Method of Vacuum Water Absorption to Determine the Porosity of Hardened Concrete

Yue Li
Beijing University of Technology, Beijing, China
Email: liyue@bjut.edu.cn

Wanguo Dong, Hong Li, and Zhanguo Li
Beijing University of Technology, Beijing, China
Email: {dongwanguo8282, lihong8010}@163.com, lizg@bjut.edu.cn

***Abstract*—Concrete is a porous heterogeneous system in many situation, it is necessary to estimate the strength, durability, freezing and thawing performance and corrosion resistance. However, these performances are closely related to the porosity of concrete. In this paper, Method of vacuum water absorption was used to determine the porosity of concrete. Curing for specified ages (7d, 28d, 90d),the concrete block would be cut into sheets of concrete block (100 mm * 100 mm * 10 mm), then the hardened concrete was soaked in water under the vacuum condition, the mass difference before and after soaking in the water was measured. The ratio of mass difference divided by the concrete volume is considered as porosity. The results show that the porosity is closely related to the water to cement ratio (W/C) of concrete, especially at long curing ages. The air-entraining agent can improve the porosity of concrete, when the W/C is low, this effect is obvious.**

***Index Terms*—hardened concrete, method of vacuum water absorption, porosity**

I. Introduction

A. Benouis [1] established the correlation between the porosity and ultrasonic parameters, the relationship between concrete mixtures, porosity and ultrasonic velocity of concrete samples measured by ultrasonic NDT is investigated. Md. Safiuddin [2] compared the efficacy of the ASTM saturation techniques for measuring the permeable porosity of concrete, the overall experimental results reveal that vacuum saturation technique is more efficient than the cold-water or boiling-water saturation and therefore this technique should be recommended for measuring the permeable porosity of concrete. ASTM C 1084 [3] immersed the concrete in water and soaked it for a minimum of 24 h or to constant weight. Determine the mass of the sample while immersed in the water. Remove from the water, surface dry, and determine the mass. Then calculate the unit weight and loss of free water. M.K. Head [4] studied the results of an exploratory 3D study of fine pore structures in hardened cement paste. Images of pore structures were captured using a 'reverse imaging contrast' technique. Using this technique it was possible to observe the fine capillary pores and very small air pores. Operating at the limit of its capability the microscope was able to perform high resolution imaging of the internal areas of partially reacted cement grains, and pore structures approximately 0.17 Am across were measured. 3D models were produced to help visualize the true morphology and distribution of porous features. Martin K. Head [5] provided a method for combining scanning electron microscopy, and energy dispersive X-ray imaging to accurately identify complex aggregate interfaces with the cement paste in a hardened concrete. It involves the identification of aggregate chemical composition, then backscattered image capture simultaneous, and subsequent image processing and quantification by advanced image analysis. The resulting aggregate mask is able to be used in image analysis routines, allowing for porosity to be segmented and measured. Min Wu [6], [5] studied the impact of sample saturation on the analysis of pore volume and pore size distribution by low temperature calorimeter. The study of the experimental data on hardened concrete showed that for a same concrete mix, the total pore volume tested from the capillary saturated samples was always lower than the vacuum saturated samples. In addition, the observed hysteresis between the freezing and melting curves of ice content of the capillary saturated samples was more pronounced than that of the vacuum saturated samples. The main reason for this phenomenon may be related to that capillary saturation cannot fully saturate the pores under study. S. Sahu [7] studied a method to determine the W/C in hardened concrete using Backscattered Electron Imaging (BEI) by a scanning electron microscope. This method is based on concrete sections that have been vacuum impregnated with epoxy and polished to a flat surface. During impregnation, epoxy fills capillary porosity, cracks, and pores. The epoxy-impregnated porosity appears dark in BEI, while other phases appear as brighter phases. By using image analysis program, the capillary porosity of the concrete can be quantified. Reproducible quantitative data is obtained for a concrete sample of unknown W/C by using a set of standardized instrument parameters such as

Manuscript received April 24, 2015; revised August 3, 2015.

doi: 10.18178/ijscer.4.3.282-286

brightness, contrast and working distance. The W/C, which is directly related to the capillary porosity, can therefore be measured. Desmet B [8] studied the super plasticizers and high mineral addition contents used in Self-Compacting (SCC) concrete; they have an important effect on the porosity of the hardened concrete, influencing their durability and strength. In this paper, a combination of forced vacuum and boiling saturation techniques is used to determine the influence of the composition of seven SCC concretes on the open porosity. Md. Safiuddin [9] attempted to compare the efficacy of three ASTM saturation techniques for measuring the water absorption of concrete. The water absorption of two ordinary concretes was determined based on the cold water, boiling water and vacuum saturation techniques. Thus the present study suggests that the vacuum saturation technique is more efficient than both cold water and boiling water saturation methods to measure the water absorption of concrete.

