Mix Design Recycled Aggregate Pervious Concrete and the Influence on Pavement Property

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Abstract: This paper prepared recycled aggregate pervious concrete by replacing natural aggregate with 100% volume of waste concrete. We carried out experiments to study the influences of strength grade and target porosity of waste recycled aggregate concrete on the recycled one's compressive strength and permeability coefficient. Then, the optimal proportion meeting the requirements of pervious concrete pavement is obtained, which is expected to be applied to the pavement with low strength requirement and water permeability. The test results of the compressive strength and permeability coefficient of 28-day test cubes show that, considering both the compressive strength and permeability, the best proportion is as follows: the strength grade of recycled aggregate is C20 + C30, the mix proportion of aggregate is 50%, the target porosity is 15%, the water-cement ratio is 0.3, the recycled aggregate is composed of 50% recycled aggregate with a particle size of 4.75-9.5 mm and 50% that of 9.5-19 mm, and the optimal mix proportion of recycled aggregate pervious concrete (kg/m³) is: m (recycled aggregate): m (cement): m (water) = 1357.04:564.94:169.88. The compressive strength and the permeability coefficient of recycled aggregate pervious concrete based on this mix proportion are 25.07 Mpa and 6.23 mm/s, respectively, which are in line with the provisions of Technical Specification for Application of Recycled Aggregate Pervious Concrete (CJJ/T 253-2016) and can be used for pavement. The study results can provide a reference for the promotion and application of recycled aggregate pervious concrete in the pavement.

1. Introduction

With the accelerating urbanization and the gradual increase of construction waste, the disposal and reuse of waste concrete have become a more severe problem. China produces about 1.8 billion tons of construction waste every year. Still, the overall utilization rate is less than 10%, far lower than the 90% in European and American countries and 95% in Japan and South Korea. At present, waste concrete is mainly directly buried or disposed of. At the same time, the long-term excessive exploitation and consumption of natural aggregate result in its severe shortage. According to statistics, China's concrete industry is consuming about 5 billion tons of natural aggregate every year, bringing increasingly severe environmental problems, so it is imperative to conduct this study.

The rainfall in Hunan Province is about 1150 mm-2100 mm with more than 10 heavy rains every year, and the maximum rainfall in one hour of 157 mm, which is relatively high. In recent years, heavy rainfall has caused frequent urban waterlogging disasters and resulted in traffic paralysis, commuting inconvenience, seriously affecting people's production and life, and threatening urban security. Therefore, replacing the natural aggregate with the recycled aggregate of construction waste to prepare recycled aggregate pervious concrete can solve the problems of municipal pavement water, urban
waterlogging, and so on. Adhering to the concept of sustainable development can effectively facilitate China's "sponge city" construction, which can bring high economic and commercial benefits [2].

In this study, recycled aggregate pervious concrete with certain compressive strength and permeability is made from 100% volume of waste concrete with different strength grades and particle sizes through crushing, cleaning, and screening, without adding any natural aggregate. Considering the influence of the target porosity of waste on the permeability coefficient, this study carries out combined tests of recycled aggregate with different strength grades to design the recycled aggregate pervious concrete that can be applied to pavements. According to the design requirements of strength and permeability, this study tries to find out the best proportion of waste concrete to help effectively solve the pollution and landfill problems of waste concrete.

