Experimental Study on Physical and Mechanical Properties of C30 Permeable Concrete

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Abstract. In order to prepare C30 permeable concrete, the effects of water-cement ratio, mixing method, forming process and curing method on the porosity, permeability coefficient and compressive strength of permeable concrete were investigated. The permeable concrete was applied by SEM and XRD. The microstructure and chemical composition of the cemented layer were analyzed. The results show that when the amount of other ingredients is the same, increasing the amount of cement can effectively improve the strength; the mixing method of cement stone can enhance the bond between the aggregate and the cemented material; with the increase of vibration time, the compressive strength of the permeable concrete gradually increase, but the vibration time is too long, there will be a phenomenon of sedimentation; in the early stage of conservation, the water conservation can make the hydration reaction fully; 28d permeable concrete sample hydration reaction is more thorough, generating a large amount of CSH gel.

1. Introduction

In recent years, with the rapid development of China's economy and the continuous improvement of urban infrastructure, the urban ground is mostly covered by impervious concrete pavement. Especially after heavy rainfall, the drainage system is almost paralyzed, the road surface is flooded with water, and the drift of the train is extremely unfavorable for travel. In response to the phenomenon of urban shackles in China, the "sponge city" came into being. Sponge city means that the city can be like a sponge. It absorbs water, accumulates water, seeps water, and cleans water when it rains. When it is needed, it will "release" and use the stored water [1].

As an important part of sponge city construction, permeable concrete is an environment-friendly building material that is conducive to promoting water circulation and improving urban ecological environment. Since the permeable concrete needs to ensure a certain permeable requirement, there are a large number of pores inside, which restricts the development of its strength. In recent years, in order to further promote the application of permeable concrete, domestic and foreign experts and scholars mainly explore the research direction of the comparison design method [5] [8], the mineral admixture content [9] and the use of other new materials, but Under the premise of the economy, the intensity of the research is less than 30 MPa, and the factors affecting the strength from the microscopic point of view are rare. At present, permeable concrete is restricted in the promotion and application [2-3], mainly
because its compressive strength is restricted by water permeability and porosity, so it is necessary to continue to optimize the compressive strength under the premise that the water permeability meets the engineering application. the study. In this paper, C30 permeable concrete was prepared by experimental research on mixing method, molding method, curing method and water-cement ratio.

2. Experiment

2.1 Raw material

(1) Cement: This test uses 42.5 ordinary Portland cement provided by Jiangsu Helin Cement Co., Ltd. The basic performance indicators are shown in Table 1.1.

| density (g/cm³) | Setting time/min | Flexural strength/MPa | Compressive strength/MPa |
|----------------|-----------------|----------------------|--------------------------|
| Initial condensation | Final condensation | 3d | 28d | 3d | 28d |
| 3.10 | 185 | 250 | 3d | 28d | 3d | 28d |

(2) Basalt gravel: In this study, the coarse aggregate is made of 5mm-12mm and 12mm-16mm particle size grade limestone (the mass ratio of the two particle sizes is 7:3).

| Particle size (mm) | Bulk density (kg/m³) | Apparent density (kg/m³) | Void ratio (%) |
|--------------------|----------------------|--------------------------|---------------|
| 5-12               | 1568                 | 2685                     | 41.60         |
| 12-16              | 1483                 | 2838                     | 47.74         |

(3) Admixture: Jiangsu Subote's polycarboxylate superplasticizer with non-air-inducing, super-plasticizing, high-efficiency water reduction and enhancement.

(4) Water: ordinary tap water.

2.2 Test block preparation and maintenance

2.2.1 Mix ratio design

According to the CJJ/T 135-2009 "Technical Regulations for Pervious Cement Concrete Pavement", the volume ratio method is used to design the mix ratio. When the slurry falls too much under vibration or can not evenly wrap the aggregate surface, adjust the water permeable cement. The amount of concrete slurry or the amount of admixture can be used to determine the reference mix ratio for the permeable cement concrete strength test. In the strength test of permeable cement concrete, three different mixing ratios are selected, one of which is the reference mixture ratio, and the water-gluing ratio of the other two mixing ratios is increased or decreased by 0.05 compared with the reference water-to-binder ratio, and the water and aggregate are combined with the reference ratio.

