Effect of recycled aggregate reinforcement on strength of pervious concrete

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Abstract: This article compares different reinforcement schemes for recycled aggregates. This paper proposes a reinforcement scheme that the recycled aggregate is first surface-coated with a mineral admixture in a cement slurry, and then impregnated in a water glass solution under a negative pressure environment. The recycled aggregate improves particle morphology and basic properties. Compare the effect of recycled aggregate on the strength of pervious concrete before and after strengthening to improve the utilization rate of recycled aggregate in pervious concrete. The results show that the basic properties of the recycled aggregates have been significantly improved, and the main technical indicators have met the requirements for the use of "Grade II recycled aggregates." Pervious concrete's compressive strength increased 31% to 22.7 MPa.

1. Introduction

Recycled aggregate pervious concrete is a new building material that integrates drainage, water storage, ventilation and temperature adjustment. It is an important part of the construction of sponge cities [1]. On the one hand, it reduces the use of natural sand aggregates and protects the vegetation in the mountains. On the other hand, it can consume large amounts of construction waste to protect the environment[2-4]. Low-quality recycled aggregates have large dispersion and low strength, so they need to be strengthened before they can be put into use. At present, the use of single strengthening program in the reinforcement of recycled aggregates is limited to strengthening the surface of aggregates. Du Ting [5] and others prepared the aggregate reinforcement by formulating different cement grouts. Cheng Haili[6] used sodium silicate solution to impregnate the recycled aggregate. The results show that a single reinforced recycled aggregate can increase the strength of recycled aggregates to a certain extent and reduce the water absorption rate, but the strength of the concrete is less increased. In this paper, based on the single enhancement basis, the reinforcement mechanism of recycled aggregates is studied in depth, and a composite strengthening scheme is proposed that is followed by surface impregnation followed by deep impregnation.

2. Test program

2.1. Raw materials

Recycled Aggregate is produced by an enterprise in Jilin Province, broken and sieved from abandoned concrete. Its physical properties is shown in Table 1, the use of particle size range of 5 ~ 10mm. Cement is P•O 42.5 grade cement; ultra-fine silica fume’s specific surface area is 19.827m²/g, and SiO₂ content ≥90%; II grade fly ash’s specific surface area after grinding is 1.367m²/g. Water reducer
is super plasticizer, and water reduction rate is 25%. Styrene-acrylate emulsion’s solids content is 46%; sodium silicate’s module is 3.34; polyvinyl alcohol is produced by Shanxi Three-dimensional Group.

Table 1. Physical properties of recycled aggregates

| Apparent density / (kg/m³) | Bulk density / (kg/m³) | Water absorption / % | Crush index |
|---------------------------|------------------------|----------------------|-------------|
| 2340                      | 1204                   | 7.5                  | 23          |

2.2 Reinforced treatment of recycled aggregates

2.2.1 Cement slurry package.
The cement and the mineral admixture were blended and mixed in proportion to obtain a composite cementitious material with a water-cement ratio of 1:2, formulated into different cement grouts. Then the pre-wet treated recycled aggregate was immersed in the cement grout. Before the initial setting of cement, centrifugation stirring every 60min for 60s, so that the air bubbles on the surface of the aggregate can be fully absorbed and the operation repeated 3 times. Then, remove the recycled aggregate and sieve out the excess slurry. Finally, the recycled aggregate was placed in an accelerating curing box, cured for 6 hours at 60°C, and dried after being used. According to GB/T 25177-2010 Recycled Coarse Aggregate for Concrete, the physical properties of recycled aggregate was measured.

2.2.2 Chemical impregnation.
After the cement slurry was wrapped, the recycled aggregate was placed in a vacuum chamber to exhaust the air in the pores of the aggregate under a negative pressure environment. Then sodium silicate solution and polyvinyl alcohol solution with different concentrations of water were prepared and introduced into a vacuum chamber to impregnate the recycled aggregate for 1 h. Finally, remove the recycled aggregate and dry it for later use.

2.3. Preparation of pervious concrete
According to CJJ/T 135-2009 Technical Specification for Pervious Cement Concrete Pavements, permeable concrete was prepared and its basic performance was measured. The basic mixing ratio is: the designed porosity is 15%, the bone cement ratio is 3.7, the water cement ratio is 0.32, and the superplasticizer content is 0.2%. Because of the high water absorption rate of recycled aggregate, it is advisable to pre-wet the recycled aggregate to achieve a saturated dry state in order to keep the water-cement ratio of the concrete constant. The test piece size was 150×150×150mm, and the cementing method adopts the “cement-encased stone method”. The forming method was static pressure molding and it was maintained in a standard environment.

3 Reinforcement test of recycled aggregate

3.1 Cementing material strengthening
The mineral admixtures play a pozzolanic effect and morphological effects and other mechanisms, effectively fill the micro-cracks and micro-pores of recycled aggregate, and improve its performance. The different test schemes are shown in Table 2.

