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# Study on the Effect of Fly Ash Admixture on the Performance of Recycled Pervious Concrete

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***Author's contribution***

*The sole author designed, analyzed, interpreted and prepared the manuscript.*

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## ABSTRACT

In order to solve the problems of recycling of a large amount of coarse aggregate produced after the crushing of waste concrete and urban flooding, this project prepares the recycled coarse aggregate of 4.75-9.5 mm into 100 mm × 100 mm × 100 mm cubic permeable concrete specimens, and researches the influence law of different fly ash admixture on the pore space, water permeability and mechanical properties of the recycled aggregate permeable concrete, and determines the best design The optimal design ratio was determined. The experimental results show that the permeable concrete specimens prepared with recycled coarse aggregate of 4.75-9.5mm particle size and mixed with fly ash were cured in water, and the longer the curing age, the higher the compressive strength. With the increase of fly ash dosage, the compressive strength first rises and then decreases, and the porosity and permeability coefficient decreases continuously. When the fly ash dosage is 15%, the 28d compressive strength of recycled aggregate pervious concrete is the highest, which is 12.8 MPa. At this time, the porosity is 23.9%, and the permeability coefficient reaches 3 mm/s. Considering the overall situation, the optimum dosage of fly ash for recycled aggregate pervious concrete is recommended to be about 15%.

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## 1. INTRODUCTION

At present, the annual use of concrete in China is about 7.3 billion tons, which is among the highest in the world. However, due to building demolition and construction, engineering renovation, and other reasons, a large amount of construction waste is generated globally every year. Natural aggregate is an important part of concrete, its volume accounts for about 80% of the total volume of concrete, rough handling of waste concrete directly caused a lot of natural aggregate waste, and also caused serious damage to the environment [1-3]. In addition, in recent years, with the construction of urbanization, the heat island effect, urban flooding, and a series of urban ecological problems frequently appear, many scholars put forward the concept of "sponge city", to solve the outstanding water problems through an effective ecological approach [4-6]. As an important pavement material to promote the construction of "sponge city", pervious concrete can increase the permeable and breathable area of the city, which can not only effectively solve the outstanding drainage problems in China, but also alleviate a series of urban environmental problems such as the "heat island effect" in the city. In addition, fly ash is one of the main solid wastes produced by burning coal, which can be harmful to the environment if not disposed of in time. Fly ash contains a large amount of silica, alumina, and iron oxide as its main components and has been widely used as an admixture in concrete [7-8].

Based on this, this project was carried out by making recycled coarse aggregate from demolished construction waste, casting recycled aggregate pervious concrete, studying the effect of fly ash admixture on the basic physical mechanics and permeability of recycled aggregate pervious concrete, and comparing it with the performance of natural aggregate pervious concrete, summarizing the effect of fly ash on the performance of recycled aggregate pervious concrete, and obtaining the optimal fly ash admixture on the recycled aggregate pervious concrete. The best design ratio of recycled aggregate pervious concrete under the influence of the optimal amount of fly ash is obtained. Combined with microscopic analysis, the microscopic mechanism of the effect of fly ash on recycled aggregate pervious concrete was investigated. To provide a reference for the application and promotion of recycled coarse aggregate and fly ash in sponge city construction [9].

## 2. MATERIALS AND METHODS

### 2.1 Experimental Materials

The main raw materials were P-O 42.5R normal silicate cement, fly ash, natural sand and gravel, and waste concrete produced by Faraki. The cement was 42.5 strength grade ordinary silicate cement produced by Faraki. The fly ash mixed in is Class II fly ash produced by Shijiazhuang Yicheng Building Materials Co., Ltd. with a density of 2600 kg/m$^3$. Natural coarse aggregate is made of ordinary sand and gravel sold by building materials stores. The recycled coarse aggregate is made of waste concrete aggregate of 4.75-9.5 mm particle size obtained after crushing by a Y132S-4 single jaw crusher and then screened and dried. The basic properties of cement are shown in Table 1. The basic properties of coarse aggregates are shown in Table 2.

### 2.2 Matching Ratio

Considering that the recycled aggregate pervious concrete needs to be compatible with both compressive strength and permeability, the ratio design was carried out according to the volume method. The water-cement ratio of recycled aggregate pervious concrete is between 0.25 and 0.35, and the water-cement ratio is 0.35. The coarse aggregate particle size is 4.75-9.5 mm. The concrete mix ratios are shown in Table 3 and Table 4 [10].