The benchmark mix ratio used in this paper is 0.25, and the target porosity is 15%. The three combinations of the trial are as follows:

| Serial number | Water cement ratio | Coarse aggregate/kg | Cement/kg | Water/kg | Water reducing agent/kg |
|---------------|--------------------|---------------------|-----------|----------|------------------------|
| P-1           | 0.30               | 1076+461            | 447       | 121      | 4                      |
| P-2           | 0.25               | 1076+461            | 486       | 121      | 4                      |
| P-3           | 0.20               | 1076+461            | 532       | 121      | 4                      |

2.2.2 Stirring method

In order to explore the effect of the mixing process on the performance of permeable concrete, two mixing methods were used in this study:
One is a feeding method. The cement, stone, water and water reducing agent are added together, and the mixture is stirred for 180s in a blender, and then discharged into a 150mm×150mm×150mm test mold. The other is cement stone method, that is, the stone and 50% water are added to stir for 60s, then the gelling material is added for 60s, and finally the water reducing agent and the remaining 50% water are added for 60s and then discharged.

2.2.3 Forming method

At present, the common molding methods for permeable concrete include static pressure forming, vibration forming, insert molding, and compact molding. Combined with the actual construction considerations, the plugging method and the static pressure forming method are not suitable for large-area construction. Therefore, this paper mainly studies two methods of vibration molding and compaction molding. The vibration molding is to divide the concrete mixture into two layers. In the 150mm × 150mm × 150mm test mode, each layer on the vibrating table vibrates for 3s, 5s, 7s, respectively, for a total of 6s, 10s, 14s, and finally compacted and smoothed the surface of the test piece with a spatula; In the molding, the concrete mixture is divided into three layers into 150mm × 150mm × 150mm test molds, each layer is manually compacted 5 times, 8 times, 11 times, totaling 15 times, 24 times, 33 times. The compacting tool is a self-made tool that welds two iron plates up and down. One of the outstanding highlights of this paper is to eliminate the individual differences by controlling the vibration time and the number of times of compaction to determine the quality of the mold.

2.2.4 Maintenance methods

Commonly used conservation methods include natural conservation, standard maintenance, and water conservation. Due to the large number of through pores in the permeable concrete, it is easy to lose water during the condensation process. Natural maintenance and standard curing are difficult to meet the requirements. Therefore, this experiment explored the effects of two methods of moisturizing and maintenance methods on the physical and mechanical properties of permeable concrete. This paper explores the effects of two curing methods on the physical and mechanical properties of permeable concrete. The moisturizing maintenance means that the test piece is covered with a plastic wrap film immediately after the mold is placed, and placed in a curing room with a temperature of 20±2°C and a relative humidity of 95% or more. After 48 hours, the mold is removed and the mold is placed and maintained. Moisturizing and curing in the room until the 28d curing age is satisfied; the water curing means that the test piece should be covered with the cling film immediately after the mold is placed, and placed in a curing room with a temperature of 20±2°C and a relative humidity of 95% or more. After 24 hours, the mold was removed and placed in a curing tank at a temperature of 20 ± 2 °C.

2.3 Physical and mechanical indicators test method

(1). Porosity determination

The test piece was immersed in water for 24 hours, and the mass m1 of the test piece was measured in water, and then the test piece was air-dried for 24 hours, and the mass m2 was measured, and the porosity P of the permeable concrete was calculated according to the formula (1).

$$ P = \left(1 - \frac{m_2 - m_1}{\rho_w V_0}\right) \times 100\% $$

Where: $V_0$—the volume of the test piece, $\rho_w$ - the density of water.

(2). Permeability coefficient

The permeability coefficient of the permeable concrete is measured in accordance with JIS A 1218 "Soil Permeability Test", which is based on Darcy's law, and the test apparatus is shown in Fig. 1. The water permeability coefficient can be calculated according to (2):
Fig. 1  test device for permeability coefficient

1—water supply system; 2—cylinder overflow port; 3—water cylinder; 4—overflow trough; 5—sink overflow port; 6—stent; 7—sample; 8—measuring cylinder; 9—Water level difference

\[ K = \frac{QL}{A\Delta h t} \]  

Where: Q - the amount of water oozing out in time t seconds (cm³); T—infiltration time (s); \( \Delta h \)—the head difference of the pressure measuring tube (cm); L—the length of the percolation (cm); A—The cross-sectional area (cm²) of the test piece.

