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Performance of New Permeable Concrete Materials based on Mechanical Strength

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ABSTRACT

The purpose of this study was to improve the application effect of pervious concrete in practical engineering. Firstly, recycled brick aggregate was prepared by crushing of waste clay bricks, and then a new type of pervious concrete was prepared after secondary grouting treatment. The effects of the content of polypropylene steel fibre, target porosity, water cement ratio and particle size of recycled brick aggregate on the new type of pervious concrete were studied. The results showed that the target porosity had the most significant effect on the mechanical strength of the regenerated brick specimens, and the smaller the target porosity was, the higher the compressive strength was, and vice versa. The particle size of recycled brick aggregate had little influence on the mechanical strength value of the specimen. Appropriate amount of polypropylene steel fibre can significantly improve the mechanical strength of the pervious concrete, and the flexural strength was higher than the compressive strength. Therefore, when the target porosity was 24%, the water cement ratio was 0.32, the content of polypropylene steel fibre was 3 kg/m3, and the particle size of recycled brick aggregate was 9.5 mm-13.2 mm, the concrete can achieve a good balance between mechanical properties and water permeability.

INTRODUCTION

At present, the surface of many cities is covered by hardened concrete pavement and buildings with reinforced concrete structures, so it is difficult for precipitation to infiltrate into the soil, resulting in excessive subsidence of groundwater level (Richards et al. 2018). In addition, the hardened pavement can't effectively regulate the urban surface temperature and humidity, which also aggravates the urban heat island effect. The hard ground brought by the urbanization process makes the urban roads lose the functions of water seepage, water storage and water discharge, and it is also very difficult for green plants to grow in the environment surrounded by the traditional hardened road surface. In the global context of maintaining ecological balance and living in harmony with the environment, as a new kind of environment-friendly pavement material, pervious concrete has been paid attention to and applied (Sutikulsombat et al. 2018). The porous properties of pervious concrete enable it to store water, reduce temperature and noise, and perform biological degradation (Akhtar & Sarmah 2018). Today, with the increasing awareness of environmental protection, the use of permeable concrete brings people more choices and more comfortable life experience. However, it is also due to the porous characteristics of pervious concrete that its strength is generally lower than that of traditional concrete, which has brought a certain degree of influence on its promotion and application. In this situation, the research and development of high-performance pervious concrete has become an important research topic for domestic scholars and municipal construction workers.

Sintered clay bricks have all-weather resistance, and the waste bricks still have a certain strength and can be recycled and reused. The coarse aggregate which is crushed, decomposed, cleaned and re-classified as concrete is called recycled brick aggregate, and it can be replaced with natural coarse aggregate to prepare a new type of permeable concrete. Domestic research shows that the performance of recycled aggregate of clay brick is close to that of lightweight aggregate, which has a negative impact on the workability of fresh concrete. Aggregate properties and mix proportion parameters have an impact on the strength of concrete. The concrete strength can reach 40 MPa - 50 MPa with proper mix ratio, which has good thermal performance and durability. At the same time, the recycled brick and tile aggregate has the characteristics of large porosity and high-water absorption, which is suitable for being a permeable material. In addition, there are more connected pores in the concrete, so that the prepared porous concrete has the characteristics of high-water permeability and high air permeability.

PAST STUDIES

Many scholars have studied pervious concrete. By setting the target porosity, Muthu et al. (2018) designed the mix ratio of pervious concrete with volume method and studied the compressive strength under different water cement ratios. They found that the main properties of pervious concrete (pervious coefficient, compressive strength and flexural strength) were closely related to both water cement ratio and target porosity. Elbar et al. (2018) used recycled aggregates in permeable concrete, and proved that the method of deploying clean water ecologically permeable concrete with recycled aggregates is feasible. Abaeian et al. (2018) studied the durability of coloured pervious concrete and analysed the influence of water binder ratio, slag, fibre and pigment on various properties of materials. In order to improve the strength and surface characteristics of pervious concrete, Lavergne et al. (2018) used rigid polymer fibre as admixture material to conduct a beneficial exploration on the performance of pervious concrete material.

MATERIALS AND METHODS

After reading relevant literature, industry and national codes, it determined to study the four experimental factors that have a great influence on the performance of pervious concrete, that is, polypropylene steel fibre content, target porosity, water cement ratio, and particle size of recycled brick aggregate.