II. Experimental

As it is shown in the Fig. 1 and Fig. 2, the cement used is P.I/II 42.5 Portland Cement, and the sand is river sand with fineness modulus 2.8, and the coarse aggregate is 5-25mm gravel. The concrete with water/cement ratios (W/C) in the range of 0.30 to 0.50 and the air entraining admixture of 0 and 0.04% by mass of the total cementations' materials were prepared (Table I). For each mix, three samples were prepared. The raw materials were mixed with tap water and compacted into moulds (100mm×100mm×100mm) and placed in a curing chamber at 100% RH, 20℃ until the ages of 7 days, 28days and90days.At the end of each designated curing period, the concrete was cut into piece samples(100mm×100mm×10mm).

The samples is first oven dried at 105℃ for 2 hours and then be weighted. The dry samples were put in vacuum water saturated machine, evacuated for 2 hours, and then soaked in water for 24 hours. Use a cloth to wipe up the wet surfaces of specimen and weigh the samples. The ratio of weight difference before and after soaking in water divided by the concrete volume is considered as porosity.

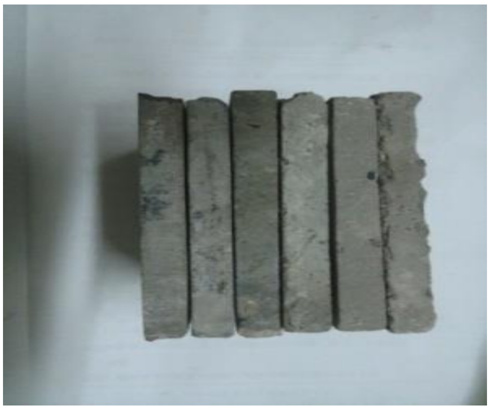


Figure 1. Samples of sheet concrete

Figure 2. Samples of sheet concrete

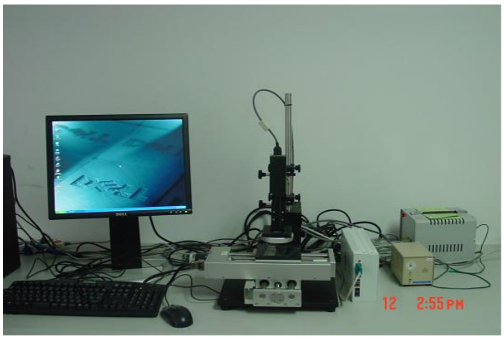


Figure 3. MIC-840-01 Pore structure tester of hardened concrete

TABLE I. Mix Proportions of the Concrete

NO	W/C	Water (kg/m^3)	Cement (kg/m^3)	Aggregate (kg/m^3)	Sand (kg/m^3)	Water reducer (kg/m^3)	Air-entraining agent (kg/m^3)
1	0.3	120	400	1268	653	4	0
2	0.4	160	400	1200	618	0	0
3	0.5	200	400	1132	583	0	0
4	0.3	120	400	1268	653	4	0.04
5	0.4	160	400	1200	618	0	0.04
6	0.5	200	400	1132	583	0	0.04

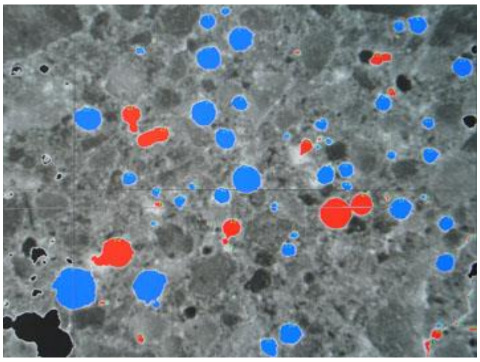


Figure 4. Digital Image hardened concrete bubble distribution

In order to verify the accuracy of the method of vacuum water absorption, the porosity of hardened concrete was determine by Pore structure tester of hardened concrete (MIC-840-01), Which can determine the 9.917μm～2185.740μm pore size. The Pore structure tester of hardened concrete was shown in Fig. 3 and the test results of pore distribution was shown in Fig. 4. The porosity of samples at various curing ages in Table I were determined by Pore structure tester of hardened concrete.