(3).SEM and XRD microscopic testing

Microscopic analysis of the permeable concrete hardened specimens were selected from the fractured samples after the strength test (mainly selecting the cementation interface between the stone and the cementitious material), some of the samples were ground into powder, and all the samples were first stopped with absolute ethanol. The sample was dried to a constant weight in a vacuum oven at 50 °C before the experiment. The phase composition of the permeable concrete samples was measured by D-max-RB X-ray diffraction (XRD) instrument. The morphology and energy spectrum analysis of the hydrated concrete hydration products were observed by QUANTA200 environmental scanning electron microscope produced by FEI Company.

3. Test results and analysis

In this test, the cement slurry can be evenly wrapped around the surface of the aggregate without the slurry to obtain the reference water-to-binder ratio; then the relationship between the strength, porosity and permeability coefficient of the pervious concrete obtained from the three kinds of trial mix ratio is determined. The water-to-binder ratio; and the amount of cement and water is determined accordingly to determine the optimum mix ratio. By using the best mix ratio, the effects of different mixing methods, forming methods and curing methods on the performance of permeable concrete were explored; finally, the permeable concrete with strength above 30Mpa was prepared.

3.1 The best mix ratio is determined

In the process of determining the best fit, the test is carried out by the method of mixing the cement stone [6], the molding method of manual compaction [7], and moisturizing maintenance. The results are shown in Table 4.

Table 4  physical and mechanical properties of permeable concrete with different water cement ratio

| Serial number | Water cement ratio | Porosity/% | Water permeability coefficient/mm·s⁻¹ | 7-day compressive strength/MPa | 28-day compressive strength/MPa |
|---------------|--------------------|------------|--------------------------------------|-------------------------------|-------------------------------|
| P-1           | 0.30               | 24         | 6.012                                | 7.8                          | 13.0                          |
| P-2           | 0.25               | 27         | 6.478                                | 10.3                         | 16.6                          |
| P-3           | 0.20               | 26         | 6.267                                | 12.5                         | 19.2                          |
By comparison, it can be found that in the case of the same stirring mode, forming mode and curing mode, increasing the amount of cement can increase the thickness of the cement layer wrapped around the aggregate, thereby forming a good interface bonding state, and between the aggregates in the concrete unit volume. The number of bonding points is increased, thereby effectively improving the strength of the permeable concrete. Through data analysis, in the above-mentioned trial mix ratio, when the actual water-to-binder ratio is 0.23, the strength and porosity can achieve better results. Therefore, we determined that the P-3 mix ratio is the best mix ratio, as shown in Table 5:

| Water cement ratio | Coarse aggregate/kg | cement/kg | water/kg | Water reducing agent/kg |
|--------------------|---------------------|-----------|----------|-------------------------|
| 0.23               | 1076+461            | 532       | 121      | 4                       |

3.2 Effect of mixing method on the performance of permeable concrete

The mixing method has an effect on the strength, water permeability and porosity of the permeable concrete. The results are shown in Table 6:

| Serial number | Porosity /% | Water permeability coefficient/mm·s⁻¹ | 7-day compressive strength/MPa | 28-day compressive strength/MPa |
|---------------|-------------|--------------------------------------|--------------------------------|---------------------------------|
| Cement stone  | 13.0        | 2.95                                 | 21.8                           | 29.8                            |
| One shot      | 13.9        | 3.01                                 | 15.6                           | 21.4                            |

