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Experimental Study on Mechanical Properties of Permeable Concrete

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Abstract. The mechanical properties of permeable concrete are mainly affected by the water-cement ratio and coarse aggregate gradation. In order to further clarify the relationship between the tensile strength and compressive strength of porous concrete and the above-mentioned influencing factors, the test pieces of different test ratios were tested by preparing porous concrete test blocks and using RFPA2D numerical simulation method. The results show that the tensile and compressive strength of the permeable concrete gradually decreases with the increase of the water-cement ratio under the same conditions of coarse aggregate gradation. In the case of the same water-cement ratio, the tensile and compressive strength of the permeable concrete gradually increases as the particle size of the coarse aggregate increases. The larger the coarse aggregate particle size, the greater the increase in tensile strength.

1. Introduction

In recent years, the concept of “sponge city” has been proposed due to the high attention paid to urban and non-point source pollution. The so-called sponge city is a metaphorical city like a sponge. When it encounters rainfall, it can absorb, store, infiltrate, purify and regulate the water cycle on the spot or nearby. When the drought is short of water, the surviving water can be released and the city facing the nature. Adaptability in disasters and environmental changes ^[1]. Porous concrete meets the requirements of the “sponge city” concept, which is an eco-friendly concrete. It has good mechanical properties and is breathable, water permeable and lightweight. Currently, pavement work such as sidewalks, driveways and parking lots have been widely used ^{[2] [3]}. In this paper, the physico-mechanical properties of permeable concrete with different water-to-binder ratio and coarse aggregate grade are compared and analyzed, and the relevant influencing factors and performance change laws are explored to provide theoretical basis and technical support for the more widely and rational application of permeable concrete in sponge city construction.

2. Experiment

2.1. Materials

The constituent materials describe as follows:

- Cement: Using P•O 42.5 ordinary Portland cement.
- Water: Pure water.
- Coarse aggregate: Granite gravel is used to obtain 5-10mm, 5-15mm, 5-20mm particle size



by its own sieve. The basic performance is shown in Table 1.

Table 1. Basic properties of coarse aggregate.

Aggregate grading (mm)	Apparent density (kg/m ³)	Bulk density (kg/m ³)	Void ratio (%)
5-10	2737	1877	30.0
5-15	2683	1773	33.9
5-20	2609	1692	36.9

2.2. mixture ratio

The volumetric method is generally used in the laboratory for the design of the permeable concrete mixing ratio ^[4]. The mixing ratio used in this test is shown in Table 2.

Table 2. Pervious concrete mixture ratio (kg /m³).

Water cement ratio	Aggregate grading (mm)	Cement (kg)	Coarse aggregate (kg)	Water (kg)
0.35	5~10	149	1917	55
0.35	5~15	207	1774	72
0.35	5~20	251	1646	88
0.4	5~10	138	1916	55
0.4	5~15	192	1773	77
0.4	5~20	234	1646	94
0.45	5~10	129	1916	58
0.45	5~15	180	1773	81
0.45	5~20	219	1646	98

2.3. Preparation process and test method

The test for the compressive strength and splitting tensile strength of permeable concrete is carried out in accordance with the requirements of the Standard Test Method for Mechanical Properties of Ordinary Concrete.

3. Test results and analysis

3.1 Compressive strength test results and analysis

Through the compressive test of different coarse aggregate grading and different water-to-binder ratio of porous concrete, the compressive strength value is obtained, as shown in Figure 1.

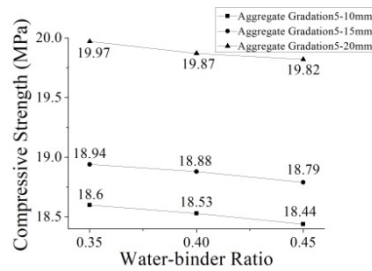


Figure 1. Relationship between water-to-binder ratio, aggregate gradation and concrete compressive strength.

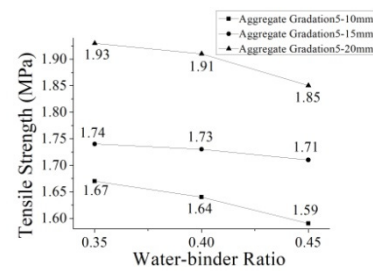


Figure 2. Relationship between water-to-binder ratio, aggregate gradation and concrete tensile strength.

As shown in Figure 1, in the case of the same coarse aggregate gradation, as the water-to-binder ratio increases, the compressive strength of the permeable concrete gradually decreases. The main reason is that the cement particles are filled with water. Even if the cement hydration reaction is sufficient, the obtained hydration product cannot fill the volume of cement and water before the reaction, that is, the voids cannot be sufficiently filled. Therefore, as the water-to-binder ratio increases, the voids increase and the compressive strength decreases [5].

