Study on mechanical properties of polymer pervious cement concrete

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Abstract. The effects of polymer type, polymer dosage, concrete dosage per unit volume and water content on compressive strength and permeability coefficient of polymer permeable cement concrete were studied through experiments. The results show that the addition of polymer can improve the compressive strength of permeable concrete and have a lower influence on the permeability coefficient. Meanwhile, the compressive strength of the polymer permeable concrete increases with the increase of age, and the permeability coefficient tends to be stable with the change of age.

1. Introduction

Pervious concrete is made of concrete of a honeycomb structure with a large number of penetrating pores between the aggregate skeleton, which is made of concrete of a specific grade of aggregate, cement, admixture and water in a specific proportion, without or containing a very small amount of fine aggregate. Generally, the permeability of permeable concrete is between 15% and 25%, mostly large pores with a diameter of more than 1 mm, and the permeability coefficient is 2-6 mm/s, up to 10 mm/s [1]. Due to its strong permeability, permeable concrete is widely used in drainage structures in roads, buildings [2], water conservancy and other fields. However, problems such as unstable permeability and low mechanical property generally exist.

Polymer pervious cement concrete is a pervious cement concrete containing organic polymer which is mixed with polymer in the mixing stage of cement concrete on the basis of ordinary pervious concrete. Compared with ordinary permeable concrete, the polymer can form a film with high adhesion between the cement slurry and the aggregate, and finally form a network structure in which the cement slurry and the polymer film are intertwined, thereby improving a series of the effect of ordinary permeable concrete performance, for example, improves the bondability between the cement paste and the aggregate, reduces the microcracks in the hardened cement paste, improves the compressive and flexural strength of the concrete, and, in addition, due to the excellent toughness of the polymer, combined with the pore structure of the permeable concrete, can make the polymer pavement surface layer have good shock absorption performance and sound absorption and noise reduction effect [3]. At the same time, it can also improve the fire endurance of a structure [4]. However, at present, there are few researches on the performance of polymer permeable cement concrete in China, and there are relatively few practical engineering applications. Therefore, it is necessary to carry out comparative systematic and in-depth research. Therefore, the choice of raw materials for the test, mainly coarse aggregate type, particle size, polymer powder properties.
In this paper, the compressive strength and permeability coefficient test of polymer permeable concrete was carried out to study the effects of polymer type, dosage, cement dosage and water-cement ratio on the mechanical properties and permeability of polymer permeable concrete, providing a basis for the preparation of polymer permeable cement concrete with good permeability and mechanical properties in engineering.

2. Materials and methods
Pervious polymer concrete is a kind of porous concrete material, which is made of coarse aggregate, polymer cementing material, and water.

2.1. Materials

2.1.1. Coarse aggregate. According to Technical specification for pervious cement concrete pavement (CJJ/t135-2009)[5], aggregates used in pervious cement concrete must be made of hard, durable, clean and confined crushed stone. The performance index of gravel shall meet the secondary requirements in GB/T 14685 of the current national standard [6] and comply with the provisions in Table 1.

| Measurement unit | 1     | 2     | 3     |
|------------------|-------|-------|-------|
| size (mm)        | 2.4-4.75 | 4.75-9.5 | 9.5-13.2 |

The stone used in this test is gravel, and the stone size is 4.75-9.5mm. As shown in Figure 1. The bulk density is 1.56 g/cm³, and the apparent density is 2.86 g/cm³.

2.1.2. Polymer adhesive. The polymer adhesive used in polymer permeable concrete should have the characteristics of high physical strength, moderate curing speed and low curing shrinkage. Considering the economic cost, it should also consider its environmental protection [7]. Refer to the existing literature, select 3 kinds of adhesives commonly used in polymer permeable concrete: butyl styrene emulsion, polyvinyl alcohol produced by Beijing Mengtai Weiye Building Materials Co., Ltd., polymer cemented powder produced by Shandong Sanken Co., Ltd., as shown in Figure 2.
2.1.3. **Water.** The water used in the test was ordinary tap water, and the water temperature was around 20 °C.

