Experimental Study on Mechanical Properties and Water Permeability about 107 Glue for Slag Permeable Brick

Xiaoxia Chen and Qingxian Fan
(Anyang Institute of Technology, Anyang 455000, China)
E-mail: hnaycxx@163.com

Abstract. The main materials of the slag permeable brick were blast furnace slag, the waste generated in metallurgical industry, cement, and 107 glue as well, which were used in architecture as main cementitious material. The influence of 107 glue on the mechanical properties and water permeability of slag permeable brick were analyzed, and the formula and technological parameters of permeable brick were optimized by the method of contrast experiment. The permeability coefficient was the best when the compressive strength was satisfied, and the optimal mix ratio was also determined.

Keywords: Slag permeable brick; 107 glue; mechanical properties; water permeability

1. Introduction
Sponge city in China is the international term for "low impact development rainwater system construction". According to Ministry of Housing and Urban Rural Development, it refers to taking corresponding measures to strengthen the planning and control of the city, more comprehensive and in-depth excavation of construction projects, road works and green space system on the accumulation, absorption, infiltration and slow release of natural precipitation, so that natural rainfall forms an effective control of surface runoff, natural accumulation, infiltration and purification of the city (YU at el 2015).

On 5th March 2017, at the 5th meeting of the 12th National People's Congress of the People's Republic of China, premier Li Keqiang mentioned in his report on the work of the government: 'to promote sponge cities, it is necessary to plan urban overground and underground construction as a whole, to start construction of urban underground comprehensive pipelines corridors more than 2000 kilometers, which will make the city have both ‘face’ and ‘content’".

Starting from the function and purpose of the construction of sponge city, the application of permeable brick pavement needs to systematically consider a series of factors, such as topography and landform, underground conditions, coordination with surrounding buildings (structures) and the applicable conditions for determining the type of structure (WEI at el 2017). Slag permeable brick made of slag material can be widely used in walkways, city or block squares, park walkways and other medium and small public places, with good compressive performance, high strength, strong water permeability and other characteristics. It is an ideal material to beautify the road surface, and to prevent water accumulation on the road surface. At the same time, it also has good water permeability and air permeability. By the absorption of heat when the road evaporates water, it is extremely effective in relieving urban heat island effect (GAO at el 2016).
2. Experimental Method

2.1. Raw Materials
Cement: Ordinary Portland cement (42.5R), which is selected and produced by Anyang Jinhubo Cement Company.

Aggregate: blast furnace slag is used to replace slag and stone powder, and the aggregate size is 2.5-10.0 mm, 5.0-10.0 mm and 5.0-15.0 mm. Slag particles are uniform, less impurities, clean surface, mud content is no more than 1%, organic content is no more than 1%. The apparent density is 3440kg/m$^3$ and the water absorption ratio is 5.81%. Slag is derived from Anyang Iron & Steel Group Co. Ltd.

Additives: 107 glue comes from Anyang Wenfeng Dongfang Coating Factory.
Water: tap water.

1.2 Test device
(1) Vibrator for concrete test;
(2) Maintenance box;
(3) Permeability coefficient test device;
(4) Hydraulic pressure testing machine.

3. Test Mix Design
By changing the mix proportion parameters reasonably, on the premise that the slag is encapsulated by cement slurry, the communication gap between slags can be increased as much as possible. After consulting the references and a large number of tests, it is determined that the glue ratio (the percentage of glue to glue and water) is 0%, 1%, 2% and 3%; the bone-to-cement ratio is 3.5, 3.7 and 3.9; and the water-to-cement ratio is 0.38, 0.4, 0.42.

3.1. Preparation of Specimens
The dimension of compressive specimen is 150mm×150mm×150mm; the size of the permeable specimen is 100mm with a diameter of 50mm.

3.2. Test Method
(1) Compressive strength
According to national code Permeable brick (JC / T945 - 2005), the compressive area is 150 mm×150mm, loading rate is (0.3-0.5) MPa/s. Take the arithmetic mean of 5 pieces of test results.

(2) Permeability coefficient
A cylinder with a diameter of 100 mm and a height of 50 mm is taken as the sample [6].