2. Raw Materials and Test Methods

2.1. Raw Materials

2.1.1. Recycled Coarse Aggregate

The recycled coarse aggregate used in this test is taken from the construction waste concrete, crushed by jaw crusher and manual labor, and divided into two groups with particle sizes ranging from 4.75-9.5 mm and 9.5-19 mm through square hole sieve. The recycled aggregate pervious concrete is prepared by the aggregate which is cleaned and dried manually to remove surface impurities, as shown in Figure 1. Aggregate gradation is shown in Table 1.

| Size of Sieve Pore (mm) | 19 | 9.5 | 4.75 |
|-------------------------|----|-----|------|
| Percent Passing (%)     | 100| 30  | 0    |

Table 1 Aggregate gradation

2.1.2. Cement and Water

The cement is the South P·O 42.5 grade ordinary portland cement produced by Nanfang Cement Co., Ltd., and the test mixing water is the tap water in the laboratory. The basic property indexes of cement are shown in Table 2[3].

| Density /kg·m⁻³ | Setting Time / min | Stability | Flexural Strength / MPa | Compressive Strength / MPa |
|-----------------|------------------|----------|-------------------------|---------------------------|
|                 | Initial Setting Time | Final Setting Time | 3d  | 28d | 3d  | 28d |
| 3100            | 180              | 270      | Qualified              | 4.4 | 7.6 | 24.4 | 46.7 |

Table 2 The basic properties of cement
2.2. Mix proportion Design

The fundamental property index of recycled aggregate pervious concrete is permeability, and the most significant influencing factor is the target porosity \[^4\]. In the mix proportion design, the target porosity should be designed first as 10%, 15%, 20% and 25%, respectively. The recycled aggregate with different strength grades of C20, C30 and C40 are mixed with each other in the proportion of 50%. There are \(3 + C_3^2 = 6\) combinations, and each design has three standard test cubes of 150mm×150mm×150mm. According to Technical Specification for Application of Recycled Aggregate Pervious Concrete (CJJ/T 253-2016), the water-cement ratio of recycled aggregate pervious concrete is better between 0.25-0.35, and the effect of slightly adjusting the water-cement ratio on the strength is not obvious. The test adopts the water-cement ratio of 0.3, and the recycled aggregate comprises particles of sizes 4.75-9.5 mm and 9.5-19 mm, with each size accounting for 50% of the total portion. The mix designs of pervious concrete are shown in Table 3.

| Combination   | Design Porosity | Water-Cement Ratio | Material Usage (kg/m³) |
|---------------|-----------------|--------------------|------------------------|
|               |                 |                    | Coarse Aggregate       | Cement          | Water          |
|               |                 |                    | 4.75-9.5 mm           | 9.5-19 mm       |                |
| RAC1          | 10%             | 0.3                | 670.62                | 661.73          | 198.52         |
| RAC1          | 15%             | 0.3                | 670.62                | 576.79          | 172.84         |
| RAC1          | 20%             | 0.3                | 670.62                | 491.85          | 148.15         |
| RAC1          | 25%             | 0.3                | 670.62                | 406.91          | 121.48         |
| RAC2          | 10%             | 0.3                | 685.43                | 606.42          | 181.73         |
| RAC2          | 15%             | 0.3                | 685.43                | 522.47          | 157.04         |
| RAC2          | 20%             | 0.3                | 685.43                | 437.53          | 131.36         |
| RAC2          | 25%             | 0.3                | 685.43                | 352.59          | 105.68         |
| RAC3          | 10%             | 0.3                | 709.14                | 600.49          | 179.75         |
| RAC3          | 15%             | 0.3                | 709.14                | 516.54          | 154.07         |
| RAC3          | 20%             | 0.3                | 709.14                | 430.62          | 129.38         |
| RAC3          | 25%             | 0.3                | 709.14                | 345.68          | 103.70         |
| RAC1+RAC2     | 10%             | 0.3                | 678.52                | 649.88          | 195.56         |
| RAC1+RAC2     | 15%             | 0.3                | 678.52                | 564.94          | 169.88         |
| RAC1+RAC2     | 20%             | 0.3                | 678.52                | 480.99          | 144.20         |
| RAC1+RAC2     | 25%             | 0.3                | 678.52                | 396.05          | 118.52         |
| RAC1+RAC3     | 10%             | 0.3                | 670.62                | 659.75          | 198.52         |
| RAC1+RAC3     | 15%             | 0.3                | 670.62                | 575.8           | 172.84         |
| RAC1+RAC3     | 20%             | 0.3                | 670.62                | 490.86          | 147.16         |
| RAC1+RAC3     | 25%             | 0.3                | 670.62                | 405.93          | 121.48         |
| RAC2+RAC3     | 10%             | 0.3                | 709.14                | 610.37          | 182.72         |
| RAC2+RAC3     | 15%             | 0.3                | 709.14                | 525.43          | 158.02         |
| RAC2+RAC3     | 20%             | 0.3                | 709.14                | 440.49          | 132.35         |
| RAC2+RAC3     | 25%             | 0.3                | 709.14                | 355.56          | 106.67         |

