

Research and development of mechanical properties of new drainage bricks

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Abstract. The new type of drainage brick is an environmental protection paving materials, it is a kind of drainage brick with tapered hole made by special hole making process.. It has good water vapor permeability and good "sound absorbing" function to reduce noise in the city. Its special tapered through-hole structure is conducive to solving the problem of easy plugging of the pores in the traditional water-permeable paving materials and has a certain purifying effect on the tail gas of automobiles. In view of the special structural design of the new drainage brick, the effects of the raw material ratio and the number of through-holes on the flexural strength, splitting tensile strength and water permeable performance were studied by laboratory tests. The results show that the special structural design of the new drainage brick can well solve the problem of mutual restriction between the strength and the water permeability of the traditional permeable brick and has the characteristics of high strength and strong water permeability. And by adjusting the number of bright holes, we can prepare different performances of drainage bricks to meet different needs.

1. Introduction

With the development of economy and the acceleration of urban modernization, the natural soil vegetation in urban construction is constantly covered by buildings and various impervious grounds[1]. These impervious grounds provide convenience for people, but they also make it impossible for ground surface rainfall to infiltrate the land and insulate water vapor heat exchange. Leading to urban water-logging, the lack of water and heat island effect bring many negative effects to the ecological environment of the city. In recent years, countries in the world have paid special attention to the promotion of "sponge cities" in major cities, that is, cities have good "elasticity" in adapting to environmental changes and responding to natural disasters brought about by rain, that is, water and water storage when it rains, seep water, clean water, and "freeze" stored water when needed. Building a "sponge city" can effectively alleviate the negative impact of urban impervious road surface on urban ecology, coordinate the development of cities and nature, and take a sustainable development path of maintaining ecological balance[2].

The use of permeable materials for laying various venues and roads to increase the permeability of water has become an important means of building "sponge cities"[3]. Through the research on the existing technology and application of pervious bricks, it has been found that the majority of existing pervious bricks rely only on the gaps between the adjacent bodies of the pervious bricks to allow water to permeate or the water in the bricks to penetrate the water. Even if the same batch of products has poor water permeability, In addition, dust formed by wind and sand, organic matter formed by road pollution, oil pollution, etc. can easily block the water-permeable space, so that the permeability of



water-permeable bricks decreases, and even the water-permeability function is lost. This project breaks the traditional design idea to produce a new type of drainage block with large water seepage. On the one hand, it plays an important role in the city's water storage function. On the other hand, it solves the conflicting issues between the strength and water permeability of existing permeable pavement products. Contributing to the construction of "sponge city".

2. Sample preparation

2.1. Design ideas

This article adopts the method of discovering problems→analyzing problems→resolving problems as a research idea. Firstly, it summarizes the investigation and research of common permeable bricks in the market, and finds that the traditional permeable paving materials mainly have the following problems: 1) Permeable bricks on the market are more pleasing in shape, but their shape characteristics are all through the connected pores formed when the bricks are formed. The quality is difficult to control, and the water permeability is low and easy to plug; 2) Traditional permeable bricks are constrained by the principle of water permeability, and their water permeability is inversely proportional to the strength, which directly leads to the quality problems of the permeable bricks in practical use; 3) Long-term rain, easy to be rolled off, dents, short repair and maintenance cycles; 4) The traditional permeable brick usually has to go through high temperature kiln burning or pressing molding, the cost is high and it is easy to cause secondary pollution. Although the traditional permeable paving materials can solve the problem of urban rigidity, the actual use effect is far from satisfactory[4]. In summary, the problems that exist are mainly related to the molding process and the hole making method.