III. Result and Discussion

The porosity of concrete without air-entraining agent and with air-entraining agent are determined by the method of vacuum water absorption and the testing results are showed in Table II and Table III.

TABLE II. The Porosity of Concrete without Air-Entraining Agent

NO	W/C	Age/day	Porosity/%
1	0.3	7	7.98
2	0.3	28	7.43
3	0.3	90	7.18
4	0.4	7	12.81
5	0.4	28	8.71
6	0.4	90	7.99
7	0.5	7	14.13
8	0.5	28	10.20
9	0.5	90	9.16

TABLE III. The Porosity of Concrete with Air-Entraining Agent

NO	W/C	Age/day	Porosity/%
1	0.3	7	11.18
2	0.3	28	8.59
3	0.3	90	7.38
4	0.4	7	12.89
5	0.4	28	10.84
6	0.4	90	8.64
7	0.5	7	15.51
8	0.5	28	12.77
9	0.5	90	10.59

A. The Influence of Water to Cement Ratio on Porosity

From the Fig. 5, it can be seen that, the porosity of the concrete decrease as the growth of ages, for example, the 7d porosity is higher than that of 28d and 90d, which is obvious when the W/C is 0.4 and 0.5.The reason is that, the hydration degree of cement is low before 7d, which leads to higher porosity. While, the 28d or 90d hydration degree increase obviously, and the hydration products fill some of the pore, which leads to the decrease of porosity. The porosity of concrete reduces significantly from 7d to 28d, while, the porosity of concrete reduces a little from 28d to 90d due to the cement hydrated relatively complete after 28d. When the hydration age is 7d, there are no obvious linear relationships between W/C and porosity, especially the porosity increases obviously when W/C increases from 0.3 to 0.4. At 28d and 90d, there are good linear relationships between the porosity and W/C.

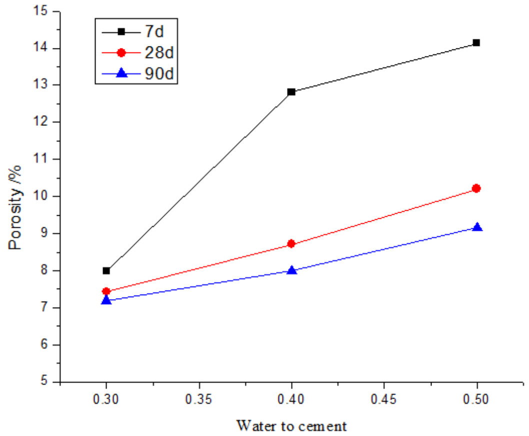


Figure 5. The relationship between porosity and water to cement ratio

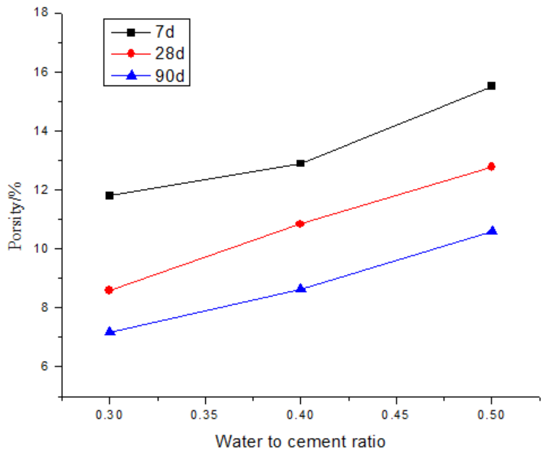


Figure 6. The relationship between porosity and water to cement ratio

From Fig. 6, the following conclusions can be drawn. The air-entraining agent obviously increases the porosity of concrete. For example, the porosity of the sample with W/C 0.3 at 7d increases from 7.98% to 11.18%. While, the influence of air-entraining agent on the porosity of concrete (W/C of 0.4 and 0.5) is not obvious, the corresponding porosity increased from 12.81% and 14.13% to 12.89% and 15.51%, separately.

The 7d porosity of concrete with air-entraining agent has a better linear relationship between porosity and W/C than that of samples without the air-entraining agent. Compared with the concrete without the air-entraining agent, there are good linear relationship between the 28d and and 90d, there are good linear relationships between the porosity and W/C.

