids content in hardened concrete (A_{300}/A) was provided. The A_{300}/A ratio was around 50%, except mixture A-12%. In that case a lot of micropores accumulated creating the large pores, hence the proportion A_{300}/A decreased compared with other concrete mixtures (Fig. 1). Assuming similar air void distribution for all tested concrete mixtures the rate of capillary suction can be attributed to the air voids content in the cement matrix.

(a) (b)

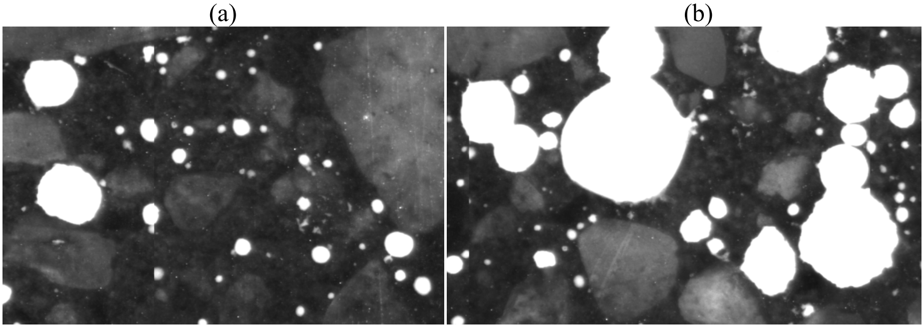


Fig. 1. Picture of air voids distribution in concrete (a) A-6% and (b) A-12% – the same scale

The summary of water absorption kinetics results of concrete mixtures with different air content is shown in Figure 2. For both series of concrete mixture the tendency was similar to Liu [2] investigation, however comparison of results of water absorption is difficult because many factors have impact on rate of sorptivity. The rate of water absorption can be considered only for the same w/c, because tendency is not linear for conditioning presented in ASTM C1585 [7]. The function of water absorption to square root of time (initial rate of water absorption) is close to linear relationship. S-shaped curves [8] and decrease of water absorption rate over time (at the end of first 6 h) [25] are not observed. Influence of air content on initial rate of water (S_i) absorption is statistically significant for mixes with more than 6% of entrained air. The secondary rate of water absorption slightly decreases between 24 h to 72 h and remains constant after 72 h. Phenomenon is typical for high quality concrete conditioned according to ASTM C1585 [7]. Statistically significant differences of secondary rate of water absorption (S_s) between concrete mixes were observed after 72-96 h of water absorption measurement.

(a)