Test Method of Mechanical Properties

Compressive strength: The size of the test specimen is 100 mm * 100 mm * 100 mm. During the test, a pair of relatively flat sides are selected as the pressure surface. In order to ensure uniform pressure, the pressure surface must be treated. Due to the low compressive strength of pervious concrete, the test loading speed should be 0.3 MPa/s, and the compressive strength value should be the average value of three test specimens. If the maximum or minimum of the three test values exceeds 15% of the median, this test should be repeated.

Flexural strength: The size of the test specimen is 100 mm * 100 mm * 400 mm. During the test, a pair of relatively flat sides are selected as the compression surface. The test loading speed is 0.02 MPa/s, and the flexural strength value is taken as the average value of the three test pieces. If the maximum or minimum of the three test values exceeds 15% of the median value, or if the failure surface is outside the two concentrated loads, the test should be repeated.

Formula for calculating compressive strength of pervious concrete cube:

$$f_{cu} = \alpha \times \frac{P}{A} \quad \ldots(1)$$

Where, f_f is the compressive strength value of permeable concrete, Mpa; P is the failure load of cube test block, mm^2; and α is the conversion factor of the test block size, and the test piece of this test is 0.95.

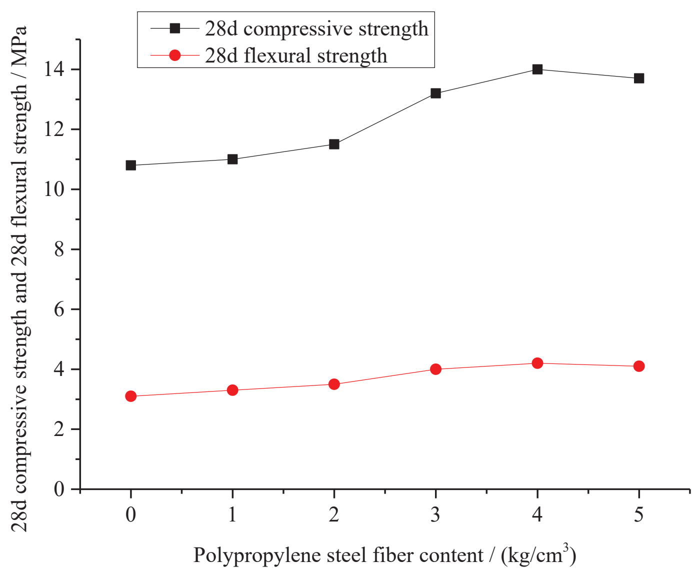

Fig. 1: Influence curves of compressive strength and flexural strength of polypropylene steel fibre.

Formula for calculating the flexural strength of permeable concrete:

$$f_f = \alpha \times \frac{PL}{bh^2} \qquad \ldots(2)$$

Where, f_f is the flexural strength value of permeable concrete, Mpa; P is the failure load of prismatic block, N; L is the support spacing (span), L = 3h, mm; and α is the conversion factor of the test block size, and the test piece of this test is 0.85.

In addition, DY-2008 automatic concrete pressure testing machine and WA-100 universal testing machine are selected for compressive strength testing and flexural strength testing.

RESULTS AND DISCUSSION

The Influence of Polypropylene Steel Fibre Content on Mechanical Properties of Recycled Brick Pervious Concrete

The content of polypropylene steel fibre was determined to be 0 -5 kg/m^3. The influence of polypropylene steel fibre on compressive strength and flexural strength is shown in Fig. 1.

The mechanical properties of recycled brick pervious concrete were much lower than that of dense concrete due to the unfavourable strength factors such as high crushed value of recycled brick aggregate and large porosity of pervious concrete. As can be concluded from Fig. 1, the compressive strength and flexural strength of the concrete showed an increasing trend with the increase of polypropylene steel fibre content. When polypropylene steel fibre content was 3 - 4 kg/m^3, the addition of an imitation steel fibre was equivalent to connecting a number of rebars between the recycled brick aggregates, it increased the bridging role between aggregate and binder surface and limited the deformation and stress of the concrete specimen. The test results showed that the appropriate amount of polypropylene steel fibre can significantly improve the mechanical strength of recycled brick aggregate pervious concrete specimens.

Influence of Target Porosity on Mechanical Properties of Recycled Brick Aggregate Pervious Concrete

According to CJJ / T235-2016, when the measured effective porosity of pervious concrete was more than 10%, it can meet the requirement of water permeability. The effects of target porosity on compressive strength and flexural strength are shown in Fig. 2 and Fig. 3.

