The relationship between strength and depth of water penetration in concrete by using pull-off and cylindrical chamber tests and developing a new theory

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ABSTRACT

The depth of water penetration in concrete is used to measure the permeability of concrete. In the valid international standards, to do this, first water under pressure enters the concrete, and then by breaking the concrete sample, the depth of water penetration into the concrete is measured. Meanwhile, if there is a need to evaluate the durability of a concrete structure or a concrete water source on site, there is no accurate on-site test to do this. Therefore, in this article, the depth of water penetration in concrete has been measured by using the in-situ and modern cylindrical chamber test. Then, using the structural characteristics of the microscopic pores of concrete, which is obtained by mercury test, a new theoretical model has been presented, which can be used to measure the water penetration depth in concrete with high accuracy. . While comparing the penetration depth obtained from the cylindrical chamber test and the new theoretical model, the surface resistance of concrete has been determined using the surface pull test. The obtained results show an inverse relationship between strength and water penetration depth in concrete. It was also found that the cylindrical chamber test has the ability to measure the depth of water penetration in concrete without breaking the sample and with a high confidence of 93%. The extracted new equations also showed very high accuracy to evaluate the depth of water penetration into concrete.

KEYWORDS

Pull-off test, depth of penetration, concrete, new equations, permeability.

1. Introduction

In the design of various concrete structures, in addition to the required strength, the durability of concrete should also be considered. In other words, concrete should be designed in such a way that it has both adequate strength and low permeability. Due to the penetration of damaging factors into the concrete and the reduction of its durability, it is very important to know the permeability of concrete. Also, the permeability of concrete can be affected under extreme conditions such as high temperatures [1], high water pressure [2], continuous freezing and thawing [3], chloride attack [4], sulfate attack [5]. In addition, the surface permeability of concrete has a significant impact on its short-term and long-term performance [6]. Permeability characteristics are of great importance for the resistance of concrete to external influences.

It is worth noting that the pores of cementitious materials with a wide diameter range and a very irregular morphology cause the complexity and roughness of the entire microscopic structure of the pores. All dimensions in conventional geometry are integers. Conventional geometry, known as Euclidean geometry, defines dimensions as one-dimensional, two-dimensional, and three-dimensional. However, capillary channels in concrete have irregular shapes, and this

geometry cannot provide accurate information about the complexity and distribution of pores. Due to the wide variety of capillary channels in concrete and similar environments, researchers have used fractal theory. This theory, due to its special capabilities, allows for the investigation of the complexity with fractional dimensions associated with these channels. Also, the information obtained from this theory can be used in the analysis of the distribution of pores and permeability of concrete. In recent years, the fractal theory proposed by Benoit Mandelbrot [7] has been used to describe the pore structure of cement composite materials, which has also been used in the studies of various researchers [8]. On the other hand, the pore structure of cementitious materials is considered as a very complex system, which cannot be completely characterized by conventional parameters such as porosity, pore volume and pore diameter distribution [9-10]. However, through fractal analysis, the complexity of the pore structure of concrete can be effectively measured and compared [11-12]. The previously presented models used to measure the permeability of concrete have an important gap. The models of previous researchers do not consider the curing time and age of concrete, while the permeability model presented in this study considers the time variable. Which makes this new model more complete than the existing models; in a way that it makes it possible to measure the permeability of concrete with respect to changes in time and curing process with little difference from the corresponding values of laboratory results.

2. Materials Used

The materials used are: type 2 cement, urban drinking water, epoxy resin glue and polycarboxylate type superlubricant.

Results from the "pull-off" method

According to Figure 1-a, with increasing curing time of the samples, an increase was also observed in the results of the "surface pull" test. Figure 6 shows the results of the "surface pull" test obtained from concrete samples at curing ages of 7, 28, and 90 days. This increase is about 21% in 28-day-cured samples compared to 7-day-cured samples and about 37.6% in 90-day-cured samples compared to 28-day-cured samples. The increase in compressive strength in the mentioned treatments also has a similar trend. The increase in the strength of the surface layer at different strengths indicates the progress and formation of more cement hydration products, which leads to a denser structure. The development of strength is strongly dependent on the type and volume of hydration products formed and therefore is attributed to reactions between solid and liquid components