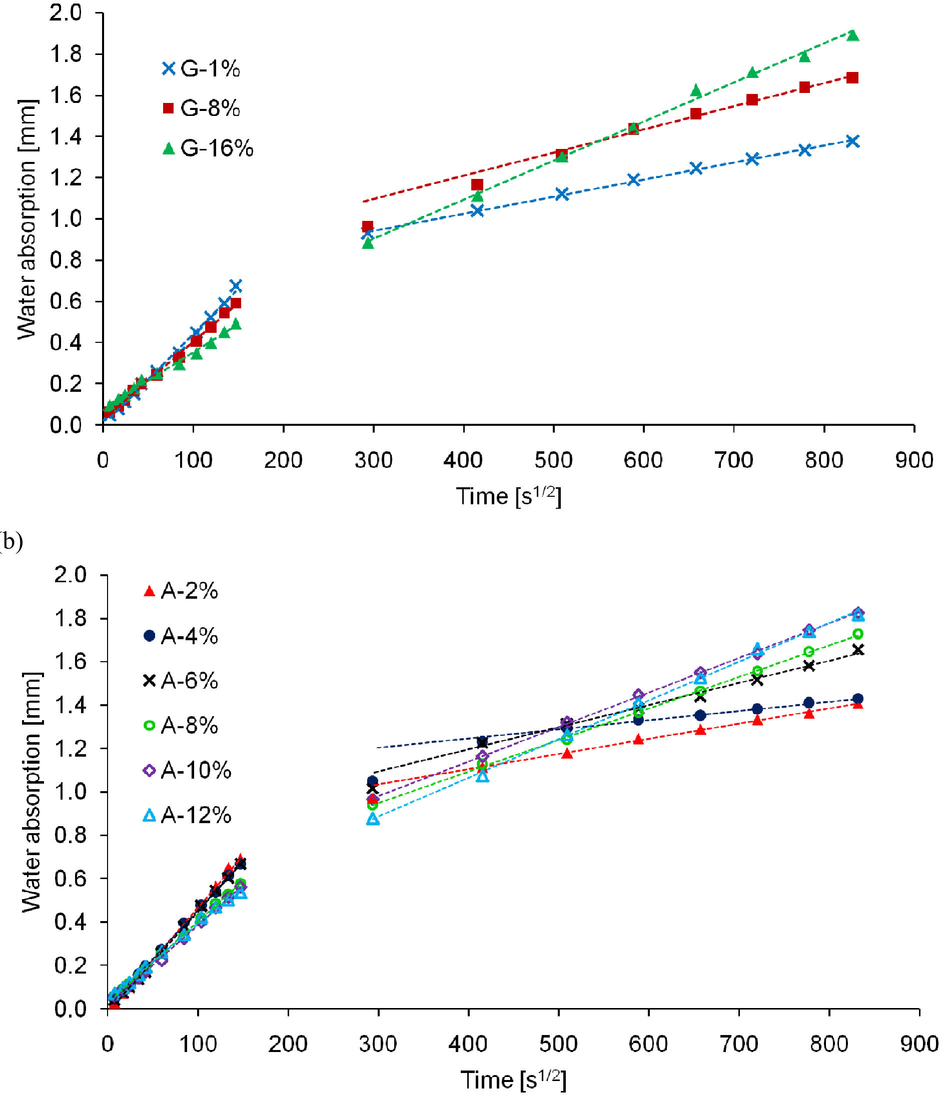


Fig. 2. Comparison of water absorption kinetics of concrete with different air content (a) series G, (b) series A

The indication procedure of the parameters describing capillary suction of concrete is shown in Figure 3. Initial rate of water absorption (S_i) and secondary rate of water absorption (S_s) were calculated using the least squares method. The coordinates of nick points: time(t_n) and absorption for t_n (I_n) were also determined. Those parameters are widely known and used to assess the fluid transport properties of concrete [4]. In addition, the water absorption after 60 seconds of measurement (I_{60}) was indicated.

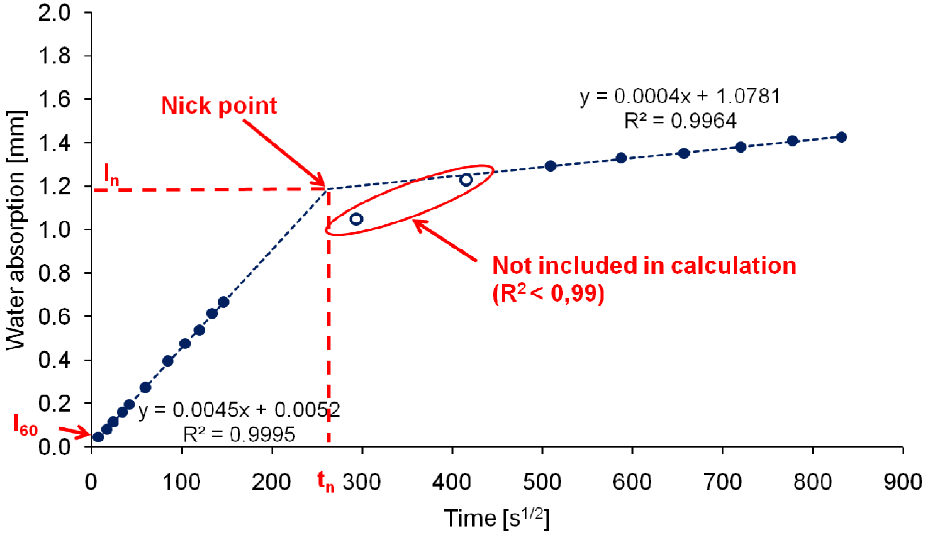


Fig. 3. Example of calculation of water absorption parameters - concrete mixture A-4%