B. The Influence of Age on Porosity

From Fig. 7, we can draw the following conclusions: the porosity of all samples decrease as the growth of ages. Especially from the age of 7 days to 28 days, the porosity of concrete with W/C 0.4 and 0.5 reduces greatly, i.e., it reduces from 12.81%, 14.13% to 8.71% and 10.2% respectively. Compared with the porosity of sample with 0.3, the porosity of concrete with 0.4 and 0.5 reduces lesswith the increasing ages. The porosity increases with the W/C increasing. For example, the porosity of concrete increases largely as the W/C increasing from 0.3 to 0.4. however, when the W/C increase from 0.4 to 0.5, the porosity increases a little.

From Fig. 8, the following conclusions can be drawn: the porosity of all samples decrease as the growth of age. Compared with the concrete without air-entraining agent, the porosity of concrete with W/C 0.3 and air-entraining agent reduces more obviously.

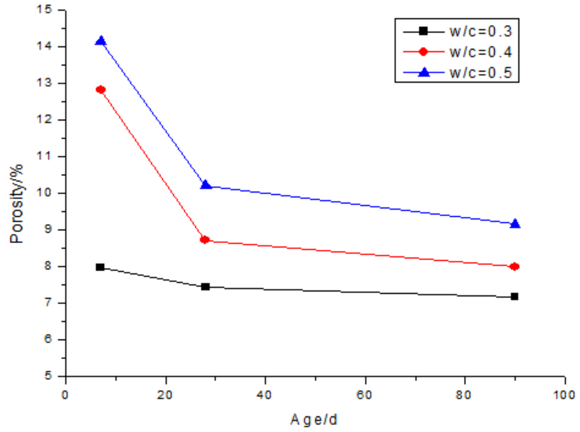


Figure 7. The relationship between porosity and ages without air-entraining admixture

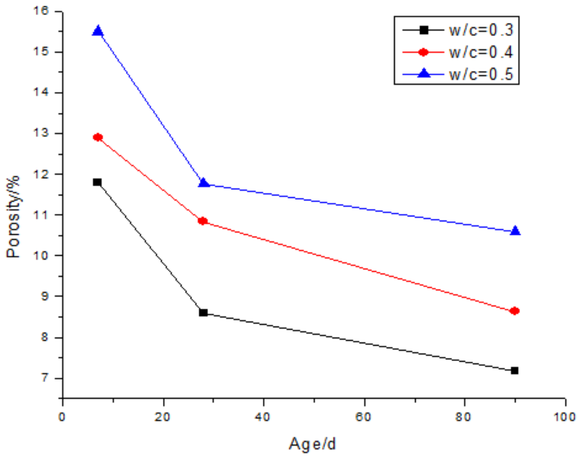


Figure 8. The relationship between porosity and ages (With air-entraining agent)

C. Test Results of Pore Structure of Hardened Concrete Tester

The test results tested by Pore structure tester of hardened concrete were shown in Table IV and Table V.

TABLE IV. THE POROSITY OF CONCRETE WITHOUT AIR-ENTRAINING AGENT

NO	W/C	Age/day	Porosity/%
1	0.3	7	1.08
2	0.3	28	1.01
3	0.3	90	0.92
4	0.4	7	1.38
5	0.4	28	1.27
6	0.4	90	1.12
7	0.5	7	1.67
8	0.5	28	1.45
9	0.5	90	1.22

TABLE V. THE POROSITY OF CONCRETE WITH AIR-ENTRAINING AGENT

NO	W/C	Age/day	Porosity/%
1	0.3	7	3.52
2	0.3	28	3.13
3	0.3	90	3.01
4	0.4	7	4.19
5	0.4	28	3.45
6	0.4	90	3.02
7	0.5	7	4.78
8	0.5	28	3.96
9	0.5	90	3.75

Form Table IV and Table V, it can be seen that the test results by Pore structure tester of hardened concrete were quite different with that by vacuum water absorption, conspicuous lower than that by vacuum water absorption. For example, the porosity of the sample 1 in Table IV by Pore structure of hardened concrete tester is lower 68.5% than that in Table II by vacuum water absorption. The reason is that the test range of Pore structure of hardened concrete tester is 9.917μm～2185.740μm. The pore at the range of <9.917μm and >2185.740μm cannot be tested and the irregular pores also are ignored due to the parameter setting of the instrument. So the method of vacuum water absorption can test a greater range pore size. While, the porosity change trend with the increases of W/C and curing ages tested by Pore structure tester of hardened concrete is consistent with that tested by vacuum water absorption.