Note: RAC1, RAC2 and RAC3 represent the waste concrete with strength grades of C20, C30 and C40 as recycled coarse aggregate, respectively.

2.3. Production and Maintenance of Pervious Concrete

The concrete is prepared by mixing cement with stones. First, mix 50% water with all coarse aggregate for 30s; and then, mix the remaining mixed water with cement ash for 90s; and finally, fill the mould, and demould and sample it after 1 day. The test cubes of recycled aggregate pervious concrete are placed
in the standard curing room, with a temperature of 20 ± 2 ℃, a relative humidity of over 95%, and a curing time of 28 days.

2.4. Test Method

2.4.1. Mechanical Property Tests
According to Standard for Testing Methods on Mechanical Properties of Ordinary Concrete (GB/T 50081-2002), the compressive strength of the standard test cubes of recycled aggregate pervious concrete aged 28 days under standard curing is tested by a hydraulic press, and the test results are the average value of three 150mm×150mm×150mm standard test cubes.[5]

2.4.2. Study on Permeability
According to the Technical Specification for Pervious Cement Concrete Pavement (CJJ/T 135-2009), the permeability coefficient is measured by the head-fixed method. The test device is shown in Figure 3.
As shown in Figure 4, cement is applied on the sides of three 150mm×150mm×150mm standard test cubes formed with different numbers and is put in water with the water level 10 cm higher than the test cubes. Then, they are soaked for 20 minutes. Finally, they are taken out to be connected with the square cylinder of the water permeability test device. The gaps around the test block are sealed with plasticine, and the perimeter of the unit is sealed with clear tape, in which way, the water only penetrates from the surface of the test cubes. An overflow tank is arranged with the valve opened to allow the water flow in. When water flows out of the overflow tank, the inflow is adjusted to keep a certain water level difference of the square cylinder. When the water flows from the overflow tank and the square cylinder become stable, a measuring cylinder is adopted to receive water at the outlet. The water outflow Q is recorded within the corresponding time, and is measured 3 times to obtain the average value. The calculation formula of permeability coefficient is as follows [6]:

\[ K_T = \frac{Q \cdot L}{A \cdot h \cdot t} \]  

where

- \( K_T \) -- the permeability coefficient when water reaches T ℃, mm/s;
- Q -- the amount of water flowing through the pervious concrete test cubes within time t, mm³;
- L -- the thickness of pervious concrete test cubes, mm;
- A -- cross-sectional area of pervious concrete test cubes, mm²;
- h -- water level difference, mm;
- T -- test time, s.

3. Test Results and Analysis

3.1. Influence Analysis on Compressive Strength

The test results are shown in Table 4.