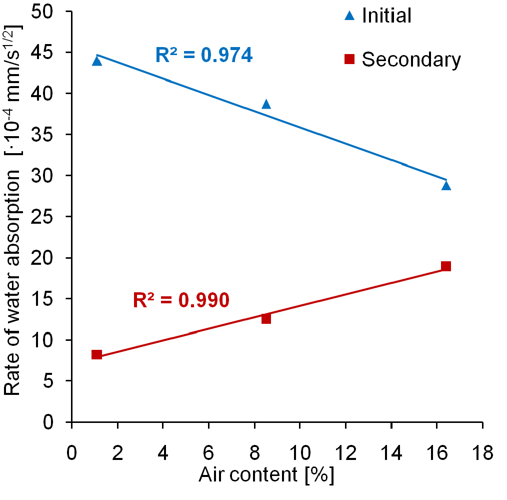
Calculation results of capillary suction measurement were collected in Table 5. Results of S_i ranged from $28.9 \cdot 10^{-4}$ mm/s$^{1/2}$ to $44.0 \cdot 10^{-4}$ mm/s$^{1/2}$ and from $36{,}1 \cdot 10^{-4}$ mm/s$^{1/2}$ to $48.0 \cdot 10^{-4}$ mm/s$^{1/2}$ for concrete series G and A, respectively. The S_s results do not exceed $19 \cdot 10^{-4}$ mm/s$^{1/2}$ and $15.9 \cdot 10^{-4}$ mm/s$^{1/2}$ for concrete series G and A, respectively. Indicated time of nick point t_n ranged from 9 h to 28 h. No significant relation between nick point and the air content of concrete was found. Observation is contradictory to Liu [2] conclusion, that increase of air content in concrete extends time of appearance of nick point of water absorption.

Table 5. Calculation of water absorption parameters
(S_i – initial rate of water absorption, S_s – secondary rate of water absorption, t_n – time of nick point, I_n - water absorption for t_n, I_{60} – initial 60 second of water absorption)

	S_i [$\cdot 10^{-4}$ mm/s$^{1/2}$]	S_s [$\cdot 10^{-4}$ mm/s$^{1/2}$]	t_n [h]	I_n [mm]	I_{60} [mm]
G-1%	44.0	8.3	10.3	0.85	0.048
G-8%	38.8	12.5	20.3	1.06	0.062
G-16%	28.9	19.0	28.1	0.94	0.096
A-2%	48.3	7.0	10.8	0.96	0.028
A-4%	45.0	5.6	19.0	1.18	0.046
A-6%	45.9	10.2	13.8	1.01	0.041
A-8%	37.6	14.6	12.3	0.83	0.058
A-10%	36.6	15.9	14.7	0.87	0.059
A-12%	36.1	17.9	9.1	0.68	0.071

A linear correlation between the rate of water absorption and the content of air was found for both series of concrete specimens (Fig. 4). The S_i decrease with the increase of air content in cement matrix, for S_s the linear relationship is opposite. Results confirm observation presented by authors of papers [2;4].