4. Test Results and Analysis

4.1. Test Results
During the test, the ratio of bone-to-cement (3.5, 3.7, 3.9) and the ratio of the water-to-cement (0.38, 0.4, 0.42 are fixed, with different glue ratio ranging from 0% to 3%. The compressive strength and permeability coefficient of the test samples are shown in Table 1.
Table 1. Test data

| group | name | bone-to-cement ratio | water to cement ratio | glue ratio | compressive strength (Mpa) | permeability coefficient (cm/s) |
|-------|------|----------------------|----------------------|------------|-----------------------------|--------------------------------|
| A     | A1   | 3.5                  | 0.4                  | 0%         | 46.8                        | 0.014                          |
|       | A2   | 3.5                  | 0.4                  | 1%         | 40.443                      | 0.156                          |
|       | A3   | 3.5                  | 0.4                  | 2%         | 23.803                      | 0.132                          |
|       | A4   | 3.5                  | 0.4                  | 3%         | 13.364                      | 0.102                          |
| B     | B1   | 3.5                  | 0.42                 | 0%         | 48.529                      | 0.023                          |
|       | B2   | 3.5                  | 0.42                 | 1%         | 39.286                      | 0.05                           |
|       | B3   | 3.5                  | 0.42                 | 2%         | 36.4                        | 0.036                          |
|       | B4   | 3.5                  | 0.42                 | 3%         | 35.243                      | 0.028                          |
| C     | C1   | 3.7                  | 0.38                 | 0%         | 52.689                      | 0.018                          |
|       | C2   | 3.7                  | 0.38                 | 1%         | 24.037                      | 0.198                          |
|       | C3   | 3.7                  | 0.38                 | 2%         | 17.108                      | 0.113                          |
|       | C4   | 3.7                  | 0.38                 | 3%         | 13.637                      | 0.102                          |
| D     | D1   | 3.7                  | 0.4                  | 0%         | 49.868                      | 0.113                          |
|       | D2   | 3.7                  | 0.4                  | 1%         | 22.243                      | 0.142                          |
|       | D3   | 3.7                  | 0.4                  | 2%         | 14.443                      | 0.107                          |
|       | D4   | 3.7                  | 0.4                  | 3%         | 12.168                      | 0.096                          |
| E     | E1   | 3.9                  | 0.38                 | 0%         | 20.228                      | 0.142                          |
|       | E2   | 3.9                  | 0.38                 | 1%         | 14.092                      | 0.192                          |
|       | E3   | 3.9                  | 0.38                 | 2%         | 10.4                        | 0.156                          |
|       | E4   | 3.9                  | 0.38                 | 3%         | 6.812                       | 0.136                          |
| F     | F1   | 3.9                  | 0.4                  | 0%         | 47.84                       | 0.057                          |
|       | F2   | 3.9                  | 0.4                  | 1%         | 33.852                      | 0.227                          |
|       | F3   | 3.9                  | 0.4                  | 2%         | 32.708                      | 0.107                          |
|       | F4   | 3.9                  | 0.4                  | 3%         | 31.252                      | 0.092                          |

4.2. Results and Analysis

4.2.1. Influence of Glue Ratio on Compressive Strength of Slag Permeable Bricks. According to the different glue ratio, the test results of it on the compressive strength are shown in Table 2.

Table 2. Effect of glue ratio on compressive strength

| glue ratio | A group | B group | C group | D group | E group | F group |
|------------|---------|---------|---------|---------|---------|---------|
| 0%         | 46.8    | 48.529  | 52.689  | 49.868  | 20.228  | 47.840  |
| 1%         | 40.443  | 39.286  | 24.037  | 22.243  | 14.092  | 33.852  |
| 2%         | 23.803  | 36.4    | 17.108  | 14.443  | 10.4    | 32.708  |
| 3%         | 13.364  | 35.243  | 13.637  | 12.168  | 6.812   | 31.252  |

Table 2 shows that the compressive strength decreases gradually with the increase of the glue ratio when the bone-to-cement ratio is 3.5, 3.7, 3.9, and the water-to-cement ratio is 0.38, 0.4, and 0.42, respectively. When the glue ratio is 0%, the bone-to-cement ratio is 3.7, and the water-to-cement ratio
is 0.38, the compressive strength is the highest that any others’. The smallest fluctuation range of compressive strength was in group B (the bone-to-cement ratio 3.5, the water-to-cement ratio 0.42) and the largest was in group D (the bone-to-cement ratio 3.7, the water-to-cement ratio 0.40), which means group B is less sensitive to the glue ratio while group D is the opposite. When the bone-to-cement ratio is 3.5 and the water-to-cement ratio is 0.42, the 107 glue has the least influence on permeable bricks. At the same time, it can be judged that the 107 glue has no positive effect on the compressive strength of slag permeable brick, but has the opposite effect. That is to say, the compressive strength of slag permeable brick decreases with the increase of the glue ratio.