2.1.4. **Cement.** The cement used in the test was Jin Yu P. O. 42.5 ordinary Portland cement with a density of 3.10 g/cm³.

![Image of polymer types](image1)

**Figure 2.** Polymer type.

2.2. **Test plan**

In this test, four influencing factors were considered: polymer type, polymer content, concrete volume per unit volume and amount of water. The tests were carried out in groups A and B. Porosity of pervious concrete is usually 15% - 25%. According to the requirements of the project, the target porosity is set at 18%. Mix ratio calculation refers to the calculation method in Technical specification of pervious cement concrete pavement. The water-cement ratio is 0.3 based on existing experience [8]. Among them, Group A conducts qualitative tests first, and completes the corresponding performance test of polymer permeable concrete. The mix ratio is adjusted based on the test of Group A, and the test of Group B is designed. The specific A group mix ratio design is shown in Table 2.

| Coarse aggregate (kg/m³) | Polymer type                        | Polymer content (kg/m³) | Water cement ratio | Cement (kg/m³) | Water (g/m³) | Target porosity |
|--------------------------|-------------------------------------|-------------------------|--------------------|----------------|--------------|-----------------|
| A1 1531                  | butyl styrene emulsion              | 60                      | 0.3                | 329            | 81.6         | 18%             |
| A2 1531                  | polyvinyl alcohol                   | 10                      | 0.3                | 352            | 108.6        | 18%             |
| A3 1531                  | /                                   | /                       | 0.3                | 362            | 108.6        | 18%             |

2.3. **Experiment method**

Considering the particularity of the porous concrete structure, it is not necessary to use mechanical vibration to make the fresh concrete flow and compact like ordinary concrete. This fitting experiment was carried out by manual insertion molding. The compressive strength of the test piece is referred to GB/T50081-2002 "Standards for Test Methods for Mechanical Properties of Ordinary Concrete" [9]. Compression test piece size is 100mm × 100mm × 100mm, the three test block is a set, and average the results. The test of the water permeability coefficient of the polymer permeable concrete is carried out according to Appendix A of the Technical Specification for Application of Pervious Cement Concrete Pavement (CJJ/T135-2009). The test piece is a cylindrical test piece with a diameter of 100 mm and a height of 50 mm, which is molded by a mold [10]. The experiment device is shown in Figure 3. The three block is a set, and the result takes the average.
The water permeability coefficient is calculated as follows:

\[ k_T = \frac{QL}{AHt} \]  

In the formula: 
- \( k_T \) — Water permeability coefficient of sample when water temperature is \( T \) °C (mm/s); 
- \( Q \) — The amount of water seeping out in \( t \) seconds (mm³); 
- \( L \) — Thickness of the sample (mm); 
- \( A \) — The surface area of the sample (mm²); 
- \( H \) — Water level difference (mm); 
- \( t \) — Time (s).

The test results are expressed as the average of 3 samples, and the calculation is accurate to 0.01 mm/s.

3. Test results and analysis

It can be seen from the results of Table 3 and Figure 4 that the compressive strength of polymer permeable concrete of different polymer adhesive types is styrene-butadiene emulsion > polyvinyl alcohol. It can be seen from the A3 control group that the incorporation of polymer has significant compressive strength to permeable concrete, permeable coefficient also has a certain degree of improvement, the size of the slump is not mixed with polymer > polyvinyl alcohol > styrene-butadiene emulsion, indicating that the incorporation of the polymer can improve the adhesion of the permeable concrete mixture to a certain extent. For the analysis of macroscopic reasons, the addition of polymer emulsion improves the working performance of freshly mixed concrete. The polymer slurry coats the aggregate evenly and increases the bond between the aggregates, while the mud and the aggregate form a higher viscosity. The film of the force builds up the bond and eventually increases the compressive strength of the concrete.