### 2.3 Experimental Setup

It mainly includes a 2000kN concrete uniaxial compression loading testing machine, permeable cement concrete pavement permeability coefficient testing device, concrete curing water tank, 220v small electric cement mixer, and Sunyu SOPTOP DMSZ5 HD electronic digital microscope.

### 2.4 Test Methods

The compressive strength of cubic specimens of recycled aggregate pervious concrete and natural aggregate pervious concrete compressive strength test was developed concerning the national standard GB/T 50081

"Test Methods for Mechanical Properties of Ordinary Concrete" (GB/T 50081-2002). As the size of the standard specimen is 150mm×150mm×150mm, the compressive strength should be calculated by multiplying the coefficient by 0.95. After the specimen is taken out, it needs to be dried out due to the water curing mode. Compressive strength test press in line with GB/T3159 "hydraulic universal testing machine" requirements, set the press compressive strength load loading rate of 0.5MPa per second, every three specimens for a group. Stop loading after the concrete specimen is destroyed, calculate the average value, process the data，and analyze the results. According to GB/T 50081-2019 "concrete physical and mechanical properties test method standard", the calculation of compressive strength is shown in formula (1).

$$\mathbf{f} = \frac{F}{A} \tag{1}$$

Where: f denotes the compressive strength of the pervious concrete specimen in MPa; F is the load on the specimen when it is damaged in N; A denotes the compressed area of the specimen in $mm^2$.

The porosity and permeability coefficient of recycled aggregate pervious concrete was determined by the Technical Specification for the Application of Recycled Aggregate Pervious Concrete (CJJ/T 253-2016) and the Technical Specification for Pervious Cement Concrete Pavement (CJJ/T 135-2009). The calculation of the permeability coefficient is shown in Equation (2).

$$K_t = \frac{Q \bullet L}{H \bullet A \bullet \mathrm{t}} \tag{2}$$

Where: k is the permeability coefficient in mm/s; Q is the volume of seepage water in t time in $mm^3$ ; L is the height of the specimen in mm; H is the head difference in mm; A is the cross-sectional area of the specimen in $mm^2$; t is the length of seepage in s.

The porosity test of the recycled aggregate pervious concrete specimens was carried out after reaching the curing age, and the calculation of porosity is shown in Equation (3).

$$P_{\mathrm{pc}} = \left[1 - \frac{m_2 - m_1}{V \bullet \rho_w}\right] \tag{3}$$

Where: V is the volume of the specimen; $m_1$ is the mass of the specimen after 24 h of immersion in water; $m_2$ is the mass of the specimen after 24 h of air-drying; $\rho_w$ is the density of water. To ensure the accuracy of the calculation results, the test was repeated three times for $m_1$ and $m_2$.

## 3. EXPERIMENTAL PROCESS

Both natural aggregate pervious concrete and recycled aggregate pervious concrete are prepared by the net cement paste wrapping method, and the specimens are cast and shaped by inserting and pounding in layers, and the specific sample-making operations are as follows: (1) Add all coarse aggregates to the mixer at one time, and first add 20% water and mix for 30s to make the aggregate surface evenly wet. (2) Add cement and fly ash mixture and mix for 90s. cement and fly ash will form a thin layer evenly on the surface of the aggregate to promote the bonding of the aggregate surface and help improve the strength of pervious concrete. (3) Add the remaining water and mix for 90s, which can effectively avoid the phenomenon of segregation. (4) The test pieces are poured in three layers by inserting and pounding method, each layer is about the same thickness, and the test pieces are pounded vertically 20~30 times evenly from the edge to the center according to the spiral direction, the pounding rod should touch the bottom of the test mold when pounding the bottom layer, and the pounding rod should be inserted into the following layer 20~30mm when pounding the top layer.(5) The prepared concrete block test pieces are grouped and marked, and the mold is dismantled after 24h curing at room temperature, and then put into the water tank according to the code The groups are cured for 7 days and 28 days respectively. After putting the specimens, the surface of the water tank is covered with plastic film, and the water needs to be replenished regularly afterwards to meet the later hydration water requirement of fly ash pervious concrete.

The finished natural aggregate pervious concrete specimens and recycled aggregate pervious concrete specimens are shown in Fig 1. and Fig 2.