It was found that under the premise of a certain particle size of recycled brick aggregate, when the target porosity was too small (the amount of cementitious material was relatively large), too much cementitious material would block the connected path of the test block when the test block was formed, and the phenomenon of "bottom sealing" would occur at the bottom of the test piece. When the target porosity was too large (the amount of cementitious material was relatively small), the cement slurry can't evenly wrap the recycled brick aggregate, so that the aggregate can't effectively bond together to produce qualified test blocks. As can be concluded

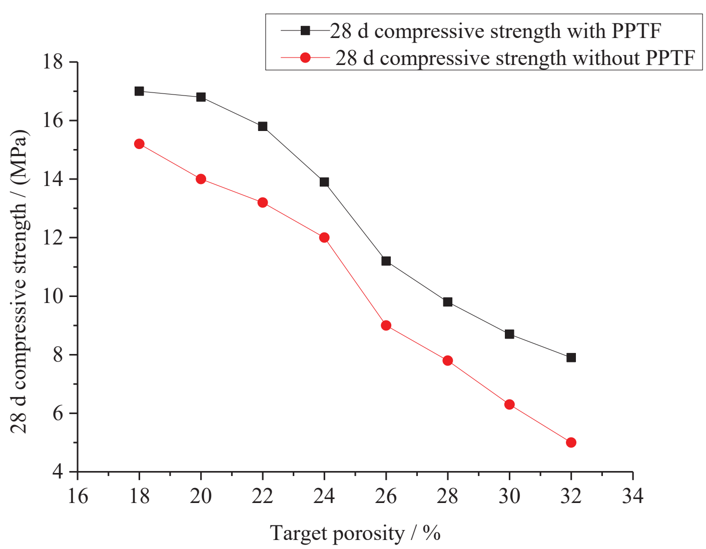

Fig. 2: Influence curve of target porosity on compressive strength.

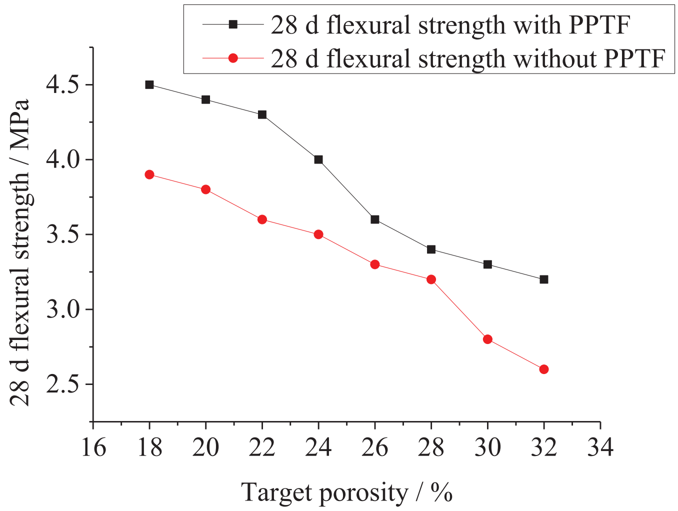

Fig. 3: Influence curve of target porosity on flexural strength.

from Fig. 2 and Fig. 3, with the increase of the target porosity, the compressive strength and flexural strength of the concrete presented a decreasing trend, and the decreasing range was large. This was because in order to meet the requirement of water permeability, pervious concrete required a larger porosity, resulting in its compressive strength and flexural strength were much smaller than ordinary concrete. When the target porosity was large, there were more interstitial spaces between the aggregates, but there were fewer cementing points between the aggregates, and the concrete strength was low. The strength mainly came from the bond effect between polypropylene steel fibre and recycled brick aggregate. When the target porosity was small, the cement slurry was well cemented to the regenerated brick aggregate, and the strength of the specimen was high and mainly came from the cementing effect between the aggregates, while the strengthening effect of polypropylene steel fibre was not significant. When the target porosity was 22% - 26%, the compressive strength of the concrete was about 14% higher than that of the concrete without the addition of steel fibre, and the flexural strength was about 16% higher than that of the concrete without the addition of steel fibre. This was because the bearing pressure failure of pervious concrete was the loss of cementation force between the aggregates rather than the fracture of the aggregate itself. The "hoop" effect of the steel fibre can make the recycled brick aggregate bond together better and force synergistically. At the beginning of the force, the cohesive force of the cementitious slurry between the aggregates and the mechanical bite force of the steel fibres were combined. As the load continued to increase, the adhesive force between aggregates was destroyed and gradually lost, and the bearing capacity of the imitation steel fibre continued. However, when the polypropylene simulated steel fibre was significantly deformed or pulled out as a whole, the integrity of the test specimen was destroyed and it exited the working state.