(a)



(b)

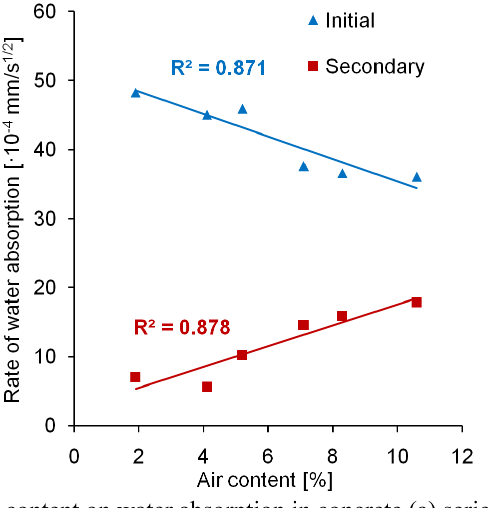


Fig. 4. Effect of air content on water absorption in concrete (a) series G, (b) series A

Water absorption for first 60 seconds of measurement capillary suction (I_{60}) increases linearly with the air content in tested specimens of concrete (Fig. 5). Phenomenon is related to the air content in concrete - the increase of air voids in cement matrix increases a specific surface area of concrete specimen. At the beginning of capillary suction measurement the partially dried surface contacts with water causing water uptake of concrete surface. Appearance of small holes on the surface of air entraining concrete increases the surface area available to wetting. Linear correlations between I_{60} and air content are presented in Figure 5. The results for both concrete series were similar, regardless the concrete composition. Therefore I_{60} value is strictly related to specific surface area and does not represent the capillary suction of cement matrix.

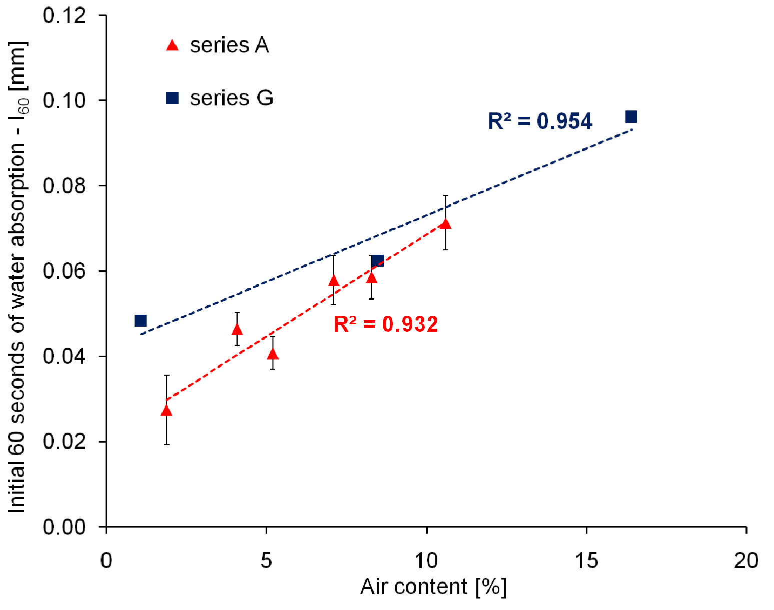


Fig. 5. Effect of air content on the initial 60 seconds of capillary suction in concrete

Increase of the air content in concrete does not influence the porosity accessible to water (PAW) and resistivity (CR) of concrete (Fig. 6). The variation of air content in concrete caused negligible statistically changes of PAW and CR. The PAW results were 13.5%, 13.5% and 14.3% for the air content 1%, 8%, 16%, respectively. The similar small differences were observed for the CR results: 27.5 kΩcm, 27.2 kΩcm and 30.9 kΩcm, respectively.