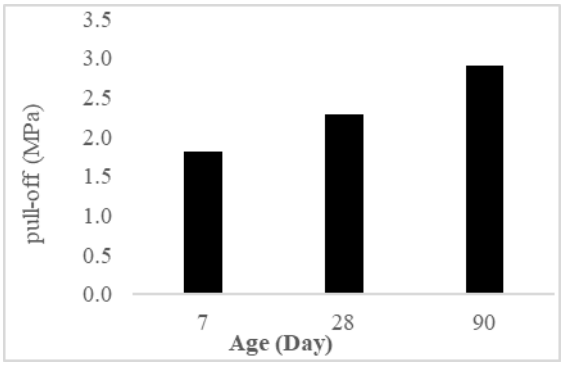

Figure 1: Results of the "Pull from Surface" test

3. Conclusions

- Studies have shown that permeability is of particular importance in the durability of concrete. Its main parameters, including penetration rate, penetration depth and permeability coefficient, play a significant role in determining the performance and durability of concrete.

- The results of this research show that reducing the surface resistance of concrete leads to an increase in its permeability. In this situation, damaging factors will be able to penetrate into the concrete, which will ultimately lead to a reduction in the useful life of the structure.

- According to the results obtained from the new fractal model, it can be stated that this model is capable of measuring permeability with high accuracy. In addition, this model can be used to estimate the permeability of ordinary concrete.

4. References

[1] Shen, L., Zhang, L., Yang, X., Di Luzio, G., Xu, L., Wang, H., & Cao, M. Multiscale cracking pattern-based homogenization model of water permeability in hybrid fiber-reinforced concrete after high-temperature exposure. Journal of Building Engineering, 84(2) (2024) 1-17.

[2] Zhang, G., Zheng, H., Wei, X., Li, Z., Yan, Z., & Chen, X. Concrete mechanical properties and pore structure influenced by high permeability water pressure. Developments in the Built Environment, 17(2) (2024) 1-11.

[3] Zeng, W., Wang, W., Pan, J., & Liu, G. Effect of steel fiber on the permeability of freeze-thaw damaged concrete under splitting tensile and compressive loads. Journal of Building Engineering, 80(2) (2023) 1-14.

[4] Zeng, W., Zhao, X., Zou, B., & Chen, C. Topographical characterization and permeability correlation of steel fiber reinforced concrete surface

under freeze-thaw cycles and NaCl solution immersion. Journal of Building Engineering, 80(4) (2023) 1-17.

[5] Zhang, J., Zhou, L., Nie, Q., Wu, H., & Wu, L. Effects of calcium sulfate whiskers and basalt fiber on gas permeability and microstructure of concrete. Construction and Building Materials, 411(1) (2024) 134369.

[6] Yang, J., Dong, Q., Chen, X., Shi, B., & Wang, X. Evaluation of concrete surface permeability: A dynamic water film-based approach. Measurement, 224(1) (2024) 113863.

[7] Mandelbrot, B. B., & Mandelbrot, B. B. The fractal geometry of nature. New York: WH freeman. 5 (1982) 468 pages.

[8] Xuan, W., Chen, X., Yang, G., Dai, F., & Chen, Y. Impact behavior and microstructure of cement mortar incorporating waste carpet fibers after exposure to high temperatures. Journal of Cleaner Production, 187(7) (2018) 222-236.

[9] Gao, Y., Jiang, J., De Schutter, G., Ye, G., & Sun, W. Fractal and multifractal analysis on pore structure in cement paste. Construction and Building Materials, 69(3) (2014) 253-261.

[10] Chen, X., Zhou, J., & Ding, N. Fractal characterization of pore system evolution in cementitious materials. KSCE Journal of Civil Engineering, 19(1) (2015) 719-724.

[11] Ma, H., Sun, J., Wu, C., Yi, C., & Li, Y. Study on the pore and microstructure fractal characteristics of alkali-activated coal gangue-slag mortars. Materials, 13(11) (2020) 2442.

[12] Mahamud, M., López, Ó., Pis, J. J., & Pajares, J. A. Textural characterization of chars using fractal analysis. Fuel Processing Technology, 86(2) (2004) 135-149.