| Combination | Design Porosity | Compressive Strength (MPa) | Average Value (MPa) |
|-------------|-----------------|-----------------------------|---------------------|
| RAC1        | 10%             | 28.20                       | 29.10               | 31.40 | 29.57 |
| RAC1        | 15%             | 14.00                       | 15.20               | 16.90 | 15.37 |
| RAC1        | 20%             | 13.40                       | 14.90               | 16.40 | 14.90 |
| RAC1        | 25%             | 10.30                       | 11.70               | 12.30 | 11.43 |
| RAC2        | 10%             | 30.80                       | 31.70               | 34.90 | 32.47 |
| RAC2        | 15%             | 17.50                       | 19.00               | 20.30 | 18.93 |
| RAC2        | 20%             | 15.10                       | 16.90               | 18.90 | 16.97 |
| RAC2        | 25%             | 12.80                       | 13.40               | 14.60 | 13.60 |
| RAC3        | 10%             | 27.90                       | 28.90               | 31.80 | 29.53 |
According to the test results in Table 4 and the mix proportion design results, with the increase of target porosity, the amount of cement and water decreases, the cohesive force among aggregates decreases, and the compressive strength of recycled aggregate pervious concrete gradually decreases in the case of the same strength grade combination of recycled aggregate. At the same time, the compressive strength of the recycled aggregate combination with strength grade of C40 is low because a lot of impurities are mixed into the recycled aggregate during crushing. According to **Technical Specification for Application of Recycled Aggregate Pervious Concrete (CJJ/T 253-2016)**, when the compressive strength of pervious concrete reaches 20MPa, it can be applied to the pavement, and there are 8 groups of test combinations meeting the requirements. The test results show that the compressive strength achieves the best performance when the strength grade of recycled aggregate is C30 and the target porosity is 10%. As shown in Figure 5, when the design porosity is from 10% to 15%, the compressive strength of recycled aggregate pervious concrete with strength grade of C20, C30, C40, C20 + C30, C20 + C40, C30 + C40 decreases by 48.0%, 41.7%, 44.9%, 8.6%, 46.6% and 40.4% respectively. When the design porosity is from 15% to 20%, it decreases by 3.0%, 10.4%, 10.9%, 10.8%, 20.8% and 18.3% respectively. When the design porosity is from 20% to 25%, it decreases by 23.3%, 19.9%, 19.8%, 27.7%, 31.1% and 26.9% respectively. As shown in the figure, the compressive strength of recycled aggregate pervious concrete with strength grade of C20 + C30 basically changes linearly, and its decrease is not obvious with the increase of design porosity.

![Figure 5](image_url)
3.2. Result Analysis of the Permeability Coefficient

The test results are shown in Table 5.

Table 5  Analysis of permeability test results

| Combination | Design Porosity | Permeability Coefficient (mm/s) | Average Value (mm/s) |
|-------------|-----------------|---------------------------------|----------------------|
| RAC1        | 10%             | 3.60                            | 3.91                 | 4.11                  | 3.87                  |
| RAC1        | 15%             | 7.57                            | 8.05                 | 8.69                  | 8.10                  |
| RAC1        | 20%             | 9.61                            | 10.12                | 10.32                 | 10.02                 |
| RAC1        | 25%             | 11.04                           | 12.00                | 13.08                 | 12.04                 |
| RAC2        | 10%             | 2.48                            | 2.64                 | 2.77                  | 2.63                  |
| RAC2        | 15%             | 6.72                            | 6.86                 | 7.07                  | 6.88                  |
| RAC2        | 20%             | 9.17                            | 9.65                 | 10.33                 | 9.72                  |
| RAC2        | 25%             | 15.02                           | 15.48                | 16.41                 | 15.64                 |
| RAC3        | 10%             | 2.47                            | 2.63                 | 2.79                  | 2.63                  |
| RAC3        | 15%             | 7.89                            | 8.30                 | 8.96                  | 8.38                  |
| RAC3        | 20%             | 12.09                           | 12.21                | 12.45                 | 12.25                 |
| RAC3        | 25%             | 18.77                           | 19.35                | 20.32                 | 19.48                 |
| RAC1+RAC2   | 10%             | 3.82                            | 3.98                 | 4.10                  | 3.97                  |
| RAC1+RAC2   | 15%             | 5.85                            | 6.29                 | 6.54                  | 6.23                  |
| RAC1+RAC2   | 20%             | 6.13                            | 6.71                 | 7.08                  | 6.64                  |
| RAC1+RAC2   | 25%             | 9.30                            | 10.05                | 10.83                 | 10.06                 |
| RAC1+RAC3   | 10%             | 2.22                            | 2.33                 | 2.40                  | 2.32                  |
| RAC1+RAC3   | 15%             | 5.17                            | 5.37                 | 5.67                  | 5.37                  |
| RAC1+RAC3   | 20%             | 12.69                           | 13.60                | 14.73                 | 13.67                 |
| RAC1+RAC3   | 25%             | 14.51                           | 15.08                | 15.82                 | 15.14                 |
| RAC2+RAC3   | 10%             | 2.60                            | 2.75                 | 2.96                  | 2.77                  |
| RAC2+RAC3   | 15%             | 9.17                            | 9.89                 | 10.79                 | 9.95                  |
| RAC2+RAC3   | 20%             | 10.58                           | 11.11                | 11.57                 | 11.09                 |
| RAC2+RAC3   | 25%             | 19.49                           | 20.22                | 21.37                 | 20.36                 |