**Table 1. Basic properties of P-O 42.5R ordinary silicate cement cement**

| Name | Water consumption of standard consistency (%) | Adequacy | Coagulation time (min) | | Flexural strength (MPa) | | Compressive strength (MPa) | |
|---|---|---|---|---|---|---|---|---|
| | | | Initial condensation | Final condensation | 3d | 28d | 3d | 28d |
| P-O42.5R | 27.4 | Qualified | 233 | 290 | 4.5 | 8.3 | 25.1 | 51.0 |

**Table 2. Basic properties of coarse aggregates**

| Aggregate Type | Performance density ($kg/mm^3$) | Grain size (mm) | Water content (%) | Bulk density ($kg/m^3$) | Crushing index (%) | 10min Water absorption rate (%) |
|---|---|---|---|---|---|---|
| Natural Coarse Aggregate | 2830 | 4.75-9.5 | 0.2 | 1550 | 15.5 | 0.4 |
| Recycled Coarse Aggregate | 2620 | 4.75-9.5 | 2.8 | 1360 | 35 | 4.1 |

**Table 3. Recycled aggregate permeable concrete mix ratio**

| Number | Design porosity | Water to ash ratio | Recycled aggregates ($kg/m^3$ ) | Cement ($kg/m^3$ ) | Fly ash mixing amount | Fly ash ($kg/m^3$ ) | Water ($kg/m^3$ ) |
|---|---|---|---|---|---|---|---|
| 1 | 20% | 0.35 | 1330 | 350 | 0% | 0 | 122.5 |
| 2 | 20% | 0.35 | 1330 | 332.5 | 5% | 17.5 | 122.5 |
| 3 | 20% | 0.35 | 1330 | 315 | 10% | 35 | 122.5 |
| 4 | 20% | 0.35 | 1330 | 297.5 | 15% | 52.5 | 122.5 |
| 5 | 20% | 0.35 | 1330 | 280 | 20% | 70 | 122.5 |

**Table 4. Natural aggregate pervious concrete mix ratio**

| Number | Design porosity | Water to ash ratio | Natural aggregates ($kg/m^3$ ) | Cement ($kg/m^3$ ) | Fly ash mixing amount | Fly ash ($kg/m^3$ ) | Water ($kg/m^3$ ) |
|---|---|---|---|---|---|---|---|
| 6 | 20% | 0.35 | 1550 | 520 | 0% | 0 | 182 |
| 7 | 20% | 0.35 | 1550 | 494 | 5% | 26 | 182 |
| 8 | 20% | 0.35 | 1550 | 468 | 10% | 52 | 182 |
| 9 | 20% | 0.35 | 1550 | 442 | 15% | 78 | 182 |
| 10 | 20% | 0.35 | 1550 | 416 | 20% | 104 | 182 |

## 4. COMPRESSIVE STRENGTH ANALYSIS OF PERVIOUS CONCRETE WITH NATURAL AND RECYCLED AGGREGATES

The compressive loading test of concrete specimens was carried out by a uniaxial compressive loading testing machine, and the obtained curves of the effect of fly ash on the compressive strength of permeable concrete specimens are shown in Fig. 3 and Fig. 4.

According to the experimental data, it can be seen that the compressive strength of pervious concrete with natural aggregate and the compressive strength of pervious concrete with recycled aggregate both show a trend of increasing and then decreasing with the increase of fly ash admixture.

Fig. 3 shows the effect of different amounts of fly ash on the compressive strength of pervious concrete with natural aggregate. It can be seen that the appropriate amount of fly ash mixed into the natural aggregate pervious concrete can significantly improve the compressive strength, and the modification effect is obvious.When the fly ash admixture rate of natural aggregate pervious concrete was 15%, the 7d strength and 28d strength reached the highest value [11].

The 7d compressive strengths were 11.8MPa, 13.1MPa and 15.3MPa when the fly ash admixture rate was 5%, 10% and 15%, respectively, which increased 11.32%, 23.58% and 44.34%, respectively, compared with the natural aggregate pervious concrete without fly ash; the 28d compressive strengths were 16.7MPa, 18.5MPa, and 21.6MPa, respectively, compared with the natural aggregate pervious concrete without fly ash. The 28d compressive strengths were 16.7MPa, 18.5MPa, and 21.6 MPa, which were 9.87%, 21.71% and 42.11% higher than those of natural aggregate pervious concrete without fly ash. The reasons for this analysis are that: ① the main components of fly ash are SiO2 and A12O3, which can react with Ca(OH)2 produced by cement hydration to produce calcium alumina, C-S-H and other substances, making the internal structure of natural aggregate pervious concrete more dense. ②The fineness modulus of fly ash is small and the specific surface area is large, and after the reaction of equal amount of replacement cement, it can effectively fill the tiny pores inside the natural aggregate pervious concrete. Therefore, the appropriate amount of fly ash on the strength of natural aggregate pervious concrete to improve the modified effect is obvious.