Table 2. Test scheme and result of cementitious material strengthening

| Serial number | Admixture combination | Dosage / % | Apparent density / (kg/m³) | Water absorption / % | Crush index |
|---------------|-----------------------|------------|---------------------------|----------------------|-------------|
| A1            | cement                | -          | 2470                      | 8.4                  | 18.3        |
| A2            | SF                    | 5          | 2566                      | 7.6                  | 16.6        |
| A3            | FA                    | 20         | 2503                      | 8.0                  | 18.1        |
| A4            | SP                    | 20         | 2521                      | 7.8                  | 16.9        |
| A5            | SF+FA                 | 5+15       | 2552                      | 5.7                  | 14.9        |
Table 2 shows that the cement slurries formulated with different schemes could improve the performance of recycled aggregates to some extent, and both the crushing index and the apparent density were improved, but the water absorption rate was increased to a small extent or even slightly increased. After the cement slurry was encased and reinforced, a crust layer formed on the surface of the recycled aggregate, and the content of pin-like particles was significantly reduced. In addition, the fine particles filled the pores and micro-fractures on the surface of the recycled aggregate, and the hydration reaction enhanced the aggregate. However, due to the high water absorption of the slurry itself, the water absorption of the recycled aggregate is less affected. Among them, the A3 group of cement mortar mixed with silica fume, fly ash prepared by the hydraulic slurry index reduced by 35%, the best enhancement.

### 3.2. Composite reinforcement

Based on the strengthening of the cement slurry, it was "secondarily strengthened" with a chemical solution. Taking A5 group as the control group, using different concentrations of water glass solution and polyvinyl alcohol solution impregnated recycled aggregate, the test results are shown in Table 3.

| Serial number | Dipping treatment                  | Apparent density / (kg/m³) | Water absorption / % | Crush index |
|---------------|-----------------------------------|----------------------------|----------------------|-------------|
| A5            | Unprocessed                        | 2452                       | 5.7                  | 14.9        |
| A6            | Sodium silicate solution           | 2460                       | 3.7                  | 13.4        |
| A7            | Polyvinyl alcohol solution         | 2473                       | 4.3                  | 14.0        |

According to the test, sodium silicate solution and polyvinyl alcohol solution can further reduce the water absorption, and can strengthen the inside of the aggregate under the negative pressure environment. The chemical solution can improve the surface state of the aggregate and reduce the water absorption. The best concentration of water glass was 15% and the soaking time was 1 hour.

### 3.3 Analysis of strengthening mechanism of recycled aggregate

On the one hand, cement slurries were filled with micro-fractures and larger pore structures of recycled aggregates under centrifugal agitation. Due to the fine phasing of ultra-fine fly ash, silica fume and cement powder, it was possible to further strengthen aggregates, inside the pores. The mechanism of pozzolanic effect and micro-aggregate effect of mineral admixtures play a role in the hardening process of composite cement slurry. Hydration products interweave and fill in the micro-fractures of aggregates and form a dense structure of cement shells on the outer surface of aggregates. The thickness was about 70~100μm, which significantly improved the structural shape and strength of recycled aggregates. On the other hand, in the vacuum environment, the sodium silicate solution penetrated the "cement shell" of the aggregate surface, utilized the phase transition process of the water glass from the liquid phase to the solid phase, and coagulation hardens, and the precipitated calcium silicate gel was filled and plugged. The internal pores of recycled aggregates increased their robustness and crushing index, and can reduce the water absorption rate. After curing, they can form a dense layer of “glassy film” on the surface.

### 4. Strength test of recycled aggregate pervious concrete

The permeable concrete was prepared from the reinforced recycled aggregates of the A5, A6, and A7 groups. The volumetric filling method was used to design the mix. The recycled aggregate was completely replaced and the porosity was designed to be 15%. The water-cement ratio was 0.3, Water reducer dosage 0.2%. The test results are shown in Figure 1.
Fig. 1. Performance of recycled aggregate permeable concrete with different strengthening methods

4.1. Analysis of test results
According to the effect on the pervious concrete before and after strengthening the recycled aggregate, the reinforced recycled aggregate can increase the strength of the pervious concrete. Among them, the strength of the recycled concrete pervious concrete after reinforcement of the sodium silicate solution in the A6 group was the most obvious, reach to 22.7 MPa, and the permeability coefficient meets the requirements for use.

The mechanical properties of pervious concrete not only depend on the mechanical bite force among the aggregates, but also on the strength of recycled aggregate. It mainly affects the strength of pervious concrete from two aspects. On the one hand, the reinforced recycled aggregate significantly improves the workability of pervious concrete. The cement slurry envelops the recycled aggregate, which can obviously improve the particle morphology of the aggregate, reduce the needle-like content of the recycled aggregate, reduce the internal friction resistance among the aggregates, and increase the bulk density of the pervious concrete during the molding process. The reduction of the water absorption of the recycled aggregate can keep the water-cement ratio unchanged during the mixing process, effectively improve the workability of the pervious concrete and improve its fluidity. On the other hand, the strength of pervious concrete mainly depends on the mechanical biting force between the aggregates and the bonding force at the contact point. After strengthening the recycled aggregates, the particle morphology tends to be spherical, the contact surface between the aggregates increases, and the stress concentration phenomenon is reduced, thereby effectively enhancing the mechanical bite force between the aggregates.

5. Inconclusion
This paper studied the reinforcement scheme of recycled aggregates. The best solution was that the first layer of recycled aggregate was first coated with a layer of cement slurry mixed with mineral admixture, and then deep impregnated with sodium silicate solution in a negative pressure environment, which can significantly improve the bone. The basic performance of the recycled aggregates met the requirements for the use of "Grade II recycled aggregate". Then, after analyzing the reinforced concrete pervious concrete prepared before and after strengthening, the compressive strength was increased by 31% to reach 22.7 MPa, and the permeability coefficient satisfied the use demand.

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