Experimental study of the physical and mechanical properties of pervious concrete with recycled and gravel aggregate

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Abstract. A experiment research on pervious concrete using recycled and gravel as aggregate was carried out. The effects of aggregate binder ratio and water cement ratio on compressive strength of the concrete were studied. The results show that the water cement ratio has different influence on the compressive strength of the two kinds of concretes, while the influence rule of the aggregate binder ratio is approximately the same, but the degree is different, moreover, the compressive strength of the concrete (using gravel as aggregate) in 28 days is basically the same as that in 56 days.

1. Introduction
Low-impact development is the trend of urban construction, in 2015 and 2016, China announced the construction of 30 pilot cities with low-impact development, moreover, pervious concrete is an important part of the construction.

Pervious concrete made from aggregate, cement, water and other materials, is a new kind of concrete with continuous pores, the strength, permeability and durability that need to be considered comprehensively in the course of use.

In contrast with gravel aggregate, the feature of recycled aggregate is low-strength, roughness surface, large absorbing water and so on. Research shows that recycled aggregate can be used as aggregate in pervious concrete.

Comparative study on pervious concrete used recycled aggregate or gravel as aggregate, not only enables the construction waste resource recovery, but also mitigates the lack of gravel as well as preserves the non-renewable resources.

2. Main research content
This paper mainly focuses on the physical and mechanical properties of pervious concrete with recycled and gravel aggregate. Raw materials included cement, recycled aggregate and gravel aggregate(size of 5~10mm), silica fume, superplasticizer and water. Experimental protocol include:(1) Key points of mix proportion design; (2) Effects of aggregate binder ratio on the compressive strength; (3) Effects of water cement ratio on the compressive strength;(4) Experimental study on 56-day compressive strength of the concrete using gravel as aggregate.
3. Materials and methods

3.1. Reference standards of testing method

Five Chinese standards of testing method are referenced in this paper as follows:

- 《Standard for technical requirements and test method of sand and crushed stone (or gravel) for ordinary concrete》 (JGJ52-2006);
- 《Method of testing cements—Determination of strength》 (GB/T17671-1999);
- 《Test methods for water requirement of normal consistency, setting time and soundness of the Portland cement》 (GB/T1346-2001);
- 《Autoclave method for soundness of Portland cement》 (GB750-92);
- 《The test sieving method for fineness of cement》 (GB/T1345-2005).

3.2. Selection of Materials

1. Cement: Ordinary Portland cement with the strength grade 42.5 was selected, and its properties are shown in Table 1.

| Aggregate type | Gravel aggregate | Recycled aggregate |
|----------------|------------------|--------------------|
| Subject of entry | Aggregate size /mm | 5–10 | 5–10 |
| Apparent density / (kg.m\(^{-3}\)) | 2649 | 2234 |
| Bulk density / (kg.m\(^{-3}\)) | 1503 | 1301 |
| Void fraction (%) | 43.3 | 41.8 |
| Water absorption (%) | 1.02 | 4.52 |
| Crushing value index (%) | 6.36 | 12.65 |

Notes: 1. The water requirement for normal consistency increased is 144.5g.
2. The fineness of cement is tested by 80μm sieve.
3. Gravel aggregate: The physical and mechanical properties of the aggregate are shown in Table 2.
4. Superplasticizer: Polycarboxylate superplasticizer was selected and its water reducing rate is over 25%.
5. Silica fume: Silica fume was used as mineral admixture and its properties are shown in Table 3.

| Table 1 Physical-mechanical properties of cement |
|-----------------------------------------------|
| Apparent density [g/cm\(^{3}\)] | Fineness [%] | Setting time [min] | Flexural strength [MPa] | Compressive strength [MPa] | Soundness |
|-----------------------------------------------|
| Initial | Final | Initial | Final | 3d | 28d | 3d | 28d |
| 3.1 | 3.4 | 224 | 297 | 5.9 | 8.8 | 30.6 | 63.4 | qualified |

| Table 2 Physical and mechanical properties of aggregate |
|--------------------------------------------------------|
| Subject of entry | Aggregate type | Gravel aggregate | Recycled aggregate |
|-------------------|----------------|------------------|--------------------|
| Aggregate size /mm | 5–10 | 5–10 |
| Apparent density / (kg.m\(^{-3}\)) | 2649 | 2234 |
| Bulk density / (kg.m\(^{-3}\)) | 1503 | 1301 |
| Void fraction (%) | 43.3 | 41.8 |
| Water absorption (%) | 1.02 | 4.52 |
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4. Mix design and concrete preparation