Influence of Water Cement Ratio on Mechanical Properties of Recycled Brick Aggregate Pervious Concrete

The research data showed that the optimal water cement ratio of pervious concrete is between 0.25 and 0.4. The effect of water cement ratio on compressive strength and flexural strength is shown in Fig. 4 and Fig. 5.

As can be concluded from Fig. 4 and Fig. 5, the relationship between mechanical strength and water cement ratio is different from that of ordinary dense concrete. With the increase of water cement ratio, the compressive strength and flexural strength of the pervious concrete first increased and then decreased. When the water cement ratio was between 0.32 and 0.34, the compressive strength was about 14.7 mpa and the flexural strength was about 4.5 mpa, both of which were the maximum values of the test.

The addition of an appropriate amount of steel fibre increased the bonding strength of the interface of recycled brick aggregate and significantly improved the mechanical properties of the concrete. The compressive strength was about 17 % higher than that without the addition of steel fibre, and the flexural strength was about 20 % higher than that without the addition of steel fibre. When the water cement ratio was small, the amount of water cannot meet

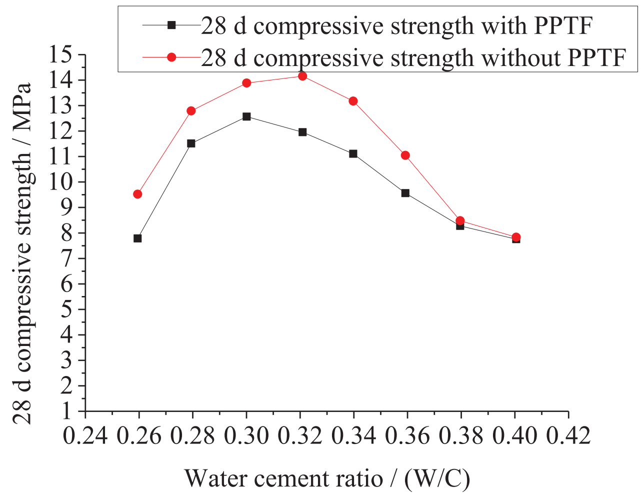

Fig. 4: Influence curve of water cement ratio on compressive strength.

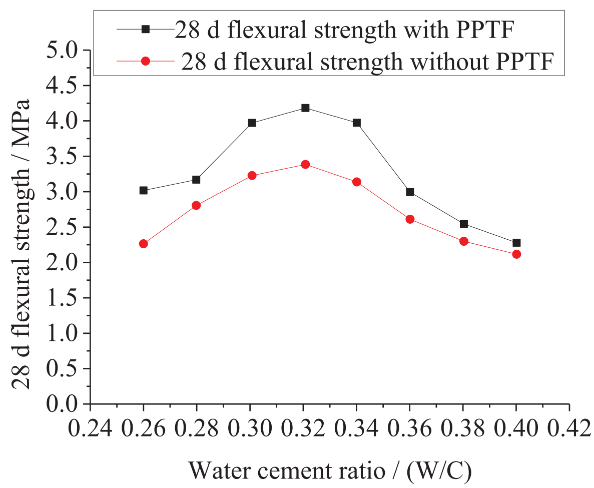

Fig. 5: Influence curve of water cement ratio on flexural strength.

the hydration effect of cement, the hydration effect of cement was not sufficient, the hydration product was less, the cement slurry and the recycled brick aggregate can't be well cemented together, resulting in the rough surface of the test block and the lack of metallic lustre or even unable to form, so the strength value of the test piece was small. In addition, doped polypropylene steel fibre would also bond part of the cement slurry, which not only had no effect on crack resistance and enhancement, but also further reduced the strength of the specimen. When the water cement ratio was too large, the hydration of cement was sufficient, but the excess free water increased the weak interface effect which was adverse to the strength. At the same time, if the water cement ratio was too large, the fluidity of the cement slurry would increase, and part of the cement slurry would slide to the bottom of the mould, resulting in the slurry film thickness of the recycled brick aggregate becoming thin and uneven. The phenomenon of "sealing the bottom" appeared at the bottom of the specimen, which was not conducive to the overall strength generation and permeability of the test block.