IV. CONCLUSION

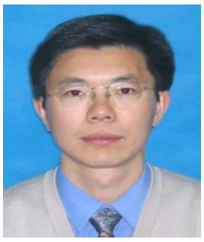
The vacuum water saturated methods are suitable for the examination of the porosity of hardened concrete. The porosity of the concrete decreases with the curing ages increasing, and increases with the W/C increasing. The air-entraining agent obviously increases the porosity of concrete. The influence of air-entraining agent on the porosity of concrete is not obvious when the W/C is relatively high. Compared with the method of vacuum water saturated, the porosity tested by Pore structure tester of hardened concrete is lower, but the porosity of the concrete also decreases with the curing ages increasing, and increases with the W/C increasing. So the porosity change trend with the increases of W/C and curing ages tested by Pore structure of hardened concrete tester is consistent with that tested by vacuum water saturated.

ACKNOWLEDGMENT

The authors would acknowledge the financial support of Natural Science Foundation of China (No. 51278014), Century Excellent Talents in University (NCET-12-0605), the Importation and Development of High-Caliber Talents Project of Beijing Municipal Institutions (CIT&TCD20150310).

REFERENCE

[1] A. Benouis and A. Grini, "Estimation of concrete's porosity by ultrasounds," *Physics Procedia*, pp. 53–58, 2011.
[2] M. Safiuddin and N. Hearn, "Comparison of ASTM saturation techniques for measuring the permeable porosity of concrete," *Cement and Concrete Research*, vol. 35, no. 5, pp. 1008–1013, 2005.
[3] ASTM C 1084, Standard Test Method for Portland-Cement Content of Hardened Hydraulic-Cement Concrete.
[4] M. K. Head and N. R. Buenfeld, "Confocal imaging of porosity in hardened concrete," *Cement & Concrete Research*, vol. 36, no. 5, pp. 896-911, 2006.
[5] M. K. Head and N. R. Buenfeld, "Measurement of aggregate interfacial porosity in complex, multi-phase aggregate concrete: Binary mask production using backscattered electron, and energy dispersive X-ray images," *Cement and Concrete Research*, vol. 36, pp. 337-345, 2006.
[6] M. Wu and B. Johannesson, "Impact of sample saturation on the detected porosity of hardened concrete using low temperature calorimetry," *Thermochimica Acta*, vol. 580, no. 3, pp. 66-78, 2014.
[7] S. Sahu, *et al*., "Determination of water-cement ratio of hardened concrete by scanning electron microscopy," *Cement and Concrete Composites*, vol. 26, no. 8, pp. 987–992, 2004.
[8] D. Desmet, *et al.*, "Porosity determination of self-compacting concretes using combined forced saturation," in *Proc. of the XIII Iccc Int. congr. on the Chemistry of Cement*, 2011.
[9] M. Safiuddin and N. Hearn, "Comparison of ASTM saturation techniques for measuring the permeable porosity of concrete," *Cement and Concrete Research*, vol. 35, no. 5, pp. 1008–1013, 2005.



Yue Li was born in March 1972; the last education was doctor of engineering in Wuhan University of technology in 1999. Now he is the professor and tutor of doctor and postgraduate of Beijing University of Technology. His research field is cement-based materials, research and application and high performance concrete structure durability and structure detection and reinforcement technology research etc. He has published over 100 papers on journals of relative field, including 50 papers searched by SCI, ISTP and EI.

Prof. Li is the membership of China Branch of the American Concerte Institute and Cement Professional Committee of Chinese Ceramic Society. He was awarded one second prize of National Science and Technology Progress and two first prizes in the provincial science and technology progress and technological invention.

Wanguo Dong was born in February 1989, He is the graduate of Beijing University of Technology, The main research field is the determination of original components of hardened concrete.

Hong Li was born in August 1991, She is the graduate of Beijing University of Technology. The main research field is the determination of original components of hardened concrete.

Zhanguo Li was born in 1980; the last education was doctor of engineering in Beihang University in 2009. Now he is the tutor of postgraduate of Beijing University of Technology.

He works in the Beijing University of Technology since he graduated, and has published over 30 papers on journals of relative field, including 10 papers searched by SCI , ISTP and EI. The main research field is construction materials, use of recyclable industrial waste and foundation treatment etc.