

Experimental Study on Mechanics and Permeability of Fly Ash Permeable Concrete

Zhenyu Qu, Xiaojun Hu

School of Urban Architecture and Transportation, Hefei University, Hefei 230601, China

Abstract. In order to explore the effects of the changes of water-glue ratio, target porosity and fly ash content on the mechanics and permeability properties of permeable concrete after being mixed with fly ash, the compressive strength, flexural strength and permeability coefficient of permeable concrete with different water-cement ratios, target porosity and fly ash content were tested. The test results show that the increase of the water-glue ratio from 0.24 to 0.33 will improve the mechanical properties of permeable concrete but reduce its permeability, and after 0.33, it will reduce its mechanical and permeability properties at the same time; the increase of target porosity will enhance the permeability of permeable concrete and reduce its mechanical properties; the increase of fly ash content from 4% to 12% will improve the mechanical and permeability properties of permeable concrete at the same time, but only increase its permeability and reduce its mechanical properties after 12%.

Keywords: Permeable concrete; water-glue ratio; target porosity; fly ash content; mechanical properties; Water permeability.

1. Prolegomenon

Since the beginning of the 21st century, cities are facing increasing water resource management problems due to the rapid development of urbanization and the intensification of urban climate change. In order to solve the problems of frequent urban floods, deterioration of river ecology, serious water pollution, and urban heat island effect, the concept of sponge city came into being [1,2]. With the development of the sponge city concept, permeable concrete can play an irreplaceable role in many places, such as sidewalks and bicycle paths in urban parks, landscape roads, and urban squares [3,4]. The pavement is paved with permeable concrete, which has the functions of drainage, anti-skid, sound absorption, noise reduction and water seepage.

Fly ash is a bulk solid residue produced by coal-fired power plants, which has similar chemical composition and reactivity to cement, and can replace a part of cement ginseng to prepare permeable concrete, which can improve the workability of permeable concrete, and also realize the resource utilization of bulk solid waste and realize the green and sustainable development of resources [5]. Liang Luming [6] successfully prepared high-performance permeable concrete by replacing 30% cement with fly ash, and the 28-day splitting tensile strength of permeable concrete was increased by 37.6% compared with that mixed with fly ash. Zerdi ^[7] conducted a mechanical strength test after using fly ash instead of 10% cement to prepare permeable concrete, and the results showed that the strength of permeable concrete mixed with fly ash was greater than that of permeable concrete without fly ash under the same mix ratio. Cheng Juan [8] used a large amount of fly ash instead of cement to prepare permeable concrete in order to reduce the production cost of permeable concrete, and its performance can still meet the use requirements. Liu Xiaofan [9] found that when the aggregate particle size is 5~10 mm, the early compressive strength of fly ash permeable concrete is slightly lower than that of ordinary permeable concrete, and the later strength is significantly improved.

In order to explore the effects of the changes of water-cement ratio, target porosity and fly ash content on its compressive strength, flexural strength and permeability coefficient after permeable concrete is mixed with fly ash, a three-factor and four-level single-factor test was set up for the water-cement ratio, target porosity and fly ash content, and the compressive strength, flexural strength and permeability coefficient of permeable concrete with different water-cement ratios, target porosity and fly ash content were tested, and the effects of different water-glue ratios, target porosity and fly ash content on the mechanics and permeability of permeable concrete were analyzed.

2. Raw materials and specimen manufacturing methods

2.1. Raw materials

Cement: P·O42.5 ordinary Portland cement aggregate: natural crushed stone produced locally in Anhui Province. Fly ash: Class I fly ash produced by Yisheng Fly Ash Plant in Gongyi City, Henan Province. Water reducer: LZ-303 polycarboxylic acid high-performance superplasticizer powder produced by Longze Water Purification Material Co., Ltd. in Gongyi City, Henan Province, has the highest water reduction rate of up to 40%. Water: Local domestic water.

2.2. Stirring method

In view of the unique porous structure of permeable concrete, it was decided to use the cement-clad method to mix permeable concrete. The specific method is to first add the coarse aggregate and 30% mixing water weighed according to the mix ratio to the compulsory mixer, and after 30 s of stirring, the surface of the aggregate will be uniformly wet, and then all the cementitious materials, 70% of the mixing water and all the water reducer are added to the mixer for a stirring time of 150 s to form a cementitious material wrapping on the aggregate surface [10].