In the case of the same water-to-binder ratio, the compressive strength of the permeable concrete gradually increases with the increase of the coarse aggregate size. It is because the gradation composition of the aggregate has an important influence on the strength of the porous concrete. The aggregates are properly matched and form an intrusion between them, which can significantly improve the overall strength of the permeable concrete [6]. Therefore, the larger the particle size of the coarse aggregate, the greater the compressive strength.

3.2. Tensile strength test results and analysis

The tensile strength of the porous concrete with different coarse aggregate grading and different water-to-binder ratio is obtained, and the tensile strength value is obtained, as shown in Figure 2. It can be seen that the change trend of the tensile strength of porous concrete is consistent with the change trend of compressive strength, which also justifies the normal proportional relationship between the split tensile strength and the compressive strength.

4. RFPA2D numerical simulation

4.1. Influence of water-cement ratio on mechanical properties of concrete

This article uses RFPA2D software to generate permeable concrete specimens. Considering that the RFPA2D software does not have a water-to-binder ratio parameter, the strength of the mortar matrix corresponds to the strength of the mortar with a water-to-binder ratio of 0.35, depending on the relationship between the water-to-binder ratio of the ordinary concrete and the mortar strength. For the values of the physical and mechanical parameters of the mortar matrix and coarse aggregate in the numerical model of uniaxial compression, see Table 3 and Table 4. The tensile strength f_a of the mortar matrix in the uniaxial tensile numerical model is set to 2.0MPa, and the rest remains unchanged. Finally, axial pressure and axial tension were applied to the concrete specimens, respectively, and the loading step was started.

Table 3. Mortar matrix parameters in uniaxial compression numerical model.

E_a (GPa)	f_a (MPa)	m	μ
32	20	3	0.2

Table 4. Coarse aggregate parameters in uniaxial compression numerical model.

E_s (GPa)	m	μ	R_{min} (mm)	R_{max} (mm)
70	6	0.2	5	10

The peak stress of the permeable concrete with the water-cement ratio of 0.35 and the aggregate grading of 5-10mm is 1.629MPa and 19.05Mpa, respectively, and the measured results of the indoor test are 1.67Mpa and 18.6Mpa. Explain that the numerical model of this simulation test is effective.

In order to study the effect of water-cement ratio on the mechanical properties of permeable concrete, this test shows the different water-cement ratio by changing the strength of the mortar matrix. On the basis of Tables 3 and 4, change the strength of the mortar matrix in the concrete specimen. The uniaxial tensile and compressive compression tests have been carried out on the test pieces with a water-cement ratio of 0.35, respectively, and their effectiveness has been proved. When the water-cement ratio is 0.4 or 0.45, the mortar matrix strength f_a in the uniaxial compression numerical model can be set to 19.6MPa and 18.9MPa, respectively, and the tensile strength f_a of the mortar matrix in the uniaxial tensile numerical model is set to 1.96MPa and 1.92MPa. The dimensions of the test piece, aggregate size and other parameters remain unchanged. See Table 5 and Table 6 for the establishment of numerical samples. In addition, in order to reflect the influence of the water-cement ratio on the strength of the test piece, we attached the fracture pattern of the test piece under the same loading step, as shown in Figures 3 and 4.

Table 5. Influence of water-cement ratio on mechanical response of permeable concrete under uniaxial compression.

Group	Water cement ratio	Peak stress (MPa)	Peak strain	Residual strength (MPa)
1	0.35	19.05	0.0019	2.578
2	0.40	18.99	0.002	2.570
3	0.45	18.95	0.002	2.553

Table 6. Influence of water-cement ratio on uniaxial tensile mechanical response of pervious concrete.

Group	Water cement ratio	Peak stress (MPa)	Peak strain	Residual strength (MPa)
1	0.35	1.629	0.0001	0.204
2	0.40	1.603	0.0001	0.198
3	0.45	1.598	0.0001	0.192

It can be seen from Table 5 that when the water-binder ratio is increased from 0.35 to 0.4, 0.45, the peak stress is slightly reduced, but the change is extremely small and negligible; the peak strain and residual strength are also substantially unchanged. It can be seen that the change of water-to-binder ratio has little effect on the mechanical properties of concrete specimens.

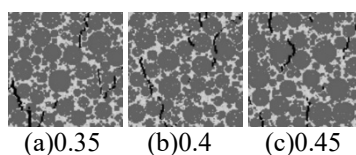


Figure 3. Failure diagram of uniaxially compressed concrete specimens with different water-cement ratio.

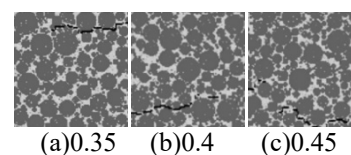


Figure 4. Failure diagram of uniaxially stretched concrete specimens with different water-cement ratio.

It can be seen from Fig. 3 and Fig. 4 that as the water-cement ratio increases, the number and width of cracks in the water-cement ratio of 0.35, 0.4, and 0.45 are basically unchanged when the number of loading steps is the same. It can be seen that the size of the water-cement ratio has no effect on the mechanical properties of the concrete specimen.