4.2.2. Influence of 107 glue ratio on permeability coefficient in slag permeable brick. Test results of permeability coefficient of 107 glue in slag permeable brick are shown in Table 5 and drawn into line chart, as shown in Table 3.

| gluing ratio | permeability coefficient(cm/s) |
|--------------|-------------------------------|
|              | A group | B group | C group | D group | E group | F group |
| 0%           | 0.014   | 0.023   | 0.018   | 0.113   | 0.142   | 0.057   |
| 1%           | 0.156   | 0.05    | 0.198   | 0.142   | 0.192   | 0.227   |
| 2%           | 0.132   | 0.036   | 0.113   | 0.107   | 0.156   | 0.107   |
| 3%           | 0.102   | 0.028   | 0.102   | 0.096   | 0.136   | 0.092   |

It can be seen from the table3 that when the bone-to-cement ratio is 3.5, 3.7, 3.9, the water-to-cement ratio is 0.38, 0.4, 0.42, the water permeability coefficient increases with the increase of the glue ratio from 0% to 1%, and then decreases with the continuous increase of the glue ratio. When the addition rate is 0%, the permeability coefficient of E group (the bone-to-cement ratio 3.9 and the water-to-cement ratio 0.38) is the best (0.142 cm/s). When the glue ratio is 1%, the water permeability coefficient is the highest in these 6 groups. Among them, the F group reaches the highest value (0.227 cm/s), in which the ratio of the bone-to-cement is 3.9 and the ratio of water-to-cement is 0.4. With the increase of the glue ratio, the permeability coefficient of E group is the highest when the glue rate varies from 2% to 3% among these 6 groups. It can also be seen from the chart that 107 glue has little effect on group B, that is, when the ratio of bone-to-cement is 3.5 and the ratio of water-to-cement is 0.42, the effect is the smallest.

4.3. Comprehensive Analysis
According to the national codes Pervious Brick (JC/T945-2005) and Concrete Pavement Brick (JC446-2000), the minimum compressive strength is no less than 35 MPa, and the minimum compressive strength of a single block is no less than 31 MPa. As can be seen from Table1, the compressive strength of A1, A2, B1, B2, B3, B4, C1, D1, F1, F2, F3, F4 can satisfy the demands that is no less than 31Mpa. A comparison chart of the permeability coefficient is drawn, as shown in Fig. 1.
The national code suggests that the permeability coefficient is qualified at 0.1~1.5 cm/s. From Fig. 1, the permeability coefficient of A1 is the lowest, and A2, D1, F2 and F3 meet the requirement. The permeability coefficient of F2 is the highest, so F2 group is the best. That is, the bone-to-cement ratio is 3.9, the water-to-cement ratio is 0.38, and the glue ratio is 1%. At this time, the compressive strength is 33.852Mpa, and the permeability coefficient is 0.227cm/s, which meets the specification requirements.

5. Conclusion
The construction of sponge city is a systematic project, which requires every key component to be combined organically. The permeable brick of pavement is a key component of the construction of sponge city (YU at el 2015). The slag permeable brick has high strength due to its coarse slag aggregate and good permeability, strong water storage characteristics because of its porous structure.

The comprehensive utilization of industrial waste slag can not only reuse the waste slag for a second time and create certain economic benefits, but also reduce the slag discharge area, ensure the sustainable development of iron and steel industry, save energy and protect the environment (ZHOU at el 2017).

The construction of sponge city is still in its infancy, and there is still a long way to go. We should do further research in the materials and construction methods to produce low-cost permeable bricks with strong bearing capacity and high permeability coefficient so as to better serve the construction of sponge city.

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