Note: RAC1, RAC2 and RAC3 respectively represent the waste concrete with strength grade of C20, C30 and C40 as recycled coarse aggregate.

The test results show that with the increase of the target porosity, the compactness of pervious concrete decreases and the permeability coefficient increases significantly. At the same time, with the change of the combination of the strength grade of recycled aggregate, the permeability coefficient changes, which may be because different combinations of pervious concrete have different compactness and thus change the water channel among aggregates. According to Technical Specification for Application of Recycled Aggregate Pervious Concrete (CJJ/T 253-2016), the permeability coefficient should not be less than 0.5 mm/s, so they all meet the application requirements of pervious concrete pavement. The test results show that the recycled aggregate combination with strength grade of C30+C40, target porosity of 25%, and aggregate mix proportion of 50%, has the highest permeability coefficient[8]. As shown in Figure 6, when the design porosity is from 10% to 15%, the permeability coefficient of recycled aggregate pervious concrete with strength grade of C20, C30, C40, C20 + C30, C20 + C40 and C30 + C40 increases by 52.2%, 61.8%, 68.6%, 36.3%, 56.8% and 72.2% respectively. When the design porosity is from 15% to 20%, it increases by 19.2%, 29.2%, 31.6%, 6.6%, 60.7%, 10.3% respectively. When the design porosity is from 20% to 25%, it increases by 16.8%, 37.9%, 37.1%, 34.0%, 9.7% and 45.5% respectively. As shown in the figure, when the strength grade of recycled aggregate is C20 and C20 + C30, the permeability coefficient of recycled aggregate pervious concrete does not increase significantly with the increase of design porosity.
3.3. Comprehensive Analysis

Under the condition of ensuring that the compressive strength and permeability coefficient meet the application specification of pervious concrete, considering the influence of strength grade and target porosity of recycled aggregate on the compressive strength and permeability coefficient of recycled aggregate pervious concrete, the compressive strength of recycled aggregate pervious concrete gradually decreases and the permeability coefficient gradually increases with the increase of target porosity. The strength grade of recycled aggregate has no obvious influence on the permeability coefficient. Considering the compressive strength and permeability, the optimal proportion for pavement is as follows: the strength grade of recycled aggregate is C20 + C30, the mix proportion of aggregate is 50%, the target porosity is 15%, the water-cement ratio is 0.3, the recycled aggregate is composed of 50% recycled aggregate with particle size of 4.75-9.5 mm and that of 9.5-19 mm, and the optimal mix proportion of recycled aggregate pervious concrete (kg/m³) is: m (recycled aggregate): m (cement): m (water) = 1357.04:564.94:169.88. The pervious concrete prepared according to this mix proportion has both good compressive strength and permeability, which are 25.07 Mpa and 6.23 mm/s respectively, and it is in line with the provisions of Technical Specification for Application of Recycled Aggregate Pervious Concrete (CJJ/T 253-2016) and can be used for pavement.