2.3. Molding method

In this test, the permeable concrete specimen is determined to be manually vibrated, which is easy to operate and does not require special machines or molds and can ensure the porosity and compactness of the specimen after molding.

3. Test protocol

3.1. Experimental mix design

In order to analyze the effects of the water-cement ratio, target porosity and fly ash content on the permeability and mechanical properties of permeable concrete after being mixed with fly ash, it was decided to use a single factor test. The effects of water-glue ratio, target porosity and fly ash content on the permeability and mechanical properties of permeable concrete were studied by designing different water-cement ratios, different target porosities and different fly ash contents. The superplasticizer content is 0.35%, and the permeable concrete mix ratio is designed by volume method.

Keeping the target porosity of 18% and the fly ash content of 12% and other conditions unchanged, the test set up five kinds of permeable concrete with different water-glue ratios of 0.24, 0.27, 0.30, 0.33 and 0.36 respectively, and the specific combination of permeable concrete under different water-glue ratios is shown in Table 1.

Table. 1 Mix ratios of permeable concrete with different water-glue ratios

serial number	Water-glue ratio	Coarse aggregates/Kg	cement/Kg	water/Kg	Fly ash/Kg	Water reducer/g
A1	0.24	1627	330	92	45	1312
A2	0.27	1627	315	97	43	1253
A3	0.30	1627	302	105	42	1222
A4	0.33	1627	289	107	39	1150
A5	0.36	1627	276	112	37	1100

Keeping the water-glue ratio of 0.30 and the fly ash content of 12% and other conditions unchanged, five kinds of permeable concrete with different target porosity were set up in the test to be 12%, 15%, 18%, 21% and 24%, respectively, and the specific combination of permeable concrete under different target porosity is shown in Table 2.

Table. 2 Mix ratios of permeable concrete with different target porosity

serial number	Target porosity	Coarse aggregates/Kg	cement/Kg	water/Kg	Fly ash/Kg	Water reducer/g
B1	12%	1627	382	130	53	1522
B2	15%	1627	342	116	47	1361
B3	18%	1627	302	105	42	1222
B4	21%	1627	262	89	35	1039
B5	24%	1627	222	75	29	900

Keeping the water-glue ratio of 0.30 and the target porosity of 18% and other conditions unchanged, five kinds of permeable concrete with different fly ash content were set up in the test to be 4%, 8%, 12%, 16% and 20% respectively, and the specific combination of permeable concrete under different fly ash content is shown in Table 3.

Table. 3 Mix ratio of permeable concrete with different fly ash contents

serial number	Fly ash	Coarse aggregates/Kg	cement/Kg	water/Kg	Fly ash/Kg	Water reducer/g
C1	4%	1627	330	105	14	1222
C2	8%	1627	316	105	28	1222
C3	12%	1627	302	105	42	1222
C4	16%	1627	288	105	56	1222
C5	20%	1627	272	105	70	1222

3.2. Test Method

(1) Compressive strength test

The cube unconfined compressive strength test was carried out on the permeable concrete specimens with a size of 100 mmX100 mmX100 mm after curing for 28 days, and the unconfined compressive strength of the cube was tested. The test instrument adopts the microcomputer control electro-hydraulic servo pressure testing machine produced by Jinan Zhongte Testing Machine Co., Ltd., and the equipment model is ZTYW-2000D.

(2) Flexural strength test

The flexural and compressive strength of the permeable concrete specimens with a size of 100 mmX100 mmX400 mm was tested after curing for 28 days. Test its flexural strength. The test instrument adopts the YES-300 digital pressure testing machine produced by Zhejiang Yingsong Instrument Equipment Manufacturing Co., Ltd.

(3) Water permeability coefficient test

The permeability coefficient expresses the permeability of permeable concrete, which mainly depends on the structural characteristics of permeable concrete and is the degree of difficulty of water flow in permeable concrete. The permeability coefficient test mainly refers to the test method of permeability coefficient in Appendix A of the JC/T2558-2020 "Permeable Concrete" standard, and the instrument used in the test is the TH-A1 concrete permeability coefficient experimental device, as shown in Figure 1 below.