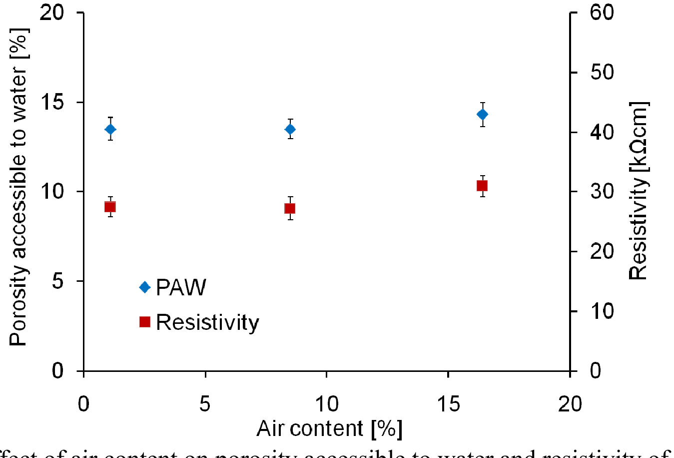


Fig. 6. Effect of air content on porosity accessible to water and resistivity of concrete

Many authors [4;19;7] presented an influence of the capillary porosity on the rate of water absorption in cement matrix. According to Wong et al. [27] the air voids in cement matrix have no impact on transport of a liquid. Only capillary pores are associated with capillary suction. The same cement paste content for series G of concrete ensured the repeatable capillary pores distribution and consequently the same volume of open porosity. The PAW measurement confirmed repeatable capillary porosity distribution.

The CR measurement results were unexpected. Full saturated concrete with increased content of air should provide a decrease of concrete resistivity. Air voids of specimens cured in water probably were only partially saturated with water and the CR measurements did not account for presence of air entrained porosity without water.

The research showed opposite conclusion to Wong et al. [27]. Occurrence of more than 6% of air voids significantly affected the initial and secondary rate of water absorption. Such large differences of air content in common used concrete do not occur at building sites and can only be considered theoretically. Probable dominant mechanism is a result of intersection of capillary pores in cement matrix by air voids and decrease of capillary suction force at the beginning of water absorption. This is manifested by decrease of initial rate of water absorption and increase of secondary rate of water absorption and is consistent with the observations of other authors, e.g. [2;28].

CONCLUSIONS

The study focused on investigation of the influence of air voids content on the rate of water absorption. Concrete mixtures were designed to obtain the similar distribution of air voids in cement matrix, which was proved by image analysis of polished sections. On the basis of results obtained in this investigation the following concluding remarks are derived:

- Linear correlation of the initial and secondary water absorption and the air content in concrete was found. Increase of the air content in concrete decreases the initial rate of water absorption and increases the secondary rate of water absorption.
- The increase in air content by less than 6% has no significant influence on the rate of concrete water absorption.
- Correlation between of the air content and the coordinates of nick point is not observed.
- The water absorption after 60 seconds of measurements is linearly correlated with the air content of concrete.
- The change of air content up to 16% has no significant impact on porosity accessible to water and on the resistivity of concrete.

ACKNOWLEDGEMENTS

The investigation was financially supported by the Project funded by the Polish National Center for Research and Development and the General Directorate for National Roads and Motorways (DZP/RID-I-37/6/NCBR/2016).

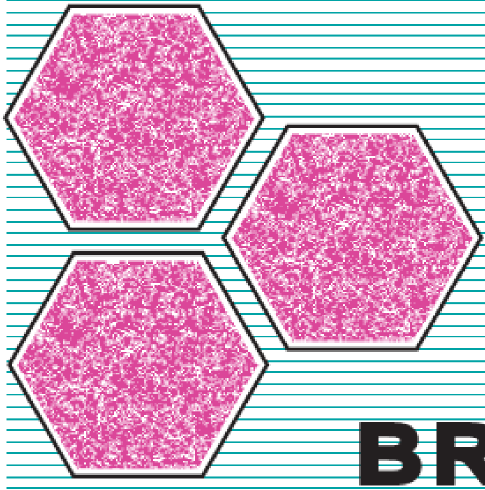
REFERENCES

1. Setzer, M.J., Auberg, R. (1995) Freeze-thaw and deicing salt resistance of concrete testing by the CDF method CDF resistance limit and evaluation of precision. Mat. and Struct., 28, 16-31.