4. Conclusion

Recycled aggregate pervious concrete is prepared from 100% volume of waste concrete and is expected to be used in pavements which have low strength requirements and needs to be pervious. This study prepared 24 groups of test samples by mixing cement with stones and explored the effects of strength grade and target porosity of recycled aggregate on compressive strength and permeability coefficient of recycled aggregate pervious concrete. The conclusion is as follows.

1) With the increase of the target porosity, the amount and area of cementation points among recycled aggregate particles decrease, the 28d compressive strength of recycled aggregate pervious concrete gradually decreases, and the permeability coefficient gradually increases, while the strength grade of recycled aggregate has no obvious effect on the permeability, so it is suggested that the porosity of recycled aggregate pervious concrete should be controlled at about 10%.

2) Under the same target porosity, the compressive strength and permeability coefficient of the recycled aggregate pervious concrete prepared with recycled aggregate of mixed strength grade are lower and higher respectively than that made with recycled aggregate of single strength grade.
3) Considering the influence of compressive strength and permeability coefficient, the best proportion of recycled aggregate used in pavement is as follows: the strength grade of recycled aggregate is C20 + C30, the mixing proportion of aggregate is 50%, the design porosity is 15%, the water-cement ratio is 0.3, the recycled aggregate is composed of 50% recycled aggregate with particle size of 4.75-9.5 mm and that of 9.5-19 mm, and the optimal mix proportion (kg/m³) of recycled aggregate pervious concrete is: m (recycled aggregate): m (cement): m (water) = 1357.04:564.94:169.88. The pervious concrete prepared according to this mix proportion has both good compressive strength and water permeability, which are 25.07 Mpa and 6.23 mm/s respectively, and it is in line with the provisions of *Technical Specification for Application of Recycled Aggregate Pervious Concrete (CJJ/T 253-2016)* and can be used for pavement.

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**References:**
[1] Chen Jialong, Fang Yuanxing. Present Situation and Problems of Concrete Aggregates in China [J]. Architecture Technology, 2005, 36(1):23-24.
[2] Chen Hai, Jiang Yuanhai, Ling Hongjie et al. Experimental Research on Recycled Aggregate in Pervious Concrete [J]. China Concrete and Cement Products, 2018, 10:107-108.
[3] Zhang Dengxiang, Mao ani. Experimental Study on Abrasion Resistance of Pervious Concrete Containing Waste Rubber [J]. Journal of Changsha University of Science and Technology:Natural Science, 2019,16 (2):58-59.
[4] Zhang Ping, Chen Jing, Lan Cong, et al. Study on Performance of Recycled Aggregate Pervious Concrete [J]. Sichuan Building Materials, 2019,45 (8):1-2.
[5] Huo Hongyuan, Fan Chengcheng, Chen aijiu, et al. Influence of the Recycled Aggregate with Different Strength on Recycled Concrete [J]. Concrete, 2017,2:60-62.
[6] Guo Lei, Liu Siyuan, Chen Shoukai, et al. Research on Mechanical Properties,Permeability and Abrasion Resistance of Fibers Modified Recycled Aggregate Pervious Concrete [J]. Transactions of the Chinese Society of Agricultural Engineering, 2019,35 (2):154-156.
[7] Wang Jiaqin, Xu shanpeng, Yang liansen, et al. Study on Mechanical Properties of Recycled Coarse Aggregate Pervious Concrete [J]. Sichuan Building Materials, 2018,44 (11): 3-4.
[8] Ling Tianqing, Chen Qiaoqiao, Qin Xin, et al. Mix Proportions Design of Pervious Concrete Pavement and Its Performance Influence Factors [J]. Journal of Chongqing Jiaotong University(Natural Science), 2019,38 (3): 39-43.