With the increase of fly ash admixture, the compressive strength shows a decreasing trend. When the amount of fly ash is 20%, the 7d compressive strength is 13.3MPa, which is about 13.07% lower than the natural aggregate pervious concrete with 15% fly ash; the 28d compressive strength is 19.1MPa, which is 11.57% lower than the natural aggregate pervious concrete with 15% fly ash. It can be seen that the excess of fly ash instead of cement does not improve the strength of natural

**Fig 1. Pervious concrete with natural aggregate mixed with fly ash**

**Fig 2. Recycled aggregate pervious concrete mixed with fly ash**

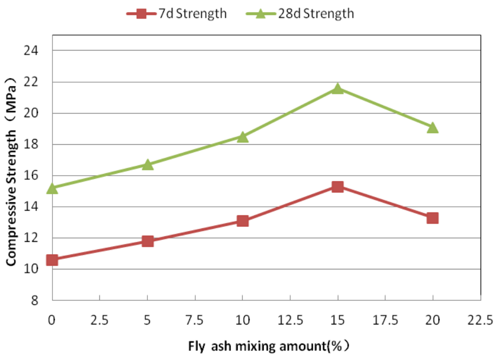


**Fig 3. Natural aggregate pervious concrete**

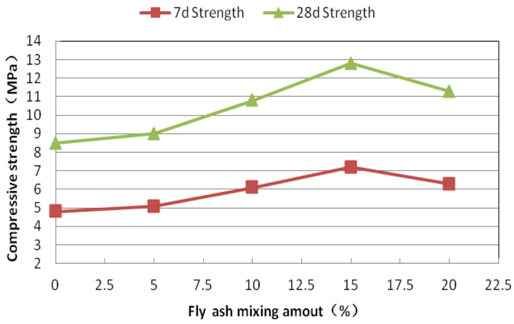


**Fig 4. Recycled Aggregate pervious concrete**

aggregate pervious concrete. The reason for this unfavorable modification effect: fly ash mainly reacts with the secondary products of cement hydration to refine the microscopic pore structure inside the natural aggregate pervious concrete, and an excessive amount of fly ash replacing cement will make the hydration products of cement insufficient to react with it, resulting in a reduction in strength.

Fig. 4 represents the effect of different amounts of fly ash on the compressive strength of pervious concrete with recycled aggregate. It can be seen that the appropriate amount of fly ash blended into recycled aggregate pervious concrete can significantly improve the compressive strength, and the modification effect on recycled aggregate pervious concrete is obvious. The 7d strength and 28d strength of recycled aggregate pervious concrete reached the highest value when the fly ash admixture rate of 15% was equally high.

The 7d compressive strengths of recycled aggregate pervious concrete were 5.1MPa, 6.1MPa, and 7.2MPa when the fly ash admixture rate was 5%, 10%, and 15%, respectively, which were 6.25%, 27.08%, and 50% higher than those of the recycled aggregate pervious concrete without fly ash; the 28d compressive strengths were 9MPa, 10.8MPa, and 12.8MPa, respectively, which were higher than those of the recycled aggregate pervious concrete without fly ash. The 28d compressive strengths were 9MPa, 10.8MPa and 12.8MPa, which increased by 5.88%, 27.06%, and 50.59%, respectively, compared with the recycled aggregate pervious concrete without fly ash.

With the increase of fly ash admixture, the compressive strength showed a decreasing trend. When the fly ash admixture was 20%, the 7d compressive strength of recycled aggregate pervious concrete was 6.3 MPa, which was 12.5% lower than that of recycled aggregate pervious concrete with 15% fly ash admixture; the 28d compressive strength was 11.3 MPa, which was 11.72% lower than that of recycled aggregate pervious concrete with 15% fly ash admixture. From this, it can be seen that the excessive amount of fly ash instead of cement, the same can not improve the strength of recycled aggregate pervious concrete.