| Table 3. Group A polymer permeable concrete test results. |
|----------------------------------------------------------|
| 28d Compressive strength(MPa) | permeability coefficient(mm/s) | slump(mm) |
| A1(butyl styrene emulsion) | 20.76 | 0.54 | 150 |
| A2(polyvinyl alcohol) | 19.8 | 0.43 | 160 |
| A3(no polymer addition) | 15.4 | 0.36 | 184 |
The addition of polymer has no significant effect on the water permeability coefficient of the permeable concrete. With the addition of the polymer, the permeability coefficient can only be increased by about 0.2 mm/s [11]. However, the water permeability coefficient is affected by the type of polymer at the same time, and the value of the water permeability coefficient varies depending on the type of polymer. It can be seen from the test results that the permeability coefficient of the polymer-pervious concrete styrene-butadiene emulsion group with the same polymer content is higher than that of the polyvinyl alcohol group, indicating that different polymer types have an influence on the performance of the polymer-permeable concrete, so it is superior. According to the results of the qualitative test of Group A, the test of Group B was re-customized and the test of polymer cement powder was added. The specific test mix ratio is shown in the following Table 4.

**Table 4.** Group B polymer permeable concrete test mix ratio.

| Coarse aggregate (kg/m³) | Polymer type                  | Polymer content (kg/m³) | Water cement ratio | Cement (kg/m³) | Water (kg/m³) | Target porosity |
|--------------------------|-------------------------------|-------------------------|--------------------|----------------|--------------|-----------------|
| B1 1531                  | butyl styrene emulsion        | 40                      | 0.3                | 394.5          | 102.8        | 18%             |
| B2 1531                  | polyvinyl alcohol             | 15                      | 0.3                | 401.5          | 120.8        | 18%             |
| B3 1531                  | polymer cemented powder       | 15                      | 0.3                | 401.5          | 120.8        | 18%             |
From the results of Figure 5. (a), the permeable concrete mixed with the same quality of polymer cemented powder and polyvinyl alcohol 28 d compressive strength of concrete were 35.36 MPa and 27.69 MPa. Respectively, the 28d permeable coefficient is 3.26 mm/s and 3.35mm/s. Comprehensive consideration, from the point of view of compressive strength, the polymer cemented powder has higher compressive strength, and the water permeability coefficient meets the requirements of the specification, the polymer cemented powder is slightly lower than the polyvinyl alcohol.

Considering the economic performance, the polymer cement powder should be used as the polymer admixture in the polymer permeable concrete.

By comparing the relationship between 7d and 28d compressive strength, the development law of compressive strength of polymer pervious concrete is different from that of ordinary silicate concrete. The early strength increases rapidly, and the growth is slow after 7d, and the compressive strength after curing to 7d reaches about 70% -80% of the curing strength of 28d. This is also in line with the existing research on polymer permeable concrete [12]. The effect of curing time on the permeability coefficient varies according to different polymers. The permeability coefficient of styrene-butadiene emulsion and polyvinyl alcohol decreased at 28d, and the permeability coefficient of polymer cemented powder 28 increased compared with 7d. This indicates that the permeability coefficient of polymer permeable concrete will change with age, and the stability of the permeability coefficient of polymer permeable concrete needs further research [13].

4. Conclusions
Through experiments, different types of polymers were compared and analyzed, and the corresponding mechanical properties and permeability properties were analyzed. The results were processed and the following conclusions were obtained.

1) Through the test comparison and combined with the existing experience, the water-permeable polymer concrete with compressive strength greater than 30Mpa and water permeability coefficient greater than 1 mm/s was obtained. And the best polymer admixture is a polymer cement produced by Shandong Sanyao Company.

2) In terms of strength, the superiority of permeable polymer concrete is mainly manifested in the early development of strength, which can reach 70% of 28 days in 7 days. Permeable polymer
concrete has a relatively high compressive strength relative to ordinary concrete. The compressive strength of polymer permeable concrete increases with age.

3) The type of polymer adhesive has little effect on the water permeability coefficient of polymer permeable concrete. Different adhesive types have a great influence on the mechanical properties of permeable concrete.

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