Influence of Aggregate Particle Size on Mechanical Properties of Recycled Brick Aggregate Pervious Concrete

After comprehensive consideration, the recycled brick aggregate with particle size of 4.75 mm - 31.5 mm was selected to design the test. The influence of particle size on compressive strength and flexural strength of recycled brick aggregate is

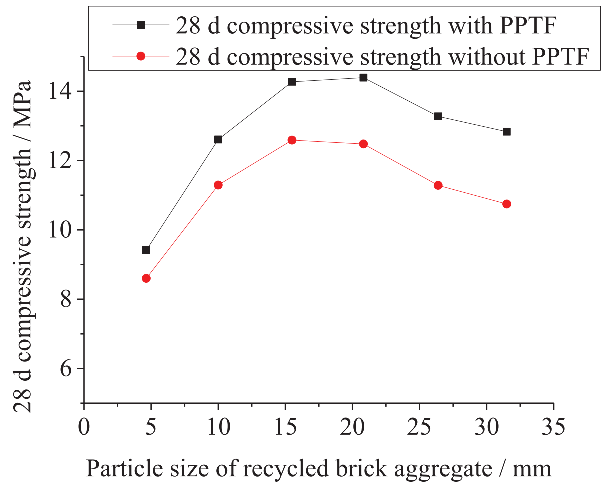

Fig. 6: Influence curve of recycled brick aggregate particle size on compressive strength.

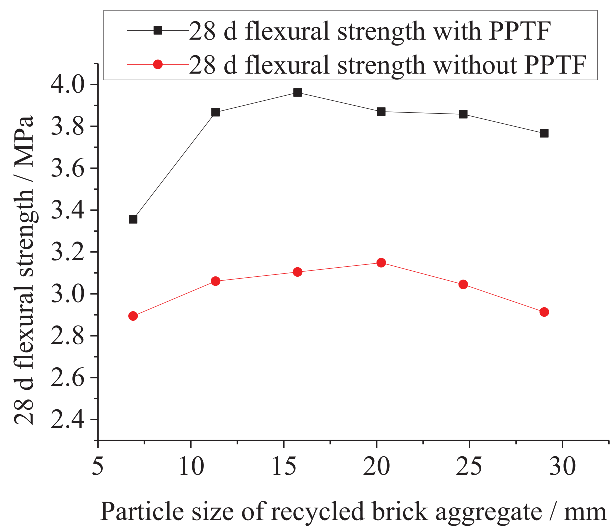

Fig. 7: Influence curve of particle size of recycled brick aggregate on flexural strength.

shown in Fig. 6 and Fig. 7.

As can be concluded from the relationship curve between the particle size of recycled brick aggregate and the mechanical strength of the specimen, the 28d compressive strength and flexural strength of the pervious concrete first increased with the increase of the particle size of recycled brick aggregate, and then tended to be stable or even slightly decreased. This was because the pervious concrete aggregate in this test was a recycled brick aggregate with a single particle size. When the particle size of recycled brick aggregate was smaller, the contact points between aggregate particles were more, the total contact area was larger, and the contact surface and contact point were cemented by cement slurry, so the strength of concrete at this time would not be too low. The test showed that when the particle size of recycled brick aggregate was 13.2 mm - 16 mm, the compressive strength of the test block was the maximum. And when the particle size of recycled brick aggregate was 9.5 mm - 16mm, the flexural strength of the test block was the maximum.

CONCLUSION

In this study, the influence of various experimental factors on the mechanical properties of recycled brick permeable concrete and the strengthening mechanism of polypropylene steel fibre were introduced, which provided a certain theoretical basis for the selection of target porosity and water cement ratio of recycled brick aggregate permeable concrete. The results showed that the compressive strength and flexural strength of recycled brick aggregate pervious concrete were lower than that of ordinary aggregate pervious concrete, especially the compressive strength was about half of that of crushed stone aggregate pervious concrete (about 14.7 MPa), which was determined by the physical and mechanical properties of recycled brick aggregate. Target porosity had the most significant effect on the mechanical strength of the regenerated brick specimens, and the smaller the target porosity was, the higher the compressive strength was, and vice versa. The particle size of recycled brick aggregate had little influence on the mechanical strength value of the specimen. Appropriate amount of polypropylene steel fibre can significantly improve the mechanical strength of the pervious concrete, and the flexural strength was higher than the compressive strength. Therefore, the new type of pervious concrete made of recycled brick aggregate mixed with polypropylene steel fibre can make solid construction waste be recycled, save natural resources and reduce the pollution of construction waste to the urban environment. In addition, it helps to improve the urban and rural ecological environment and rainwater utilization, reduce the environmental burden, conducive to water and soil conservation, and build a comfortable living environment for human beings.

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