2. Liu, Z. (2014) Frost deterioration in concrete due to deicing salt exposure: Mechanism, mitigation and conceptual surface scaling model, Phd Diss., , University of Michigan
3. Liu, Z., Hansen, W. (2016) Freeze–thaw durability of high strength concrete under deicer salt exposure. Constr. and Build. Mat., 102, 478–48.
4. Wang ,Y., Cao, Y., Zhang, P., Mad,Y., Zhao, T., Wang, H., Zhang, Z. (2019) Water absorption and chloride diffusivity of concrete under the coupling effect of uniaxial compressive load and freeze–thaw cycles. Constr. and Build. Mat., 209, 566–576.
5. Mohammadi, B. (2013) Development of Concrete Water Absorption Testing for Quality Control. Master Diss., Concordia University, Montréal.
6. Martys, N. (1995) Survey of concrete transport properties and their measurement. National Institute of Standards and Technologies, 1–40.
7. Zhang, S.P., Zong, L. (2014) Evaluation of Relationship between Water Absorption and Durability of Concrete Materials. Advances in Materials Science and Engineering, Article ID 650373.
8. Wu, Z., Wong, H.S., Chen, C., Buenfeld, N.R. (2019) Anomalous water absorption in cement-based materials caused by drying shrinkage induced microcracks. Cem. and Concr. Res., 115, 90–104.
9. Nia, S.F., Jessen, K. (2015) Theoretical analysis of capillary rise in porous media. Transp. Porous Media, 110, 1–15.
10. BS EN 13057 (2002) Products and Systems for the Protection and Repair of Concrete Structures. Test Methods. Determination of Resistance of Capillary Absorption, BSI.
11. BS EN 1015-18 (2002) Methods of Test for Mortar for Masonry. Determination of Water Absorption Coefficient Due to Capillary Action of Hardened Mortar, BSI.
12. BS EN ISO 15148+A1 (2016) Hygrothermal Performance of Building Materials and Products. Determination of Water Absorption Coefficient by Partial Immersion, BSI.
13. NT BUILD 368 (1991) Concrete, Repair Materials: Capillary Absorption Nordtest.
14. DIN 52617 (1987) Determination of the water absorption coefficient of construction materials, Deutsches Institut für Normun.
15. ASTM C1585 – 13 (2013) Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes, ASTM.
16. Zhan, J., Hong, S., Dong, B., Tang, L., Lin, C., Liu, Z., Xing, F. (2019) Water distribution modelling of capillary absorption in cementitious materials. Constr. and Build. Mat., 216, 468–475.
17. Zhutovsky, S., Hooton, R.D. (2019) Role of sample conditioning in water absorption tests. Constr. and Build. Mat., 215, 913-924.
18. Hall, C. (1997) Barrier performance of concrete: a review of fluid transport theory. Penetration and Permeability of Concrete: Barriers to Organic and Contaminating Liquids. RILEM Report 16, Stuttgart, Germany.
19. Hall, C. (1989) Water sorptivity of mortars and concretes: a review. Magazine of Concrete Research, 41, 51–61.
20. Sandström, T., Fridh, K., Emborg, M., Hassanzadeh, M. (2012) The influence of temperature on water absorption in concrete during freezing. Nordic Concrete Research, 45, 45-58.
21. PN-EN 197-1 (2012) Cement - Part 1: Composition, specifications and conformity criteria for common cements.
22. PN-EN 12390-3 (2011) Testing hardened concrete. Compressive strength of test specimens.
23. PN-EN 480-11 (2008) Admixtures for concrete, mortar and grout. Test methods. Determination of air void characteristics in hardened concrete.

