Experimental study on the performance of pervious concrete

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Abstract. With the construction of sponge city, the pervious concrete material has been developed rapidly. A high-performance pervious concrete is developed by using cement, silica fume (SF) and superplasticizer (SP). The effects of SF, SP, aggregate size, water-cement ration and aggregate-cement ratio on the permeability coefficient, compressive strength and flexural strength are studied by controlling variables, and exploring the corrosion resistance and abrasion resistance of pervious concrete. The results show that using 0.5% SP, 5% SF and small aggregate can greatly improve the strength. There is an optimum value for water-cement ratio to make the strength and permeability coefficient maximum. Compared to ordinary pervious concrete, the corrosion resistance and abrasion resistance of this pervious concrete are very good.

1. Introduction
With rapid development of economy, the step of urbanization has been quickened continuously to make land disappear. The hardened pavement paved by impervious materials such as marble, cement and asphalt is all over the city. This has changed the natural permeability of soil, and results in a range of environmental problems, such as the major water pollution in Songhua River in 2005. Due to the shortcomings of the traditional urban construction mode, Environmental Resources Agency of US proposes Low Impact Development (LID) technology in the end of 1990. After 20 years of development, LID widely used in US, New Zealand, Australia and Germany. Based on the study of LID, Xi Jinping clearly puts forward the construction of sponge city with natural accumulation, natural infiltration, and natural purification in December 2013. In October 2014, the Ministry of Housing and Urban-Rural Construction of the People's Republic of China launches the Sponge City Construction Technology Guide.

The pervious concrete material, which is born in 1852, has become one of basic materials for construction of ecological city under the guidance of sustainable development. Pervious concrete material has many advantages, such as high porosity, high permeability, high heat sink, noise absorption, and mitigation of urban heat island effect. In the 1960s, the US begins to study the performance of pervious concrete, and develops a pervious concrete that its compressive strength can reach 28 MPa in 1979; Japan sets up the Ecological Concrete Research Committee and makes a large number of research results; In France, 60% tennis courts are constructed by pervious concrete. In domestic, Chang'an University has conducted a series of studies on the physical, mechanical performance and pavement performance of pervious concrete to obtain certain rich results. Although there have been some preliminary results in China, the basic research on the pervious concrete and ecological environmental benefits are still insufficient, especially resistance erosion and abrasion resistance of pervious concrete, and the unified standard is not formed. In this paper, the abrasion
resistance and coefficient of resistance erosion of Na$_2$SO$_4$ solution and NaCl solution of pervious concrete are studied on the basis of studying the influence of various design factors on strength and permeability coefficient.

2. Test materials and methods

2.1. Materials
The experiment uses Portland cement, aggregate, silica fume (SF), superplasticizer (SP).

2.2. Preparation and Maintenance of pervious concrete
The HJW-60 mixer is used to prepare concrete. Preparation process of pervious concrete are as follows. ① Test materials are ready. ② First aggregate and 70% water are added to mix for 1 min, then admixture and 50% cementing material are added to mix for 1 min.③ Remaining cementing material and water are added to mix for 2 min. ④ The pervious concrete is molded by compaction method and vibrate method. ⑤ Conservation: Standard curing is used in test, temperature is 20 ± 1 ℃, and relative humidity is 95%. After one day, the specimen is removed from the mold and put into a curing room for certain age.

![Fig.1 The specimen of pervious concrete](image)

2.3. Permeability coefficient test method
Refers to GB/T 50123-1999, permeability coefficient is tested with constant head penetration. The test steps are as follows: ① The specimen with height of 15cm in a cylinder ($\phi_{1cm}$) is molded. ② Before the test, the seam between the specimen and device is sealed with Vaseline. ③ When the water discharged from the outlet pipe are stable, the total amount of water discharged is measured in the $t$ time.④ The permeability coefficient of pervious concrete is calculated by the formula 1.

$$k_T = \frac{Qh}{HAt}$$ ①

Which $k_T$ is the permeability coefficient (mm/s); $Q$ is the water quantity (mm$^3$) in the $t$ time; $h$ is the specimen height (mm); $H$ is the mean water level difference (mm); $A$ is the specimen sectional area (mm$^2$); $t$ is time (s).