Based on the principle analysis of the reasons for the poor effect of traditional permeable bricks and against the defects that the water permeability and strength of bricks are inversely proportional, a design idea of a new type of drainage bricks is proposed, namely, a new type of drainage bricks is prepared by using non-press forming artificial holes, has the following advantages: 1) The drainage bricks are prepared by the method of artificial hole making, the water permeability is easy to control, the strength is high, and it is not easy to fall off; 2) The pervious hole is designed as a conical through hole, and the upper hole is smaller and the lower hole is larger, it is not easily blocked by the pollutants on the road surface; 3) The fine particles in the tail gas emitted by motor vehicles can be adsorbed on the wall of the conical hole. Most of the harmful gases are decomposed by the underground microorganisms, and they play the role of purifying the automobile exhaust; 4) There are grooves on the surface of the brick, which is not only anti-skid, but also conducive to rainwater collection and infiltration; 5) The new type of drainage bricks can use the environmental protection and energy-saving materials such as subway waste, garbage incineration tailings, waste ceramics, and construction waste as raw materials to form a sustainable development project[5]; 6) A variety of pigments can be added to the drainage brick material to form a multi-colored paving process. In addition, different performance drainage bricks can be prepared to adjust the number of through-holes according to different requirements, to quickly filter surface precipitation, and to infiltrate the filtered surface rainfall into the soil or into the permeable basement, it is used to alleviate problems in urban areas, water scarcity and heat island effects. The design principle is shown in figure 1.

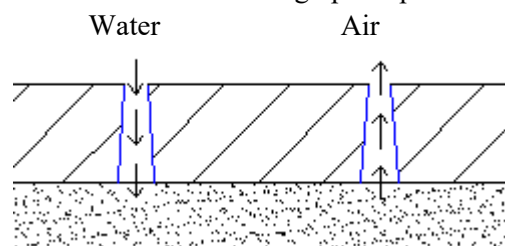


Figure1. Design principle of new type of drainage brick

2.2. Raw material selection

The main raw materials for the preparation of new drainage bricks are stone, sand, fly ash and cement. The coarse and fine aggregate screening results are shown in tables 1 and 2. The fly ash used in this experiment was taken from Fuzhou Shuangteng Building Material Co., Ltd., to meet the fly ash for use in the cement and concrete (GB/T 1596-2005) secondary standards. The specific physical performance indicators are shown in table 3. The chemical composition is shown in table 4. The cement used in this study was Conch brand P.O 42.5 ordinary portland cement produced by Anhui Digang Conch Cement Co., Ltd. In line with the "General Purpose Portland Cement" (GB175-2007) standard, it mainly acts as a binder in the experiment. The water used in the experiment was ordinary tap water, and the water reducing rate of the water reducing agent was 18% to 28%.

Table 1. Water permeable brick is used to sieve the results of gravel

Sieve(mm)	20	15	10	7.5	5	2.5	0.6
Percentage passrate (%)	100	98	96	75	10	3	1

Table 2. The permeable brick is divided by sand sieve

Sieve(mm)	5	2.5	1.5	0.6
Percentage pass rate (%)	100	96	38	5

Table3. The physical performance index of fly ash

Test items	National standard	Test results
Fineness (0.045mm square hole screen) (%)	25.0	17.0
Water requirement ratio (%)	105	87.0
ignition loss (%)	8.0	4.01
Water content (%)	1.0	0.18
Sulfur trioxide content (%)	3.0	0.24
Apparent density (kg/m ³)	/	2376
Bulk density (kg/m ³)	/	882

Table4. The main chemical composition of fly ash

ingredient	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	MgO	Na ₂ O	K ₂ O	SO ₃	C	else
content (%)	62.69	12.76	6.11	3.24	0.86	1.91	4.09	0.3	4.51	3.53

2.3. Sample preparation method

The production of new drainage bricks is carried out by self-designed molds. During the production process, the mixing, broadcasting, vibration and molding processes are used. After 24 hours of curing, the normal watering is maintained until 28 days after the mechanical performance test and water permeability test. The brick size is 250mm×250mm×60mm. The new type of drainage bricks is shown in figure 2.



Figure2. New type of drainage brick



Figure3. Schematic diagram of anti-folding test

3. Experimental research

3.1. Experimental scheme

The performance of permeable bricks mainly includes strength and permeability. In terms of strength, the compressive strength, flexural strength, splitting tensile strength and other indicators are mainly used. Permeability is measured by the permeability coefficient index. During the investigation, it was found that during the process of using existing pervious paving products on the road surface, most of the damage was broken, rather than crushed. This shows that the flexural strength and splitting tensile strength can better reflect the strength properties of pervious paving tiles than the compressive strength, and then consider that pervious paving tiles are generally used for roads with less loads. Therefore, this article will use the flexural strength and splitting tensile strength of the new drainage brick strength study.