The cement stone method firstly uses a part of the mixing water to wash the coarse aggregate, so that the surface of the coarse aggregate will produce a full range of van der Waals force, and then the aggregate is used to hit the cement, so that the fully dispersed cement particles are uniformly adsorbed in the cement. The surface, and thus the cement slurry on the cemented interface and the aggregate produce a strong and uniform adhesion, so that the forces between the particles constituting the mixture are fully exerted. The one-time feeding method has a more obvious defect. After all the cementing materials, aggregates and water are added to the mixer, the cement can easily form small cement agglomerates when the water is in contact with water. The smaller the water-to-binder ratio, the more obvious the condition of the agglomeration. These small cement agglomerates are attached to the coarse aggregate. When the coarse aggregate has a large particle size, some of the small cement agglomerates cannot be broken after the end of the mixing. After the hardening, the cement will fill the voids of the aggregate. This results in a decrease in the strength of the concrete. This situation is easy to occur considering that the ratio of water to cement in this test mixture is not large. On the other hand, from the test results, we can find that the water permeability coefficients of the two mixing methods meet the specifications. However, the cement-coated stone method can enhance the bonding of the interface, and the porosity and permeability coefficient of the permeable concrete are relatively large. It can be seen that the cement-coated stone method can improve the water permeability of the permeable concrete.

3.3 Influence of molding method on the performance of permeable concrete

In this group of experiments, the mixing method of cement-coated stone, standard curing method, vibration molding and manual compaction molding were used. It was found that the molding method had an effect on the strength, permeability coefficient and porosity of the permeable concrete. The results are as follows Table 7 shows.

| Serial number | Porosity /% | Water permeability coefficient/mm·s⁻¹ | 7-day compressive strength/MPa | 28-day compressive strength/MPa |
|---------------|-------------|--------------------------------------|--------------------------------|---------------------------------|
| Vibration 6s  | 0.204       | 5.762                                | 12.2                           | 16.7                            |
| Vibration 10s | 0.153       | 3.561                                | 17.8                           | 25.9                            |
| Vibration 14s | 0.078       | 0.932                                | 25.1                           | 35.8                            |
| Compacted15times | 0.223   | 6.012                                | 14.0                           | 18.6                            |
| Compacted24times | 0.159   | 3.353                                | 18.7                           | 26.4                            |
| Compacted33times | 0.107   | 1.531                                | 16.3                           | 22.7                            |
In this test, three sets of vibration molding were set. Through experimental comparison, we can find that the longer the vibration, the greater the compressive strength. However, the vibration time should not be too long. We can observe that when the vibration is 14s, the bottom of the test piece will appear to be thickened. This is the typical "upper slurry is rare, the lower slurry is piled up", as shown in Figure 2, which also means concrete. When stressed, the upper weak part is easily destroyed. Therefore, in order to make the water permeability and strength of the permeable concrete high, the vibration molding time should be controlled between 8-12 s.

![Fig. 2](a) a normal test block ![Fig. 2](b) a heavy pulp block

Fig. 2 the bottom surface of normal test block and heavy pulp block.

On the surface, no solidification occurred in the three sets of compacted test pieces. By analyzing the experimental data, it can be seen that the compressive strength increases with the increase of the number of times of compaction, but we find that the compressive strength of 33 times of compaction is less than the compressive strength of 24 times of compaction, which is due to the number of times of compaction. To a certain extent, the bonding layer on the surface of the permeable concrete particles will be destroyed, and the cement slurry of the bonding layer will be reduced, resulting in a decrease in the strength of the test piece. This also shows from the side that there is an optimal number of hits to achieve higher strength.

When the quality is similar, the strength of the compaction molding is slightly higher than that of the artificially compacted 24 times by the data analysis, and the sedimentation phenomenon does not occur due to the compaction molding, and the water permeability and mechanical properties of the permeable concrete are more easily realized. Coordination, the author believes that the manual method of 24 times of artificial compaction is more reasonable.

