Research on the anti-Plugging Property of Permeable Concrete Pavement

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Abstract. Permeable concrete pavement is a kind of porous road, which can allow rainwater to penetrate into the ground and maintain the recyclability of water resources. However, with constantly using, its voids may be blocked with the impurities in the rainwater, such as leaves, silt, etc. If that happens, the permeable function of the permeable concrete pavement will be affected. In this paper, the different structure of the permeable concrete pavement is studied, including the variation trend of the coefficient of permeability in the simulated plugging and the recovery rate of the permeable concrete pavement after cleaning and dredging. The results show that the upper small size coarse aggregate (4.75 mm to 9.5 mm) structure of the porous concrete is conducive to filter out most of the impurities, and it will reinforce the resistance to blocking of permeable concrete. But, it is not easy to recover after blockage, if the upper small size coarse aggregate is too thick. The anti-blocking performance and post-blocking recovery rate of permeable concrete are better, when the upper layer thickness is 15 mm.

1 Introduction

With the promotion of urban construction, the proportion of impervious pavement has been rising constantly. Ordinary concrete pavement consists mainly of proportional cementitious materials (organic, inorganic and organic-inorganic combination), granular aggregate, water, chemical admixtures and mineral admixtures. Ordinary concrete pavement brings convenience to people, which has greatly improved people's living standard and production efficiency, however, [1] this kind of pavement is impervious, and surface flow is hard to penetrate, causing flooding in urban areas. Moreover, the air permeability of ordinary concrete pavement is poor, which is not convenient for heat exchange. When the sun irradiates the ground, the temperature of the earth will rise, and it will lead to urban heat island effect and urban environment deterioration.

Compared with ordinary concrete, the preparation of permeable concrete reduces or [2] avoids the use of fine aggregate, forming intercommunicating pore microstructure. The porous structure of permeable concrete makes the pavement have good permeable performance, and the rain can seep into the ground quickly, which can effectively reduce or eliminate flood disasters caused by urban rainstorms. However, the surface runoff produced by rainfall contains a large number of suspended particles that can flow into the porous structure of permeable concrete pavement along with the water continually, leading to the decrease of permeability, shortened service life of permeable concrete pavement and increasing the occurrence of flood and freeze-thaw disasters in cities. Several measures had been proposed such as infiltration, retention, storage, purification, usage and discharge, and these would guide the promotion of sponge city construction in future.

Compared with conventional concrete, the strength and structure performance of permeable concrete are more variable, which mainly depends on the porosity. According to some literatures, [3] the porosity factors of permeable concrete pavement usually vary among 15% to 25%, and the permeability coefficients mostly range from 2mm/s to 6mm/s, but some of them even reach 10mm/s. The pores in permeable concrete pavement can be blocked by suspended particles, such as sediment and debris in surface runoff produced by rainfall, leading to the reduction of permeability and shortened service life of permeable concrete pavement. Studies [4] have shown that the permeability coefficient of less than 15% of permeable concrete pavement is more than 50mm/h after running for 5-6 years without maintenance. This paper studies the attenuation laws of permeability coefficient for permeable concrete pavement under quickly plugging and slowly plugging, as well as recovery rate through high pressure gun. The results will provide theoretical basis for the design of permeable concrete pavement with anti-plugging property and promote the use of pervious concrete.

2 Materials and procedures

2.1 Materials

Cement: P.O 42.5 produced by Lafarge Cement. The physical performance of the cement used in this article is listed in Table 1.

Aggregate: Artificial broken pebbles with single grading size. The experiment has used two different sizes of coarse aggregate, and the physical performance of coarse aggregate is shown in Table 2.

Water: tap water in Chengdu.

Sand used for clogging: manufactured sand located at Chengdu, gradation: 0~0.15mm 、 0.15mm~0.3mm 、 0.3mm~0.6mm、0.6mm~1.18mm and 1.18mm~2.36mm.

2.2 Mixture proportion and specimen preparation

As is shown in Fig.1, two kinds of permeable concrete structure are studied in this paper, and the proportions of samples are listed in Table 3.

Table 1. Physical performance of cement.

Density （g/cm^3）	Specific area （m^2/kg）	Setting time （min）		Compressive strength （MPa）		Flexural strength （MPa）	
		Initial setting	*Final setting*	*3d*	*28d*	*3d*	*28d*
3.11	374	145	540	27.4	48.9	5.6	8.1

Table 2. Physical performance of coarse aggregate.