3. Results and discussion

3.1. The strength and permeability coefficient of pervious concrete

3.1.1. The effect of SF and SP on pervious concrete. The results are shown in Table 1, the aggregate with the diameter of 4.75mm–9.5mm and aggregate-cement ratio with 4:1 are used to study the effect of SF and SP on the performance of pervious concrete. It can be seen from the table that when the compressive strength and flexural strength of pervious concrete with 5% SF is obviously improved compared with the pervious concrete without SF. When 0.5% SP or more water is added into the pervious concrete with 5% SF, the strength of pervious concrete can be continued to increase, in particular the compressive strength of the pervious concrete reached 32.1MPa and the flexural strength reached 4.5MPa with 0.5% SP and 5% SF. However, when the percentage of SF is increased to 10%,...
its strength instead appears to decrease. This is due to the addition of SF and SP. SP can increase the fluidity of cement, SF can improve microstructure of hardened cement paste by filling the hardened holes of cement paste and react with the cement. The more evenly distributed of SF in the cement, the better the pervious concrete performance. However, it should be noted that the excessive percentage of SF will reduce the amount of cement, it is not conducive to the improve performance of pervious concrete.

### Table 1. The effect of SF and SP on the performance of pervious concrete

| Aggregate size | W/C | Percentage of SF/% | Percentage of SP/% | 28d-Compressive strength (MPa) | 28d-Flexural strength (MPa) | 28d-Permeability coefficient (mm/s) |
|----------------|-----|--------------------|--------------------|-------------------------------|-----------------------------|-----------------------------------|
| 4.75–9.5mm     | 0.25| 0                  | 0                  | 13.3                          | 2.2                         | 0.8                               |
| ~              | 0.28| 5                  | 0                  | 18.1                          | 3.1                         | 0.72                              |
| 9.5mm          | 0.28| 5                  | 0.5                | 23.0                          | 3.6                         | 0.90                              |
|                | 0.28| 10                 | 0.5                | 32.1                          | 4.5                         | 0.95                              |

#### 3.1.2. The effect of aggregate size on pervious concrete.

As shown in Table 2, different sizes of the aggregate are used to the pervious concrete, and the water-cement ratio is 0.28 and aggregate-cement ratio is 4.5:1. The compressive strength, flexural strength, and permeability coefficient of the pervious concrete are measured. It can be seen from the table that the aggregate size has a significant influence on the strength of pervious concrete, but little influence on the permeability coefficient. This is because that when the aggregate size reduces, its specific surface area increases, so the contact points between the aggregates increase, this makes the strength of concrete improve. The pores of pervious concrete with small aggregate is small, but the number of pore is large. The pores of pervious concrete with large aggregate is large, but the number of pore is small. On the other hand, their porosity is similar, so the permeability coefficient of pervious concrete prepared by different aggregate size did not change significantly.

### Table 2. The influence of aggregate size on performance of pervious concrete

| Aggregate size /mm | W/C | 28d-Compressive strength (MPa) | 28d-Flexural strength (MPa) | 28d-Permeability coefficient (mm/s) |
|--------------------|-----|-------------------------------|-----------------------------|-----------------------------------|
| 4.75–9.5           | 0.28| 25.6                          | 28.7                        | 3.4                               | 4.0                             | 2.52                             |
| 9.5–16             | 0.28| 20.3                          | 23.2                        | 2.8                               | 3.1                             | 2.59                             |
| 16–19              | 0.28| 15.5                          | 17.5                        | 2.0                               | 2.24                            | 2.64                             |