24. Layssi, H., Ghods, P., Alizdeh, A.R., Salehi, M. (2015) Electrical resistivity of concrete. Concrete International, 37, 41-46.
25. NF P18-459, (2010) Concrete - testing hardened concrete - testing porosity and density
26. Nokken, M.R., Hooton, R.D. (2002) Dependence of Absorption on Degree of Saturation of Concrete. Cement, Concrete, and Aggregates, CCAGDP, 24, 20–24.
27. Wong, H.S., Pappas, A.M., Zimmerman, R.W., Buenfeld, N.R. (2011) Effect of entrained air voids on the microstructure and mass transport properties of concrete. Cem. and Concr. Res., 41,1067-1077.
28. Wang, X., Sun, M., Guo, S. (2019) Water absorption characteristics of cement-based materials based on the chemical reaction, Constr. and Build. Mat., 220, 607–614.

INSTITUTE OF FUNDAMENTAL TECHNOLOGICAL RESEARCH
POLISH ACADEMY OF SCIENCES



BRITTLE MATRIX COMPOSITES

12

Edited by

M.A. Glinicki
D. Jóźwiak-Niedźwiedzka
C.K.Y. Leung
J. Olek

Institute of Fundamental Technological Research

BRITTLE MATRIX COMPOSITES

12

INSTITUTE OF FUNDAMENTAL TECHNOLOGICAL RESEARCH
POLISH ACADEMY OF SCIENCES

BRITTLE MATRIX COMPOSITES

12

Edited by

Michał A. GLINICKI
Institute of Fundamental Technological Research
Polish Academy of Sciences Warsaw, Poland

Daria JÓŹWIAK-NIEDŹWIEDZKA
Institute of Fundamental Technological Research
Polish Academy of Sciences, Warsaw, Poland

Christopher K.Y. LEUNG
Hong Kong University of Science and Technology, Hong Kong, China

Jan OLEK
Purdue University, West Lafayette, USA

Institute of Fundamental Technological Research
Warsaw 2019

Warsaw, Poland
ISBN 978-83-65550-20-0 (print)
ISBN 978-83-65550-21-7 (online)

Produced by: ZTUREK Research-Scientific Institute

http://www.zturek.pl, zturek@zturek.pl

Table of Contents

Preface v

KEYNOTE PAPER

Multiscale modeling of strain-hardening cementitious composites based on beam theory
Christopher K. Y. LEUNG, Jie YAO, *China* 1

A new stress-strain model for concrete containing recycled concrete aggregates subjected to uniaxial compression
Fan YANG, Shuai YUAN, Jiabin LI, *Belgium* 13

Does lower elastic modulus lead to lower flexural stiffness in reinforced engineered cementitious composites?
K. A. Shan D. RATNAYAKE, Jing YU, Shubham U. BARKALE,
Dhanada K. MISHRA, Christopher K. Y, LEUNG, *China* 15

A technique to assess the impact on housing thermal performance of heavy composite walls under a dynamic cycle
Dariusz ALTERMAN, Adrian W. PAGE, Congcong ZHANG, Behdad MOGHTADERI, *Australia*
Aiman ALBATAYNEH, *Jordan* 25

Economic and reliable estimation of cementitious material properties on the basis of virtual models
Piet STROEVEN, *The Netherlands*
Marta SŁOWIK, *Poland* 35

The detailed study of the variability of portland cement composition
Martin KEPPERT, Vendula DAVIDOVÁ, Jiří JELÍNEK, Pavel REITERMAN,
Czech Republic 45

Study of exposure of carbonated low-lime calcium silicate cements (CCSCs) pastes to sulfate solutions at low temperatures
Raikhan TOKPATAYEVA, Jan OLEK, Sada SAHU, Jitentra JAIN, *USA* 53

Microstructure and performance of cementitious material - protein composite systems
Katelyn KOSAR, Ali GHAHREMANINEZHAD, *USA* 67

Monitoring of structural changes of concrete with fly ash addition during freezing-thawing
Pavel REITERMAN Petr HUŇKA, *Czech Republic* 69

Effect of addition of limestone powder on fly ash based geopolymer cured at 80°C and at ambient temperature
Mateusz SITARZ, Izabela HAGER, *Poland* 77