3.2. Design of mix proportion

In this experiment, by comparing the mechanical properties and water permeability of new drainage bricks under different water-cement ratios, the relationship between water-cement ratio and the breaking strength, splitting tensile strength and permeability coefficient of drainage bricks was studied. After several concrete tests to obtain the water-cement ratio of table 5 with different strengths, the replacement rate of fly ash was 10%, and the addition amount of water-reducing agent was 0.3%.

Table5. Water ash ratio design table

group number	Z1	Z2	Z3	Z4	Z5
Water-cement ratio	0.42	0.46	0.50	0.53	0.57

3.3. Performance test

3.3.1. Flexural strength test

The YAW-3000 pressure testing machine manufactured by Hangzhou Singo Technology Co., Ltd. was used. The relative error of the indicating machine was not more than 1% and the maximum load was 3000N. Choose 38 mm diameter of 304 stainless steel bar as supporting rod and the pressure bar, the length of 260 mm, before each use, the support bar and the pressure bar must be flat on the workbench and calibrated horizontally in the same direction in the horizontal direction to indicate that they can be used after they meet the requirements.

After the preparation of the sample is immersed in $(20 \pm 5) ^\circ\text{C}$ water, (24 ± 3) h after removal, remove the surface moisture, immediately tested. Place the test piece on the support base of the tester. The distance from the support point to the end is 30mm. Evenly load the sample until it breaks and

record the damage load. The speed of the loading should be such that the breaking load appears within the range of (45 ± 15) s. The flexural strength of a single piece can be calculated according to formula (1):

$$R_f = \frac{3pl}{2HB^2} \quad (1)$$

Where: R_f —flexural strength, unite for MPa;
 P —destructive load, unite for MPa;
 l —the distance between two support points, unite for mm;
 H —specimen width, unite for mm ;
 B — specimen width, unite for mm.

3.3.2. Split tensile strength test

The YAW-3000 pressure testing machine manufactured by Hangzhou Singo Technology Co., Ltd. was used. The upper and lower pressure plates are ball-supported and can be freely rotated; The gasket shall be placed on the contact surface between the ball bearing and the test piece. The material of the gasket shall be five-layer plywood, and the length shall be at least 10 mm longer than the expected fracture surface of the test piece. The whole piece of perforated brick with holes is used as the test piece, and the side of the sample piece is cut or polished so that the side of the sample piece is a straight face. The force cross section of the permeable brick tensile test shall meet the following conditions:

- For rectangular permeable bricks, and the force cross-section parallel or perpendicular to the sides of the specimen.
- Force cross section through the centroid of the drainage brick top.
- The failure length l of the force section should be as long as possible

Use crayons and steel ruler to draw the position line of force section on top and bottom of pavement brick. Take the position line of the force section as the middle line, and grind out a plane with a width greater than 20mm, and the upper and lower sides of the grinding surface are parallel. A level gauge and a steel spacer are used to verify on the workbench. Grinding depth should be as small as possible. Using a caliper to measure the thickness of the test piece at two loading points. Measuring the width of the loading point with a steel ruler. Immerse the test piece in $(20 \pm 5)^\circ\text{C}$ water, remove it after $(24 \pm 3)\text{h}$, dry the surface moisture and start the test immediately. As shown in figure 4, the specimen and two gasket are fixed on the test machine, and the loading speed of $0.04\text{MPa/s} \sim 0.06\text{MPa/s}$ is uniformly charged to the test piece to be broken, and the failure load P is recorded.

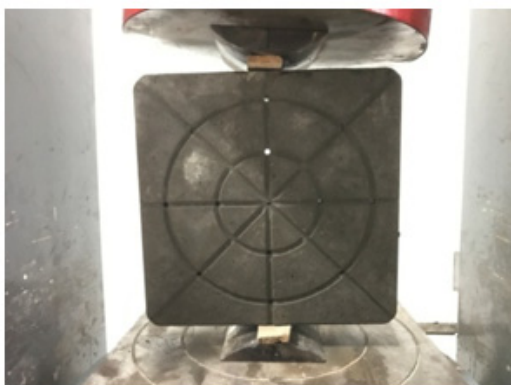


Figure4. Schematic diagram of splitting tensile test



Figure5. Experimental apparatus for water permeability coefficient

According to formula (2), the area of the failure surface of the test piece is calculated, which is accurate to 0.1mm²:

$$S = l \times t \quad (2)$$

Where: S —the area of the destruction surface, unite for mm²;

l —the average value of the two segments breaking length on the upper and lower surfaces of the test specimen, unite for mm;

t —the average value of the two thickness values measured at both ends of the failure section of the specimen, unite for mm.