Analyzing the reason for this phenomenon, the reason why fly ash can improve the strength of recycled aggregate pervious concrete specimens is that the active $SiO_2$ and $Al_2O_3$ contained in fly ash will react with $Ca(OH)_2$ and generate calcium silicate and calcium aluminate, which can play a role in improving the compressive strength. However, if the activity needs to be stimulated, certain alkaline conditions are required, and the cement cannot fully achieve the conditions for stimulating $SiO_2$ and $Al_2O_3$ at the initial stage of hydration reaction because the $Ca(OH)_2$ contained in the product is not much. As the reaction continues to occur and $Ca(OH)_2$ accumulates, $SiO_2$ and $Al_2O_3$ can be gradually excited and then start to react with $Ca(OH)_2$, and the hydrated calcium silicate and calcium aluminate obtained will fill the microscopic pores in the cementitious material and improve the degree of compactness. Meanwhile, the secondary hydration process consumes more Ca(OH)2, which improves the internal structure of the recycled aggregate permeable pervious concrete specimens, thus increasing the compressive strength of the specimens. After the fly ash admixture rate exceeded 15%, due to the excessive amount of fly ash admixture, which replaced an excessive amount of cement, it would affect the adhesion between the cementitious material and the recycled aggregate, resulting in less hydration products generated by the hydration reaction to produce strength, making the strength of the specimens decrease instead.

The compressive strength of the natural aggregate pervious concrete with fly ash is higher than that of the recycled aggregate pervious concrete under the same fly ash mixture. Meanwhile, the mechanical properties of both natural aggregate and recycled aggregate pervious concrete specimens after 28d curing in water are better than those after 7d curing, and the curing conditions are more convenient and have higher economic and practicality. The optimal amount of fly ash is recommended to be about 15%.

## 5. ANALYSIS OF PERMEABILITY COEFFICIENT OF RECYCLED AGGREGATE PERVIOUS CONCRETE

The test data in Fig 5. and Fig 6. show that the incorporation of fly ash reduces the permeability performance of recycled aggregate permeable concrete, and the porosity and permeability coefficient of concrete show a decreasing trend with the increase of fly ash incorporation. This is because the filling effect of the micro aggregate effect of fly ash, which changes the pore structure of pervious concrete and reduces the pore size as well as the porosity, and the permeability coefficient decreases.

The density of fly ash is smaller than that of cement, and the volume of the slurry part increases after using fly ash equal mass instead of cement, so the volume of the slurry part becomes larger and larger with the gradual increase of fly ash admixture, which leads to the decrease of the probability of forming connected pores inside the recycled aggregate pervious concrete, and the number and diameter of the formed connected pores are reduced, so the porosity decreases. In addition, most of the fly ash particles are spherical particles with

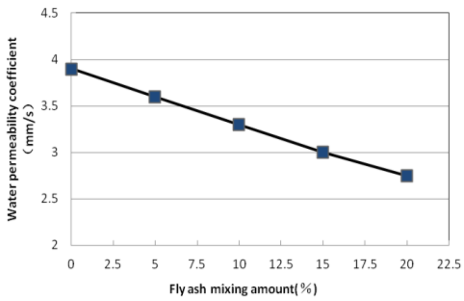


**Fig 5. Effect of different blending of fly ash on the permeability coefficient of recycled aggregate pervious concrete**

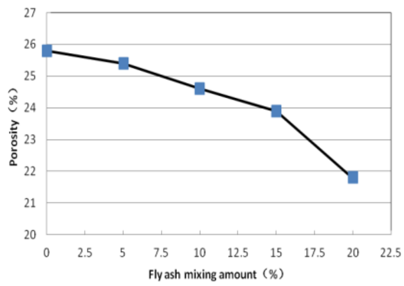


**Fig 6 . Effect of different blending of fly ash on the porosity of recycled aggregate pervious concrete**

smooth surfaces, which can reduce the internal resistance friction after mixing, thus increasing the fluidity of the slurry and weakening the cohesiveness of the slurry, so the slurry is easily influenced by gravity to flow down the aggregate and block the connecting pores in the lower part of the specimen, so that the large size connecting pores in the lower part of the specimen is reduced, and even block the connecting pores, so that the permeability coefficient is reduced [12].