On the tensile behavior and interface characteristics of carbon textile reinforced concrete
Rebecca M. C. SILVA, Flávio A. SILVA, *Brazil* 87

The effect on masonry bond strength of short steel fibres in a brittle mortar composite
Dariusz ALTERMAN, Adrian W. PAGE, *Australia*
Aiman ALBATAYNEH, *Jordan* 97

Glass fibre reinforced decorative composite: components influence and multicriterial optimisation
Tatiana V. LYASHENKO, Alexandra D. DOVGAN, Petr M. DOVGAN, *Ukraine* 107

Improved bond strength of textile-cement interface by cement based inexpensive interface coating
Raghu SRIPADA, Amr ALATAWNA, Lior NAHUM, Matan BIRENBOIM,
Oren REGEV, Alva PELED, *Israel* 117

KEYNOTE PAPER
Supplementary cementitious materials and their impact on sustainable construction
Agnieszka J. KLEMM, Rohollah ROSTAMI, Stewart MACLENNAN, *UK*
Fernando ALMEIDA, *Brazil* 127

Characterization of air entrained concrete porosity using x-ray computed micro tomography image analysis
D. F. Tiana RAZAKAMANDIMBY R., Kyoungsoo PARK, *Korea* 139

Influence of the air voids distribution in concrete on the rate of water absorption
Mariusz DĄBROWSKI, Kinga DZIEDZIC, Aneta ANTOLIK,
Michał A. GLINICKI, *Poland* 147

High Performance Concrete for Durable Highway Applications in Wet-Freeze Climates
Yuguo ZHONG, Will HANSEN, Bo MENG, *USA*
Zhichao LIU, *China* 159

Effects of aggregate size and of cement type on concrete mechanical behaviour and on gas permeability evolution with loading
Marta CHOINSKA, Stéphanie BONNET, Aurélie FABIEN,
Abdelhafid KHELIDJ, *France*
Hayder AL-KHAZRAJI, *Iraq* 173

Neutron-based methods for the development of concrete
Veronika SZILÁGYI, Katalin GMÉLING, Zoltán KIS, Ildikó HARSÁNYI,
László SZENTMIKLÓSI, *Hungary* 183

Design of heavyweight concrete used in radiation protection based on complete NAA, PGAA and XRF results. Activation and physical properties
Janette DRAGOMIROVÁ, Martin T. PALOU, *Slovak Republic*
Katalin GMÉLING, Veronika SZILÁGYI, Ildikó HARSÁNYI,
László SZENTMIKLÓSI, *Hungary* 195

Water absorption test accompanied by dynamic neutron radiography of gamma-irradiated cement samples
Yuliia KHMUROVSKA, Petr ŠTEMBERK, *Czech Republic*
Veronika SZILÁGYI, Zoltán KIS, Ildikó HARSÁNYI, *Hungary*
Svyatoslav SIKORIN, Yuliya KALADKEVICH, Eryk PAVLANSKI,
Viktar FATSEYEU, *Belarus* 211

Potential of alkali silica reaction as a function of reactive form of quartz in fine aggregate
Aneta ANTOLIK, Daria JÓŹWIAK-NIEDŹWIEDZKA, Kinga DZIEDZIC,
Karolina BOGUSZ, Piotr DENIS, *Poland* 223

Investigation of the effects of chloride-based deicers on plain and fly ash concretes containing dolomite as coarse aggregate
HyunGu JEONG, Jan OLEK, Daniel K. PANNELL, Robert GEIGER, *USA* 231

Crushed bricks as an aggregate replacement for a brittle composite material
Dariusz ALTERMAN, Adrian W. PAGE, *Australia*
Hiroshi AKITA, *Japan*
Aiman ALBATAYNEH, *Jordan* 245

INDEX OF CONTRIBUTORS 257

SUBJECT INDEX 259

* * *