Particle size （mm）	Apparent density （kg/m^3）	Packing density （kg/m^3）
4.75-9.5	2710	1700
9.5-16	2690	1700

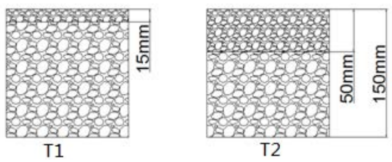

Fig. 1. Structures of permeable concrete pavement.

Table 3. Proportions of permeable concrete samples.

sample	cement （kg）	Coarse aggregate (kg)	Water to binder ratio	Size of aggregate (mm)	Upper crushing pebble thickness(mm)
T1	400	1700	0.28	4.74-9.5 /9.5-16.0	15
T2	400	1700	0.28	4.74-9.5 /9.5-16.0	50

According to literatures, [5] 7 mix proportions of plugging materials are designed in the experiment， as is shown in table 4. A special device is used to test the permeability coefficient, as is shown in Figure.3. The water head height in this device is set to 150mm. After the flow is stable, adding respectively the 7 mix proportions of plugging materials designed to 7 corresponding permeable concrete pavements samples made of the same batch, and reading the flow value every ten seconds to calculate the permeability coefficient in the following formula (1) [6-7], then potting the evolution of the permeable coefficient over time. The selection of the ideal plugging materials must consider that the results of the experiment should be evident and reasonable, so plugging materials sample 1 may be the optimal according to Fig.2. Therefore, sample 1 was used for the following quickly plugging and slowly plugging experiments.

Table 4. Plugging materials designed for permeable concrete pavement.

Sample	1.18-2.36mm(g)	0.6-1.18mm(g)	0.3-0.6mm(g)	0.15-0.3mm(g)	Under 0.15mm(g)
1	0	5	10	10	5
2	0	0	12.5	12.5	5
3	0	0	0	20	10
4	15	15	0	0	0
5	6	12	12	0	0
6	5	8	8	9	0
7	5	5	7	8	5

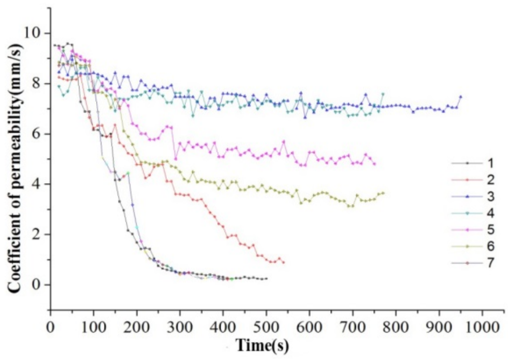

Fig. 2. Attenuation figure of permeability coefficient for permeable concrete pavement under different plugging materials.

2.3 Experiment

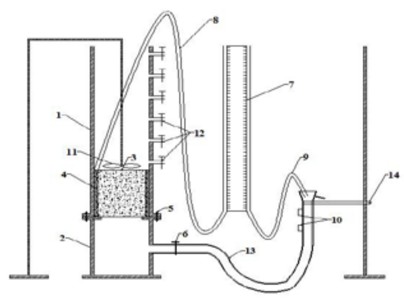

Fig. 3. Permeable coefficient measurement device.
1.Upper canister; 2.lower canister; 3.Permeable concrete pavement sample; 4.Silicone pad; 5.Bolt; 6.Valve; 7.Graduated scale; 8.Rubber hose; 9.Rubber hose; 10.Electromagnetic flow meter; 11.Propeller; 12.Valve; 13.Flexible hose; 14.Clamp.

As shown in Figure 3, a special device was made to order to test the permeability coefficient, which has been used in 2.2 above. This device includes a container, in that a permeable concrete block should be placed. The sand adder is scattered through the propeller (3). The water will enter the container through rubber hose (8), and then penetrates the preamble concrete into the cavity (2). Finally, it flows out of the container through flexible hose (13). The amount of water (Q) passed through the container in a certain time (t) can be known by the graduated scale (7). So the permeability coefficient (K_T) under a certain water pressure can be calculated by formula (1). And the water pressure can be adjusted by throttle valve (12).

$$k_T = \frac{QL}{AHt} \quad (1)$$

K_T-Permeability coefficient at T℃（mm/s）;

Q-The amount of water seeping out during time T (mm^3);

L-Thickness of the specimens (mm);

A-Above-mentioned area of the specimens (mm^2);

H- Water head (mm);

t- Time (s).