4.1. Mix design
Pervious concrete should meet the requirements of strength, permeability, cost and workability in real project. Of these parameters, the aggregate binder ratio has a greater influence on the strength and permeability of the concrete, and the water cement ratio and superplasticizer have significantly effects on cost and workability of the concrete. Aimed at the application to the project, the design steps of mix proportion have been determined after many experiments:

1. Aggregate volume required
   According to many tests and engineering examples, 1.04 m³ recycled aggregate or 1.05 m³ gravel aggregate should be used to prepare 1 m³ pervious concrete.

2. Aggregate binder ratio
   Strength and permeability are important indexes of pervious concrete, the results show that when the aggregate binder ratio is 3.5~4.5 (for gravel aggregate), the pervious concrete meets the application requirements of normal project. Therefore, the aggregate binder ratios of this article were selected as 3.5:1, 4.0:1 and 4.5:1.

3. Water cement ratio and superplasticizer admixture
   The superplasticizer is helpful to improve the strength of the pervious concrete and the workability of the mixture. In practical applications, the admixture of the superplasticizer was selected between 0.9% and 1.5%.

   The optimized dosages of the superplasticizer and the paste liquidity under different water cement ratios are shown in Table 4.

   Tab.4 Dosage of superplasticizer and dispersion of paste

   | NO. | Water cement ratio | Superplasticizer (%) | paste liquidity (mm) |
   |-----|--------------------|----------------------|---------------------|
   | 1   | 0.275              | 1.5                  | 139                 |
   | 2   | 0.300              | 1.2                  | 138                 |
   | 3   | 0.325              | 0.9                  | 139                 |

4. Water content
   In the mix design, the water content for different water cement ratios was calculated based on saturated surface drying of aggregate.

4.2 Mix proportion
   The mix proportion of pervious concrete is shown in Table 5.

   Tab.5 Mix proportion of pervious concrete

   | Aggregate type | mix | aggregate/kg | cement/kg | silica fume /kg | superplasticizer /kg | water/kg |
   |----------------|-----|--------------|-----------|-----------------|----------------------|---------|
   | gravel aggregate | G-1 | 1581         | 383.05    | 11.50           | 5.92                 | 121.92  |
   |                 | G-2 | 1581         | 383.05    | 11.50           | 4.73                 | 131.78  |
   |                 | G-3 | 1581         | 383.05    | 11.50           | 3.55                 | 141.64  |
   |                 | G-4 | 1581         | 437.77    | 13.13           | 6.76                 | 137.41  |
   |                 | G-5 | 1581         | 340.49    | 10.21           | 5.26                 | 109.86  |
   | recycled aggregate | R-1 | 1376         | 328.41    | 9.85            | 5.07                 | 130.91  |
   |                 | R-2 | 1376         | 328.41    | 9.85            | 4.06                 | 139.36  |
   |                 | R-3 | 1376         | 328.41    | 9.85            | 3.04                 | 147.82  |
   |                 | R-4 | 1376         | 375.32    | 11.26           | 5.80                 | 144.19  |
   |                 | R-5 | 1376         | 291.92    | 8.76            | 4.51                 | 120.57  |

4.3 Concrete mixing and preparation of specimens
   The mixing process of cement paste encapsulating aggregate method is selected, and cubic specimens with the size of 150 mm × 150 mm × 150 mm is prepared for measure the compressive strength.
4.4. Curing
All the specimens were held for 24h and then demoulded. Subsequently, they were cured in standard condition for 28 days or 56 days for measure the compressive strength.

5. Results and discussion

5.1. The effects of the aggregate binder ratio on the compressive strength
The relationship between compressive strength and aggregate binder ratio are shown in figure 1.

As shown in Fig.1, the compressive strength of the concrete using recycled and gravel as aggregate decreases as the aggregate binder ratio increases, but the range of change is different. Moreover, the compressive strength of the concrete with gravel aggregate is higher than that of the concrete using recycled as aggregate. When the aggregate binder ratio is 3.5, 4, 4.5, the compressive strength of the concrete with gravel aggregate is 58.1%, 104.2% and 74.4% higher than that of concrete with recycled aggregate.