The splitting tensile strength of the test piece is calculated according to formula (3) and the unit is MPa, accurate to 0.1 MPa.

$$f_{ts} = 0.637 \times k \times \frac{P}{S} \quad (3)$$

Where: f_{ts} —splitting tensile strength, unite for MPa;

P —destructive load, unite for N;

k —the correction factor for the thickness of the test piece and is based on the value in Table 9.

According to formula (4), the linear failure load of the test piece is calculated to be accurate to 0.1 N/mm :

$$F = \frac{P}{l} \quad (4)$$

Where: F —the linear failure load, which refers to the size of the load on the unit line when the test piece is in the splitting tensile strength test, unite for N/mm.

3.3.3. Permeability test

(1) Experimental equipment

Since the drainage capacity of drainage tiles is directly related to the number and size of the body through holes, the whole drainage brick is used as the water permeability sample, Permeability coefficient test device is manufactured according to the principle of the test instrument in GB/T 25993-2010 of the national standard " Permeable pavers and permeable pavement panels ", as shown in figure5.

(2) Experimental procedure

Due to the large amount of water used in this test, limited by laboratory conditions, ordinary tap water was used as test water. The water temperature during the test was 26°C, using glass glue to install the sample in the bottom of the tube and keeping the water tight around it. The water only penetrates from the upper and lower surface of the sample. After the sealing material is cured, the sample is placed in a vacuum device, vacuumed to 90 kPa ± 1 kPa, and held for 30 minutes. While maintaining the vacuum, add enough water to cover sample and make the water level higher than that of sample 10 cm, stop pumping air into vacuum state, for 20 min after removed, into the permeable coefficient test device, connect the sample with the cylinder seal. Put in the overflow tank, open the water supply valve, and let the water enter the container. When the overflow hole of the overflow tank overflows, adjust the amount of water so that the water-permeable cylinder maintains a certain water level. After the amount of overflow water from the spillway of the overflow tank and the overflow port of the permeable cylinder was stable, the cylinder was used to save water from the outlet, and the amount of water flowing out in five minutes was recorded and measured three times and averaged.

(3) Calculation of results

The permeability coefficient of the permeable brick can be calculated according to formula (5).

$$K_t = \frac{QL}{AHt} \quad (5)$$

Where: K_t — Water permeability of the sample at a water temperature of $T^\circ\text{C}$, unite for cm/s ;

Q — Water yield in seconds t , unite for mL ;

L — The thickness of the sample, unite for cm ;

A — The upper surface area of the test-piece, unite for cm^2 ;

H — The water level difference, unite for cm ;

t — Time, unite for s .

The results are expressed as the average of three samples and the results are accurate to $1.0 \times 10^{-3} \text{ cm/s}$.

The experiment to 15°C water temperature as the standard temperature, the standard temperature of the water permeability coefficient according equation (6) to calculate:

$$k_{15} = k_t \frac{\eta_t}{\eta_{15}} \quad (6)$$

Where: K_{15} — The standard temperature of the water permeability coefficient of the sample, unite for cm/s ;

η_t — the dynamic viscosity coefficient of water at $T^\circ\text{C}$, unite for $\text{kPa}\cdot\text{s}$;

η_{15} — the dynamic viscosity coefficient of water at 15°C , unite for $\text{kPa}\cdot\text{s}$.

4. Experimental results and analysis

When the samples of concrete and drainage blocks reach the specified age, they are subjected to relevant mechanical performance tests and permeability coefficient tests, obtain the compressive strength and the flexural strength, split tensile strength, and water permeability of each concrete test block. The fracture resistance test and splitting tensile test failure diagram are shown in figure 6 and 7. Calculating the average of each group of experimental data after statistical calculation, and the specific test results are shown in table 6.