The porosity is a common index to evaluate the permeability of permeable concrete. And the initial porosity of permeable concrete pavement samples can be determined by the following equation [8-9]:

$$P = 1 - \left(\frac{(W_1 - W_2)}{V_1 \rho_w}\right) \times 100\% \quad (2)$$

W_1- Mass of samples after drying in 60℃ oven for 24 hours, kg;

W_2-Mass of samples after immersing in water for 24 hours, kg;

V_1- Value of samples, mm^3;

ρ_w-Density of water, kg/mm^3.

3 Results and analysis

3.1 Measurement of porosity of permeable concrete

The results of porosity test are shown in table 5. The porosity value of permeable concrete T1 is higher than that of permeable concrete T2, because of thicker bottom layer in permeable concrete T1.

Table 5. Measured porosity values of permeable concrete

Sample	Drying mass(kg)	Mass in water(kg)	Porosity (%)	Average value of porosity (%)
T1	6.868	4.215	21.40	20.675
	7.091	4.340	18.50	
	7.035	4.395	21.80	
	7.019	4.350	21.00	
T2	7.023	4.210	16.70	18.375
	7.047	4.295	18.50	
	7.006	4.270	18.90	
	7.120	4.400	19.40	

3.2 Slow plugging test of permeable concrete pavement

Plugging material Z1 was used in plugging test, adding 5g for the interval of 1h, and the water head was set to be 100mm, without stir, to simulate the process of plugging with low speed just as normal rainfall condition. It can be seen from Fig.4 that ladders appear in the evolution curve of the permeable coefficient during the interval of the addition of the clogging material. This phenomenon [10] can be attributed to that unsteady plugging material stuck in permeable concrete can be carried away by current, leading to a transient recovery of permeable coefficient. However, there is a limit to this recovery (Table 6).

3.3 Quickly plugging test of permeable concrete pavement

Plugging material Z2 was used in plugging test, adding 30g for the interval of 90s, and the water head is set to be 100mm, stir at the speed of 30r/min. a numerical value would be readied from the electromagnetic flow-meter to calculate the permeability(Table 7).

Table 6. Mix design of plugging material used for slowly plugging test of permeable concrete

Sample	1.18-2.36mm (g)	0.6-1.18mm (g)	0.3-0.6mm (g)	0.15-0.3mm (g)	Under 0.15mm (g)	Number of times adding sand
Z1	0	0.83	1.67	1.67	0.83	24

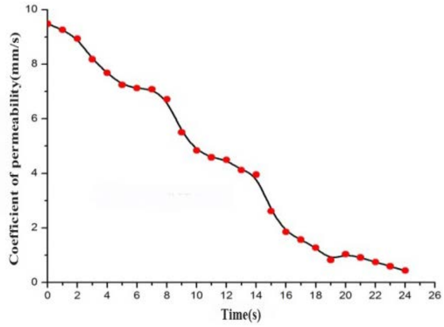

Fig. 4. Attenuation diagram of permeable concrete under slowly plugging.

It can be detected in Fig.5 that the initial permeability coefficient for each sample is different even though the samples were made the same batch. This is because permeable concrete has a porous structure with a large internal surface area, and the manual operation error occurred when the samples formed, which the consistency of the initial coefficient of permeability could not be guaranteed even though their attenuation trends were roughly the same. When the thickness of the surface layer made of 4.74-9.5mm is 15mm, the initial coefficient of permeability is bigger than that of 50mm, which is consistent with the results of the initial porosity of samples.

Compared with slowly plugging test of permeable concrete, there is no obvious that permeable coefficient recovery step on the quickly plugging attenuation diagram. This can be attributed to the short time interval of sand adding for quickly plugging test. The unstable particles could not be washed away by water after each sand addition and stayed in the permeable concrete samples together with the next time adding sand, leading to the disappearance of steps in permeability coefficient attenuation diagram and the sustained decrease of permeability coefficient for permeable concrete [11].