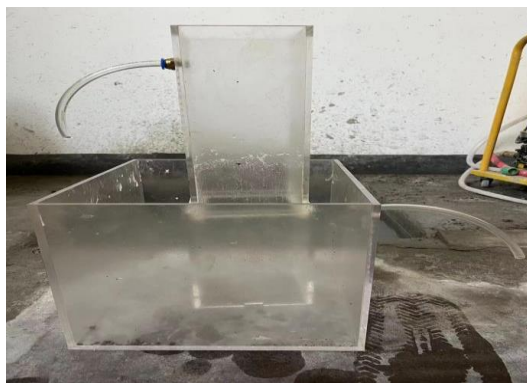


Figure. 1 Permeability coefficient tester TH-A1

4. Test results and analysis

4.1. Effect of water-glue ratio on the properties of permeable concrete

The test data obtained by compressive test, flexural test and permeability coefficient test of permeable concrete with different water-glue ratios under 28 days of standard curing are shown in Figure 2.

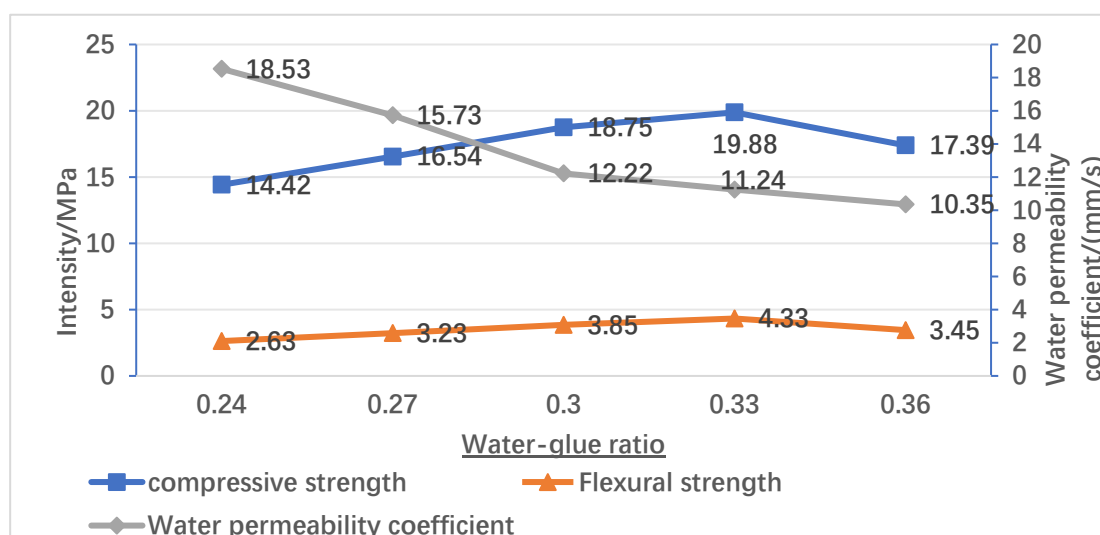


Fig. 2 Effect of water-glue ratio on permeability and mechanical properties of permeable concrete

It can be seen from Fig. 2 that with the increase of the water-glue ratio, the 28-day compressive strength of permeable concrete first increases and then decreases. When the water-glue ratio is 0.33, the maximum compressive strength is 19.88MPa, and with the increase of the water-glue ratio, the 28-day flexural strength of permeable concrete increases first and then decreases. When the water-glue ratio is 0.33, the maximum flexural strength is 4.33MPa, and the permeability coefficient of permeable concrete decreases with the increase of the water-glue ratio. When the water-glue ratio is 0.24, the maximum water permeability coefficient is 18.53 mm/s. Through the analysis of the permeability and mechanical properties of fly ash permeable concrete, a reasonable water-cement ratio of fly ash permeable concrete can be obtained as 0.33. Therefore, when the target porosity of fly ash permeable concrete mix is 18% and the fly ash content is 12%, the A4 water-glue ratio is 0.33 as the optimal mix ratio, and its compressive strength is 19.88MPa, flexural strength is 4.33MPa and water permeability coefficient is 11.24 mm/s.

4.2. Effect of target porosity on the properties of permeable concrete

The test data obtained by compressive test, flexural test and permeability coefficient test are shown in Fig. 4 under the standard curing of permeable concrete with different target porosity.