For pervious concrete with recycled aggregate, as the aggregate binder ratio was raised first from 3.5 to 4.0 and then to 4.5, the compressive strength decreased 34.9% and 46.5%, respectively, the latter is 1.33 times higher than the former.

For pervious concrete using gravel as aggregate, as the aggregate binder ratio was raised first from 3.5 to 4.0 and then to 4.5, the compressive strength decreased 15.9% and 41.0%, respectively, the latter is 2.58 times higher than the former.

This can be explained as follows: First, the binder thickness over the aggregate increases with the decrease of the aggregate binder ratio, a smaller aggregate bind ratio means a higher compressive strength. Second, there are many small cracks in recycled aggregate, and crushing value index of the recycled aggregate is 1.99 times that of the gravel. Moreover, with the increase of the amount of binder, the compensation effect of binder on the internal defects of recycled aggregates increases. Third, the non-uniformity of recycled aggregate material increases the discreteness of test data.

5.2. The effects of the water cement ratio on the compressive strength
The relationship between compressive strength and water cement ratio are shown in figure 2.
As shown in Fig.2, the compressive strength of pervious concrete using recycled and gravel as aggregate shows different development trend with the increase of water cement ratio, in addition, the compressive strength of the concrete with gravel aggregate is higher than that of the concrete using recycled aggregate. When the water cement ratio is 0.275, 0.3, 0.325, the compressive strength of the concrete with gravel aggregate is 104.2%, 50.1% and 151.5% higher than that of the concrete with recycled aggregate.

For pervious concrete with recycled aggregate, it can be seen that the compressive strength of the concrete initially increases and subsequently decreases with the increase of water cement ratio. The water cement ratio is on 0.3, the compressive strength is the largest, when the water cement ratio is 0.275 and 0.325, the compressive strength decreases by 19.2% and 31.6%.

For pervious concrete using gravel as aggregate, it can be seen that the compressive strength of the concrete initially decreases and subsequently increases with the increase of water cement ratio. The water cement ratio is on 0.3, the compressive strength is the smallest, when the water cement ratio is 0.275 and 0.325, the compressive strength increases by 10.0% and 14.6%.

This can be explained as follows: First, to the same water cement ratio, there is no uniform rule for the compressive strength of pervious concrete. Second, recycled aggregate and gravel aggregate have different material characteristics, the influence of aggregate hardness on the strength of pervious concrete exceeds that of water cement ratio on the strength of pervious concrete. Third, the large water absorption of recycled aggregate material increases the discreteness of test data.

5.3. The effects of the water cement ratio on the flexural strength

The relationship between compressive strength and sample are shown in figure 3, the relationship between porosity and sample are shown in figure 4.
As shown in Fig.3 and Fig.4, for samples No. 1, No. 3, No. 5, the compressive strength of 56 days decreased by 0.8%, 8.8% and 16.1% compared with that of 28 days while the samples No.2 and No.4 increased by 13.8% and 6.0%, at the same time, for samples except No.4, compared with the 28-day sample porosity, the 56-day sample porosity increased by 3.1%, 7.1%, 5.4% and 22.0% while the sample No.4 decreases by 11.9%. Considering the effect of porosity on the strength of pervious concrete, compared with 28-day compressive strength, the 56-day compressive strength of ordinary pervious concrete did not increase significantly.

This is because pervious concrete be destroyed in the following two main forms: destruction among the aggregate points or the deconstruction of aggregate, for concrete blocks, the increase of the strength of binder (Strength increment from 28-day-old to 56-day-old) can be neglected.

6. Conclusions
The physical and mechanical properties of pervious concrete using recycled and gravel as aggregate were systematically presented. The experimental results presented above lead us to draw the following conclusions:

1) Comparing with recycled aggregate pervious concrete, Crushing value index of gravel aggregate decreases by 50.3%, compressive strength of concrete increases by 50.1%~151.5%.

2) The compressive strength of pervious concrete with recycled and gravel aggregate decreases as the aggregate binder ratio increases, but the range of change is different.

3) The compressive strength of recycled aggregate pervious concrete and ordinary pervious concrete shows different development trend with the increase of water cement ratio.

4) The 56-day compressive strength of ordinary pervious concrete is basically the same as that of 28-day permeable concrete.

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