#### 3.1.3. The effect of water-cement ration (W/C) on pervious concrete.

As shown in Fig 2, the aggregate with the diameter of 4.75mm–9.5mm and aggregate-cement ratio with 4.5:1 are used to study the effect of water-cement ration on the performance of pervious concrete. From the figure, when water-cement ratio is less than 0.28, the compressive strength, flexural strength and permeability coefficient increase, and when water-cement ration is greater than 0.28, they begin to decrease. The reason is that when water-cement ration is relatively low, cementitious material are not adequately hydrated to cause the poor fluidity, this is not conducive to the increase of effective pores. However, when water-cement ratio is large, fluidity of cementitious material is large, this makes cementitious material gather at the bottom of structure under the action of gravity to cause uneven distribution and the effective porosity decrease, so that the compressive strength, flexural strength and permeability coefficient become decline.
3.1.4. The effect of aggregate-cement ratio on pervious concrete. The effect of different aggregate-cement ratio on the performance of pervious concrete is studied, two different sizes of the aggregate are used for pervious concrete, and the results are shown in Fig.3. It is obvious that the compressive strength and flexural strength of pervious concrete reduce with the increase of aggregate-cement ratio. At same time, the increase of permeability coefficient conforms to the approximate exponential function with increase of aggregate-cement ratio. This is because that when the aggregate-cement ratio increase, the usage of cementitious materials will reduce, cementitious material thickness of aggregate surface is thinner, and adhesion force of aggregate is lower, the connected pores and pores size increase, the resistance to water is reduced, so the permeability coefficient rapid increase and the strength reduce.

3.2. Durability of pervious concrete

3.2.1 The corrosion resistance of pervious concrete. According to GBT 50082-2009, the corrosion resistance of pervious concrete under Na_2SO_4 solution and NaCl solution is tested. The aggregate size is 4.75mm–9.5mm and aggregate-cement ratio is 4.5:1 in the test. Ordinary pervious concrete is selected as the control test. The concentrations of SO_4^{2-} and Cl^- are 10%, the coefficient of erosion resistance is ratio that compressive strength of pervious concrete conserved by erosion solution and that by water. The results are shown in Fig.4.
It can be seen from the figure, with the increase of water-cement ratio, coefficient of resistance erosion is gradually increasing trend in the experimental group of pervious concrete, and the erosion resistance of SO\(_4^{2-}\) is basically greater than that Cl\(^-\). While ordinary pervious concrete is a decreasing trend with the increase of water-cement ratio, erosion resistance of Cl\(^-\) of ordinary pervious concrete is higher than that SO\(_4^{2-}\). In general, under the conditions of SO\(_4^{2-}\) and Cl\(^-\), the erosion resistance of pervious concrete in experimental group is larger than that ordinary pervious concrete.

![Fig.4 The corrosion resistance of pervious concrete](image)

**Fig.4** The corrosion resistance of pervious concrete

3.2.2. Abrasion resistance of pervious concrete. Referring to CJJ/T135-2009 and GB/T 129988-2009, a friction device is used to test abrasion resistance, the device is show in Fig. 5. The width of grind wheel is 70 mm, thickness is 200mm, and the wheel is turned with a rate of 75 rpm. Under the same conditions, ordinary pervious concrete is selected as a control. The results are shown in table.3.

From the table, when the water-cement ration is 0.28, the pervious concrete has a smaller wear length than that in water-cement ration with 0.25. Compared with ordinary pervious concrete and pervious concrete in experimental group, it can be seen that length of abrasion trace of pervious concrete in experimental group is smaller than that of ordinary pervious concrete. When water-cement ration is 0.28, length of abrasion trace of ordinary pervious concrete is 33mm, and e pervious concrete in experimental group is only 28mm.

![Fig.5 Sketch of friction device](image)

**Fig.5** Sketch of friction device (1. hopper, 2. adjustable valve, 3. specimen, 4. lock bolt, 5. steel wheel, 6. plummet, 7. specimen bracket, 8. abrasive collector).

![Table.3 The abrasion resistance of pervious concrete](image)

**Table.3** The abrasion resistance of pervious concrete

| Water-cement ration | Experimental pervious concrete | Ordinary pervious concrete |
|---------------------|--------------------------------|---------------------------|
| 0.25                | 32                             | 35                        |
| 0.28                | 28                             | 33                        |
4. Conclusion

1. Using 0.5%SP, 5%SF and small aggregate can greatly improve the strength of pervious concrete. However, excessive percentage of SF is not conducive to the improvement of strength.

2. Water-cement ration, aggregate-cement ratio and aggregate size have some influence on the strength and permeability coefficient of pervious concrete. There is an optimum value for water-cement ratio to make the strength and permeability coefficient maximum. Aggregate can significantly improve the strength of pervious concrete. Aggregate-cement ratio is small, the strength of pervious concrete is large, but the permeability coefficient is small.

3. It is found that the corrosion resistance and abrasion resistance of this pervious concrete are very good than ordinary pervious concrete, and corrosion resistance of sulfate of this pervious concrete is greater than corrosion resistance on chloride.

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