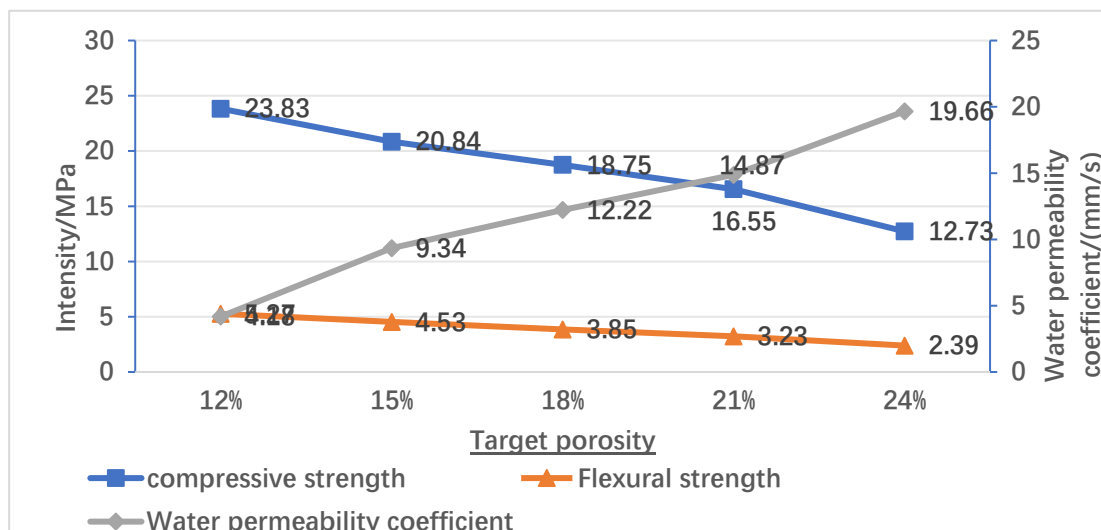


Figure. 3 Effect of target porosity on permeability and mechanical properties of permeable concrete

It can be seen from Fig. 3 that the 28-day compressive strength of permeable concrete decreases with the increase of target porosity. When the target porosity is 12%, the maximum compressive strength is 23.83MPa, and when the target porosity is 24%, the minimum compressive strength is 12.73MPa, and the 28-day flexural strength of permeable concrete decreases with the increase of the target porosity. When the target porosity is 12%, there is a maximum flexural strength of 5.27MPa, and when the target porosity is 24%, there is a minimum flexural strength of 2.39MPa. When the target porosity is 24%, the maximum permeability coefficient is 19.66 mm/s. When the target porosity is 12%, there is a minimum permeability coefficient of 4.18 mm/s. Through the analysis of the permeability and mechanical properties of fly ash permeable concrete, a reasonable target porosity of fly ash permeable concrete is 12%. Therefore, when the water-cement ratio of fly ash permeable concrete is 0.30 and the fly ash content is 12%, the target porosity of B1 is 12% as the optimal mix ratio, and its compressive strength is 23.83MPa, flexural strength is 5.27MPa and water permeability coefficient is 4.18 mm/s.

4.3. Effect of fly ash content on the properties of permeable concrete

The test data obtained by the compressive test, the flexural test and the permeability coefficient test are shown in Figure 4 under the standard curing of permeable concrete with different fly ash contents, after the compressive test, the flexural test and the permeability coefficient test test.