Figure 6. Anti-fold test brick damage graph



Figure 7. The fracturing tensile test of the brick was destroyed

Table 6. Test results Table

Specimen number	Test block compressive strength (MPa)	flexural strength (MPa)	Split tensile strength (MPa)	permeability coefficient (cm/s)
Z1-1	38.6	9.4	3.1	1.316
Z1-2	38.3	9.3	2.9	1.308
Z1-3	39.2	9.8	3.3	1.329
average	38.7	9.50	3.1	1.318
Z2-1	36.1	9.3	3.2	1.316

Z2-2	35.2	9.0	2.9	1.309
Z2-3	35.5	9.0	3.1	1.336
average	35.6	9.1	3.07	1.324
Z3-1	32.6	8.3	3.1	1.318
Z3-2	32.1	8.6	2.8	1.302
Z3-3	32.3	8.5	3.1	1.320
average	32.33	8.46	3.00	1.313
Z4-1	31.8	7.3	2.8	1.288
Z4-2	31.2	8.3	2.9	1.299
Z4-3	31.6	7.6	2.9	1.310
average	31.53	7.73	2.87	1.299
Z5-1	27.3	7.2	2.6	1.309
Z5-2	27.8	7.4	2.7	1.312
Z5-3	26.9	7.0	2.4	1.288
average	27.33	7.20	2.57	1.303

4.1. Permeable tile strength

Comparing and analyzing the test data of different control groups to obtain the comparison chart of flexural strength at different water-cement ratios, as shown in figure 8, and the comparison chart of splitting tensile strength under different water-cement ratios, as shown in figure 9.

From figures 8 and 9, it can be seen that the flexural strength and splitting tensile strength of the new drainage tiles gradually decrease with increasing water-cement ratio, but the bending strength and water-cement ratio are almost linear, and with the increase of water-cement ratio, the cracking tensile strength gradually increases. In other words, the growth rate of splitting tensile strength of drainage tiles gradually decreases as the water-cement ratio decreases. Therefore, when the strength of the concrete reaches a certain degree, the impact on the split tensile strength of the new drainage tile gradually decreases.

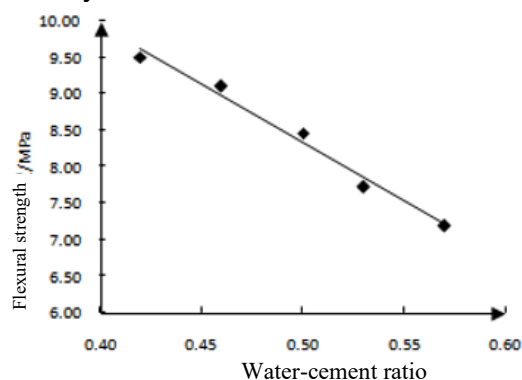


Figure8. The relationship between water ash ratio and anti-folding strength

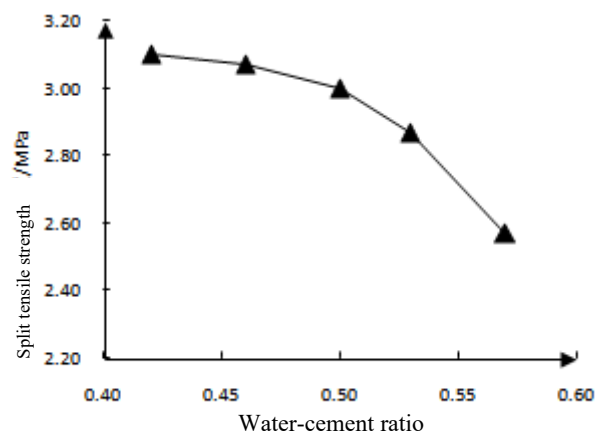


Figure9. The relationship between water cement ratio and the tensile strength

4.2. Permeability coefficient

The water permeability coefficient of the new drainage tiles with different water-cement ratios was measured by the self-made permeability coefficient experiment device. Each of the drainage tiles was provided with 13 conical through-holes, and the measured results were plotted in figure 10. In order to obtain the relationship between the permeability coefficient of the drainage tiles and the number of conical through-holes, using the “blocking method” which uses the sealing material (glass glue)

according to the principle of symmetry to seal two through-holes at a time, and then measure the different passages in order. The water permeability coefficient of the drainage tile in the case of the number of holes is shown in figure 11.