3.4 Effect of curing methods on the performance of permeable concrete

The test block of this group adopts cement stone mixing method and compacts 24 times. It adopts two different methods of moisturizing and water conservation. It is found that the curing method has influence on the strength, permeability coefficient and porosity of the permeable concrete. The results are shown in Table 8.

| Serial number | Moisturizing and curing | Water conservation | | Porosity/ % | Water permeability coefficient/mm·s⁻¹ | 7-day compressive strength/MPa | 28-day compressive strength/MPa |
|---------------|-------------------------|------------------|---|----------|------------------|----------------|------------------|
| Moisturizing and curing | 0.15 3 | 3.61 | 21.4 | 30.24 |
| Water conservation | 0.15 7 | 3.69 | 22.3 | 27.91 |

Analysis of the 7-day compressive strength, we found that the strength of the concrete test block under the curing condition in water is higher than the strength of the concrete test block under the moisturizing curing condition. The author believes that this is because at the beginning, the hydration reaction inside the concrete occurs, and the test piece is lacking inside. Water, while curing in water can create better temperature and humidity conditions, can better provide the water needed for cement hydration, and then with the increase of age, the compressive strength increases gradually, until 28d,
cement. The hydration reaction also tends to be flat, and the strength of the concrete under moisturizing is gradually closer to the strength of the concrete being cured in the water.

3.5 Microscopic analysis

(1) SEM-EDS

![SEM images of hydration reaction of pervious concrete at different ages](image)

*Fig. 3* SEM images of hydration reaction of pervious concrete at different ages

We can know that the main hydration products of ordinary Portland cement are a large amount of amorphous hydrated calcium silicate, calcium hydrated calcium aluminate gel (CSH, CAH) and a small amount of lamellar calcium hydroxide (CH) crystals, a small amount. Columnar ettringite (AFt), irregular petal-like hydrated calcium sulfoaluminate (AFm), etc. [12]. Figure 3 (a), (b), SEM image measured for the test block moisturizing 7d and 28d. The cross section of the 7d sample is shown in (a). The crystals in the figure are columnar and lamellar, and the distribution is relatively loose and the degree of crystallization is low. The 28d sample section is shown in (b). The figure is filled with amorphous crystals. Although it is also disorderly arranged, its crystals are full and the degree of crystallization is relatively high. Combined with EDS analysis, the crystals contain Ca, Si, Al, O and H elements. The atomic percentages of Al and Si are similar. It can be seen that the crystals should be C-S-H and C-A-H. However, the percentage of C-S-H atoms in (b) is significantly larger than in (a), which indicates that the hydration reaction of permeable concrete continues to occur over time.

(2) XRD test

![XRD patterns of hydration reaction of pervious concrete at different ages](image)

*Fig. 4* XRD patterns of hydration reaction of pervious concrete at different ages

Figure 4 is an XRD pattern of the hardened body powder at 7d and 28d hydrated. The main characteristic peak positions of the two samples are basically the same, that is, the characteristic peaks of the main hydration products C-S-H and CH. We can also find samples at 39.42°. There is a main characteristic peak of SiO2 at 43.18°. There is a main characteristic peak of Al2O3. Compare 2 samples at 29.42°. The peak intensity of the C-S-H main characteristic peak is obviously different.
The peak intensity (176) of the C-S-H main characteristic peak of the 28d sample is significantly higher than that of the 7d sample, indicating that there is a new C-S-H crystal in the slurry.

4. Conclusion
(1) The permeable concrete has different physico-mechanical properties due to different mixing methods. The cement-coated stone method can uniformly disperse the fully dispersed cement particles on the surface of the aggregate, enhance the adhesion between the cement slurry and the aggregate, and greatly improve the strength of the test block.
(2) The permeable concrete has different physical and mechanical properties. The vibration molding time should be controlled at 8-12 s, the time is too long, and the phenomenon of sedimentation is prone to occur; while the time is too short, the porosity is too large, and the strength is low. For the compaction molding method, as the number of times of compaction increases, the test block does not show a phenomenon of sedimentation, and the strength first increases and then decreases, and the best number of times of compaction is 24 times.
(3) The permeable concrete has different physical and mechanical properties. The 7-day compressive strength of the permeable concrete under water curing conditions is higher than that of the permeable concrete test block under moisturizing conditions; and for the 28-day compressive strength, the strength of the concrete under moisturizing is gradually close to the strength of the concrete cured in the water.
(4) By SEM scanning electron microscopy and XRD pattern analysis, we found that the 28d sample crystals are arranged more closely, the structural surface is more integrated, and the hydration product C-S-H is also more.

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