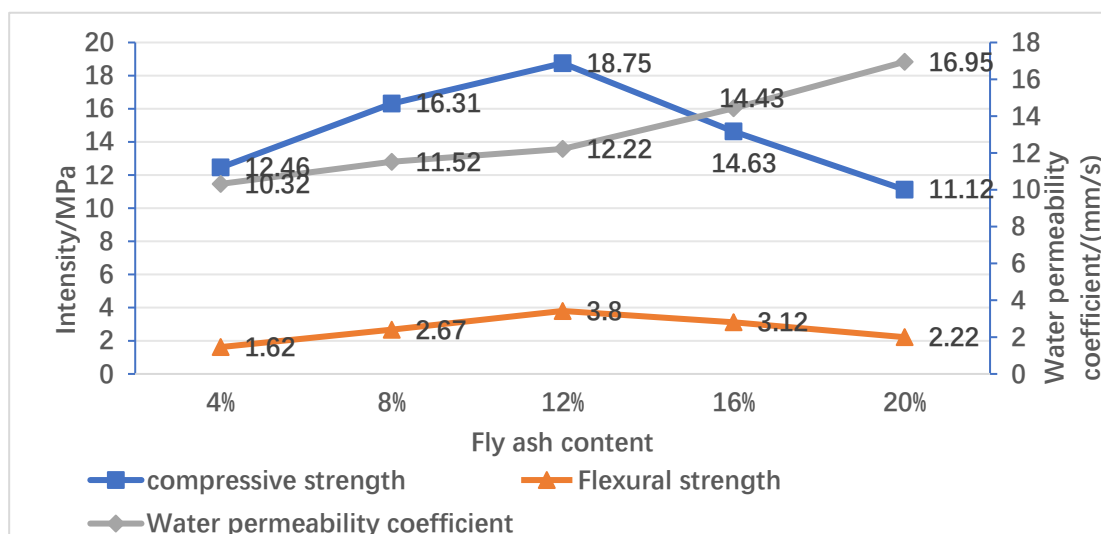


Fig. 4 Effect of fly ash content on the permeability and mechanical properties of permeable concrete

It can be seen from Fig. 4 that with the increase of fly ash content, the 28-day compressive strength of permeable concrete first increases and then decreases. When the fly ash content is 12%, the maximum compressive strength is 18.75MPa, and with the increase of fly ash content, the 28-day flexural strength of permeable concrete increases first and then decreases. When the fly ash content is 12%, the maximum flexural strength is 3.85MPa, and the permeability coefficient of permeable concrete increases with the increase of fly ash content. When the fly ash content is 20%, the maximum water permeability coefficient is 16.95 mm/s. When the fly ash content is 4%, there is a minimum permeability coefficient of 10.32 mm/s. Through the analysis of the permeability and mechanical properties of fly ash permeable concrete, a reasonable fly ash content of fly ash permeable concrete can be obtained as 12%. Therefore, when the water-glue ratio of fly ash permeable concrete is 0.30 and the target porosity is 18%, the C3 fly ash content of 12% is taken as the optimal mix ratio, and its compressive strength is 18.75MPa, flexural strength is 3.85MPa and water permeability coefficient is 12.22 mm/s.

5. Conclusion

The 28-day compressive strength and flexural strength of fly ash permeable concrete will increase with the increase of the water-cement ratio before the water-cement ratio reaches 0.33, and decrease with the increase of the water-cement ratio after the water-cement ratio reaches 0.33, and decrease with the increase of the target porosity, and will increase with the increase of fly ash content before the fly ash content reaches 4% to 12%, and decrease with the increase of fly ash content after the fly ash content reaches 12%.

The permeability coefficient of fly ash permeable concrete will decrease with the increase of water-glue ratio. It will increase with the increase of target porosity; It will increase with the increase of fly ash content.

References

- [1] Yang Yang, Lin Guangsi. Southern Architecture,2015(03):59-64.
- [2] Liu Yanan. Research on the application and promotion of permeable pavement in sponge city [D]. Beijing University of Civil Engineering and Architecture,2017.
- [3] Yu Yongxia. Research on the application of permeable concrete in sponge city construction [D]. Anhui University of Science and Technology,2016.
- [4] Wei Sheng, Wang Junling, Zhang Yajun, et al. Municipal Technology,2014,32(04):28-31.)
- [5] Shi Yaqian, Guan Yushan, Ge Weizhe, et al. Value-added utilization of fly ash building materials:latest technology and future prospects [J/OL].Journal of China Coal Society:1-19[2024-01-07].<https://doi.org/10.13225/j.cnki.jccs.ZZ23.1224>.
- [6] Liang Luming. Comprehensive utilization of fly ash,2018(05):58-62.)
- [7] Zerdi T A, Mahmadmosin, Samee M A, et al. Experimental Investigation on Strength Developement of Fly Ash Pervious Concrete [J]. Paripex - Indian2016,5(5):174-176.
- [8] Cheng Juan, Guo Xiangyang. Effect of fly ash and mineral powder on the properties of permeable concrete [J]. Building Blocks and Block Construction,2007(05):27-30.)
- [9] Liu Xiaofan, Bai Xiaohui, Wang Zhazhan, et al. Experimental study on fly ash modified permeable concrete [J]. Concrete and Cement Products,2014(01): 20-23.DOI:10.19761/j.1000-4637.2014.01.006.
- [10] Huang Xianquan, Liu Weidong, Xiong Jianping. Highway,2021,66(04):11-17.)