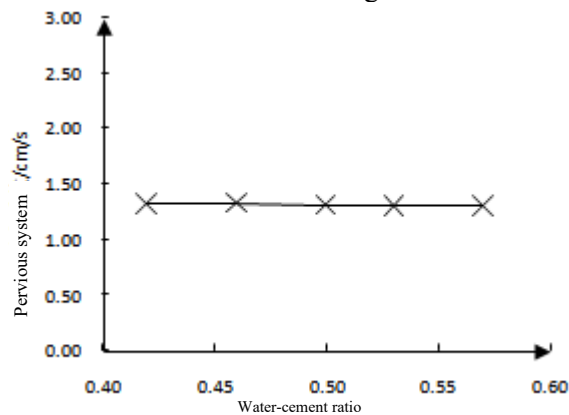


Figure10. Water cement ratio and water permeability coefficient diagram

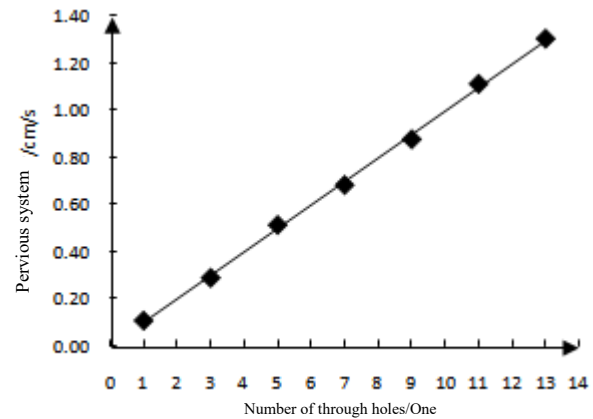


Figure11. The coefficient of water permeability and the number of holes

It can be seen from figure 10 that the water permeability coefficient is almost unchanged with the change of water-cement ratio. This is because of the special through-hole structure of the new drainage brick, which allows the water to directly penetrate the ground through the through hole. It can be seen from figure 11 that the water permeability coefficient of the new drainage brick is proportional to the number of through holes. Thus, it can be determined that the water permeability of the new drainage bricks is only related to the number of through holes, but not to the size of the water-cement ratio.

4.3. Compared with the performance of common permeable tile

For comparison, the performance of concrete permeable tiles and ceramic permeable tiles was evaluated through literature collection. In addition, the sand-based permeable tiles produced by a factory in Fuzhou were tested for flexural strength and splitting tensile strength by laboratory tests. Tests are shown in figures 12 and 13 and the results are shown in table 7.



Figure12. Permeable brick flexural test



Figure13. Water permeable brick splitting tensile test

Table7. Performance test comparison table

classify	flexural strength (MPa)	Splitting Tensile strength (MPa)	Permeation coefficient (10^{-2} cm/s)
Concrete permeable brick	3.42	/	50

Ceramic permeable brick	4.5	/	3.1
Sand-based permeable brick	3.9	1.2	1.36
new drainage tiles	9.8	3.2	132.9

It can be seen from table 7 that because of its special structural design, the new drainage bricks are superior to the commonly used pervious bricks in terms of flexural strength, splitting tensile strength, and water permeability, which is beneficial to the popularization and application of new drainage bricks.

5. Conclusion

1) The flexural strength of new type of drainage tile is 9.8MPa, the splitting tensile strength is 3.2MPa and the water permeability coefficient is 1.329 cm/s, which are better than the GB/T 25993-2010 standard requirements of the "Pavement Pavement and Pervious Pavement Panel" standard.

2) The special design idea of the new drainage tiles solves the problem of the shift of strength and water permeability of conventional permeable tiles, which is beneficial to the further development of permeable paving materials.

3) Experiments show that when the strength of the tile material reaches a certain level, the impact on the split tensile strength of the new type of drainage tile is gradually reduced, so the strength of the material cannot be increased blindly so as to avoid unnecessary waste.

4) Due to the influence of through holes and grooves, the fracture surfaces of the flexural and splitting tensile tests are in the middle of the tile body. Therefore, the position and shape of the through holes and grooves need to be further improved.

Acknowledgments

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