4.2. Influence of coarse aggregate size on mechanical properties of concrete

In order to study the effect of coarse aggregate size on the mechanical properties of concrete, the maximum and minimum radii of aggregates in concrete specimens were changed on the basis of

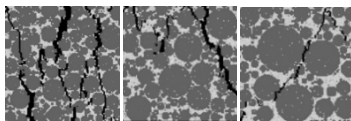
Tables 3 and 4. In order to more accurately find out the influence of coarse aggregate size on the mechanical properties of concrete, this simulation experiment took 8 groups for simulation. The matrix strength was uniformly set to the matrix strength when the water-cement ratio was 0.35 above, and the dimensions and other parameters of the test piece remained unchanged. Eight sets of numerical samples were established, see Tables 7 and 8. The most representative of the three sets of simulation test results are selected for explanation. In addition, in order to reflect the influence of the aggregate size on the crack position and shape of the specimen, we attached the fracture pattern of the concrete specimen with the same loading step, as shown in Fig. 5 and Fig. 6.

Table 7. Influence of aggregate size on uniaxial compression mechanical response of permeable concrete.

Group	Aggregate grading (mm)	Peak stress (MPa)	Peak strain	Residual strength (MPa)
1	5~8	17.125	0.002	2.072
2	8~10	17.336	0.002	2.073
3	10~12	17.542	0.002	2.075
4	12~14	17.822	0.002	2.08
5	14~16	18.011	0.0021	2.081
6	16~18	18.23	0.0021	2.088
7	18~19	18.694	0.0021	2.09
8	19~20	19.16	0.0021	2.092

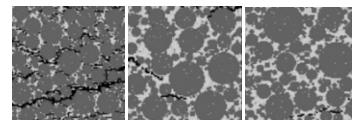
Table 8. Influence of aggregate size on uniaxial tensile mechanical response of permeable concrete.

Group	Aggregate grading (mm)	Peak stress (MPa)	Peak strain	Residual strength (MPa)
1	5~8	1.514	0.00010	0.162
2	8~10	1.573	0.00010	0.164
3	10~12	1.611	0.00010	0.169
4	12~14	1.654	0.00011	0.171
5	14~16	1.682	0.00011	0.172
6	16~18	1.701	0.00011	0.182
7	18~19	1.747	0.00011	0.197
8	19~20	1.787	0.00011	0.204



(a)5~8mm (b)14~16mm (c)19~20mm

Figure 5. Failure diagram of uniaxially compressed concrete specimens with different aggregate particle sizes.



(a)5~8mm (b)14~16mm (c)19~20mm

Figure 6. Failure diagram of uniaxially stretched concrete specimens with different aggregate particle sizes.

It can be seen from Table 7 that when the aggregate particle size increases from 5 to 8 mm to 14 to 16 mm and 19 to 20 mm, the strain and residual strength corresponding to the peak stress are basically unchanged. However, the peak stress of the permeable concrete is significantly improved when the aggregate size is increased. This is because under the same conditions, the compressive strength of the permeable concrete will increase as the aggregate size increases, and the permeable concrete will resist the external load. Correspondingly, the higher the peak stress of the permeable concrete [7].

It can be seen from Table 8 that when the aggregate particle size increases from 5~8mm to 14~16mm and 19~20mm, the peak stress and residual strength of the permeable concrete are obviously improved when the aggregate particle size increases. This is because, under the same

conditions, the tensile strength of the permeable concrete will increase as the aggregate size increases. The tensile strength of permeable concrete is much less than the compressive strength, indicating that permeable concrete is a quasi-brittle material.

It can be seen from Fig. 5 and Fig. 6 that the degree of damage of the three sets of test pieces is significantly different. The specimen with the aggregate size of 5~8mm has the largest degree of damage, and the specimen with the aggregate size of 19~20mm has the least damage degree. The maximum number of cracks occurred in the specimens with an aggregate size of 5 to 8 mm, followed by the specimens of 14 to 16 mm, and the specimens with a particle size of 19 to 20 mm had the least number of fractures. The development trend of cracks is also different. Once again, the larger the aggregate size of the concrete specimen, the stronger the resistance to external loads, and the greater the uniaxial tensile strength^[8].

5. Conclusions

The following conclusions may be drawn from the results of this study:

- (1) Under the condition of uniaxial tension and compression, the coarse aggregate size has a great influence on the mechanical properties of the permeable concrete.
- (2) Under the condition of uniaxial tension and compression, the water-cement ratio has little effect on the mechanical properties of the permeable concrete.
- (3) The fracture process diagram of the test piece of the permeable concrete numerical simulation test shows that under the same loading step, the crack width and the number of cracks in the simulated test piece decrease with the increase of the coarse aggregate particle size. However, the change in the water-cement ratio has little effect on the width and number of cracks in the simulated test piece.

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