The porosity of the recycled aggregate pervious concrete specimens with 5%, 10%, 15% , and 20% of fly ash is 25.4%, 24.6%, 23.9%, and 21.8%, respectively, and the permeability coefficient is 3.6, 3.3, 3, and 2.75mm /s, respectively, compared to the specimens without fly ash with 25.8% porosity and 3.9mm/s permeability coefficient, the porosity of the concrete with fly ash is reduced by 1.55%, 4.65%, 7.36%, and 15.5%, respectively. The porosity of the concrete with fly ash decreased by 1.55%, 4. 65%, 7.36%, and 15.5%, respectively, which corresponded to the reduction of the permeability coefficient by 7.69%, 15.38%, 23.08%, and 29.49%, respectively. Therefore, under the comprehensive consideration of concrete permeability and mechanical properties, it is recommended that the amount of fly ash admixture is between 10% and 15%.

The permeability coefficient of the test results ranges from 2.75mm/s to 3.9mm/s. The permeability of the recycled aggregate pervious concrete specimens can meet the requirement of a permeability coefficient >0.5mm/s in the specification "Technical Specification for Pervious Cement Concrete Pavement" (CJJ/T135-2009).

## 6. ANALYSIS OF DAMAGE MODE AND MECHANISM OF CONCRETE SPECIMENS

The damage patterns of natural and recycled aggregate pervious concrete specimens under compression are shown in Fig 7(a) and (b).

It can be seen that when the natural aggregate pervious concrete specimen is damaged by compression, the force provided by the cementitious material is sufficient to balance the combined force transmitted to the aggregate from the surrounding contact points and restrain the aggregate from deflecting, at this time, a large stress concentration phenomenon occurs at the natural aggregate, i.e., the first fracture occurs at the tip of the aggregate particles and the adjacent aggregate contact points, resulting in a misalignment at the aggregate, which causes the cement stone wrapped around the fracture of the aggregate to Generate tensile or shear forces, resulting in cracks. As the pressure increases, the cracks gradually expand and penetrate with the cracks produced by the same damage mode in the connecting holes or around, which eventually leads to the whole specimen showing piecewise damage with less amount of broken particles [13-15].

The loading surface of the recycled aggregate pervious concrete specimen is compression damage or shear damage, and the reasons for rupture include the following two points: ① the production process of recycled aggregate, resulting in a large number of small cracks inside its aggregate; ② the cement adher to the surface of the recycled aggregate affects the adhesive properties of the newly mixed cement gel and the aggregate, forming a weak layer with a lower strength than the cement matrix.

**(a) Natural aggregate pervious concrete specimens**

**(b) Recycled aggregate pervious concrete specimens**

**Fig. 7. Compression damage pattern of natural and recycled aggregate pervious concrete specimens**

The test specimen of recycled aggregate pervious concrete is not damaged from the vicinity of the recycled aggregate, and there is an obvious "hoop effect" when it is damaged by compression, which is similar to the form of compression damage of ordinary concrete. Due to the large friction between the upper and lower plates, the upper and lower plates restrain the expansion of the specimen surface, so that the specimen surface is retained more complete after compression, the closer to the center of the specimen, the less the remaining part after compression, and at the same time, it indicates that the recycled aggregate pervious concrete is more uniform and dense inside, and the recycled aggregate is more closely connected with the cement paste [17-18].

## 7 CONCLUSIONS

The appropriate amount of fly ash admixture rate can effectively improve the mechanical properties of recycled aggregate pervious concrete and natural aggregate pervious concrete. With the increase of fly ash admixture, the compressive strength of both shows a trend of first increase and then decrease. The compressive strengths of natural aggregate pervious concrete and recycled aggregate pervious concrete were the best at 15% fly ash admixture, which were 21.6 MPa and 12.8 MPa, respectively.

Fly ash modified recycled aggregate pervious concrete will fill its internal pores and reduce the porosity and permeability to a certain extent while improving the strength. With the increase of fly ash admixture, the porosity and permeability coefficient of recycled aggregate pervious concrete keeps decreasing. When the fly ash admixture is 20%, the porosity is 21.8% and the permeability coefficient is 2.75mm/s [19-20].

According to the experimental test data, the recycled pervious concrete with 15% fly ash admixture cured in water for 28 d meets the basic requirements for use in sponge city projects, with compressive strength greater than 10 MPa and permeability coefficient greater than 0.5mm/s, which can be used for pavement pavement laying. In a comprehensive analysis, the best fly ash admixture of recycled aggregate pervious concrete is suggested to be about 15% [21].

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## COMPETING INTERESTS

Author has declared that no competing interests exist.

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