Table 7. Mix design of plugging material used for quick plugging test of permeable concrete

Sample	1.18-2.36mm (g)	0.6-1.18mm (g)	0.3-0.6mm (g)	0.15-0.3mm (g)	Under 0.15mm (g)	Number of times adding sand
Z2	0	5	10	10	5	24

3.4 Recovery test of permeability coefficient of permeable concrete

In recent years, many researchers [12] have studied the recovery of permeability coefficient of permeable concrete pavement. The main measures for improving the permeability of permeable concrete are broom sweeping, high pressure water guan washing and vacuum suction etc. After the comparing of several maintenance measures for permeable concrete pavement, researchers [13] point out that the high pressure gun is more effective than other measures. In this paper, the permeability coefficients of permeable concrete samples are restored by high pressure gun to study the recovery rate of the two permeable concrete pavements.

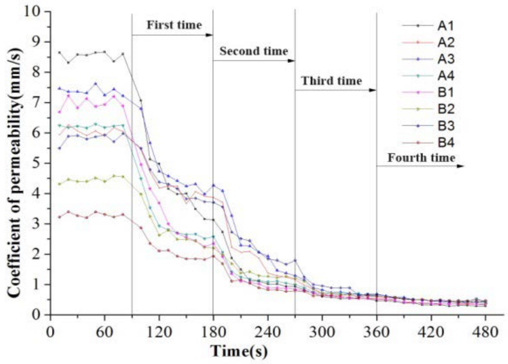

Fig. 5. Attenuation diagram of permeable concrete under quickly plugging.

The recover values and recovery rates of the samples are shown in Table 8 after the first restore with high pressure gun. From the table data, the recovery capacity of permeable concrete samples whose upper layer is 15mm is better than that of 50mm by 10%. This can be explained by that the thinner the size of the upper layer made of 4.74-9.5mm artificially broken pebbles, the easier to be washed out by high pressure gun.

Table 8. Recovery rate of permeable concrete under high pressure gun

Sample		P_I(mm/s)	P_F(mm/s)	ρ(%)
A	A1	8.544	7.141	83.58
	A2	6.044	4.968	82.20
	A3	7.378	6.003	81.36
	A4	8.094	6.748	83.37
B	B1	6.969	4.716	67.67
	B2	4.453	3.541	79.52
	B3	5.822	4.506	77.40
	B4	7.797	5.768	73.97

P_I-Initial coefficient of permeability;
P_F-Coefficient of permeability after primarily recovered test;
ρ - Degree of recovery, $\rho = (P_I/P_T) \times 100\%$

Table 9 shows the recovery and the permeable coefficients of samples after repeated plugging test. Based on the data in Table 8, the recovery rate of permeable concrete samples with 15mm upper layer are better than those blocks whose upper layer thickness are 50mm. This theoretically shows that reasonable thickness of the upper layer of the permeable concrete, to some extent, will be benefit to the recovery of the permeability coefficient of permeable concrete pavement, and prolong the life of the permeable concrete pavement.

Table 9. Recovery of permeable concrete sample after repeated plugging test

h(mm)	P_I(mm/s)	P_F(mm/s)	P_S(mm/s)	P_T(mm/s)	ρ(%)
15	7.38	6.00	5.05	5.66	76.7
50	6.22	3.84	3.39	2.75	44.2

h- Thickness of upper layer;
P_I-Initial coefficient of permeability;
P_F-Coefficient of permeability after primarily recovered test;
P_S- Coefficient of permeability after second recovered test;
P_T- Coefficient of permeability after third recovered test;
ρ - Degree of recovery, $\rho = (P_I/P_T) \times 100\%$

4 Conclusion

a) When the unit weight of the samples are same, the thinner the size of the upper layer, the larger the porosity of permeable concrete samples;

b) Due to artificial molding, initial coefficients of permeability of samples are different. The thinner the size of the upper layer is, the larger the initial permeable coefficient will be, and the higher recovery rate the permeable coefficient will have after plugging tests;

c) Steps on the attenuation diagram of permeable concrete fall slowly under slowly plugging test because of sustained flow, while there have fast attenuation rates on the permeable coefficient attenuation diagram;

d) Reasonable thickness of the upper layer will postpone the plugging and prolong the life of permeable concrete pavement, and the upper structure of 15mm would be a priority selection.

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