Comparative study on properties of recycled concrete mixed with slag and polypropylene fiber/steel fiber

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Abstract. In order to study the effect of fiber and slag on the performance of high performance recycled aggregate concrete, polypropylene fiber/steel fiber and slag are selected as admixtures, in which fiber is used as admixture and slag is equivalent to replace cement content. The influence of recycled aggregate content, admixture formula and admixture on the mechanical and water absorption properties of high performance recycled concrete and its improvement effect were analyzed systematically. The results showed that when the slag is added, the early mechanical properties of concrete have little effect, the later is slightly improved, but the water absorption of concrete is improved significantly. Adding fiber can not only improve the compressive strength, splitting tensile strength and flexural tensile strength of high performance recycled concrete, but also significantly improve the water absorption properties. Fiber and slag composite modified material can bond concrete mixture into a whole and improve the density of the mixture.

1. Introduction
Concrete is an irreplaceable man-made building material in the civil construction industry [1]. On the one hand, it needs to consume a lot of natural resources. On the other hand, with the old foundation installation and building demolition, a large amount of waste concrete is produced, causing resource waste and environmental pollution. Therefore, studying the reuse of old concrete aggregates is of great significance for saving resources and protecting the environment [2-3].

Research results at home and abroad show that compared with natural gravel, recycled concrete aggregate has higher porosity, higher water absorption, and lower strength, which limits the popularization and application of recycled aggregate to a certain extent [4-6]. At present, many scholars have improved the mechanical properties of concrete by adding fibers to recycled concrete aggregates[7-8]. Huang Zhi mixed basalt fiber into concrete and found that the fiber did not significantly enhance the compressive strength of concrete, and the flexural and tensile strength was improved to varying degrees. He Wenchang[9] mixed steel fiber into recycled concrete and found that steel fiber significantly improved the compressive, split and flexural strength of recycled concrete. Chen Aijiu [10] mixed polypropylene fiber and steel fiber into recycled concrete and found that fiber type is an important factor affecting the tensile strength and flexural strength of fiber recycled concrete. Although relevant scholars have conducted related research on the mechanical properties of waste concrete aggregates used in high-performance concrete, there are few studies on the mechanical
properties and shrinkage properties of high-performance recycled concrete with polypropylene or steel fiber and mineral admixtures.

Based on this, polypropylene fiber & steel fiber and slag are selected as external admixtures, and the compressive strength, splitting tensile strength, flexural tensile strength, water absorption properties of recycled concrete are evaluated, and the correlation between the amount of recycled aggregate, the method and amount of external admixture and the improvement effect of high-performance recycled concrete road performance was analyzed systematically.

2. Raw materials and test methods

2.1. Raw materials

2.1.1. Cementitious material

The cement is 42.5 ordinary Portland cement with specific surface area of 310 m²/kg, its specific surface area is 310m²/kg, and its technical indicators are shown in Table 1. The specific surface area of slag is 486m²/kg, and its chemical composition is shown in Table 2.

2.1.2. Aggregate

The natural coarse aggregate is crushed stone with a nominal maximum diameter of 19 mm, and the fine aggregate is sand with a fineness modulus of 3.4. Recycled concrete coarse aggregate is taken from C30 old concrete pavement. The physical properties of natural aggregate and recycled aggregate are shown in Table 3, and the particle size distribution is shown in Table 4. It can be seen from the table that natural coarse aggregate has higher density and lower water absorption rate than recycled coarse aggregate. Among them, the content of the additional mortar of the recycled aggregate is determined by the hydrochloric acid stripping method.

| Material type               | Maximum particle size of aggregate /mm | Water absorption /% | Proportion /Kg/m³ | Moisture content /% |
|-----------------------------|---------------------------------------|---------------------|-------------------|--------------------|
| Natural fine aggregate      | 4.75                                  | 1.21                | 2.53              | 0.75               |
| Natural Coarse Aggregate    | 19.0                                  | 0.62                | 2.55              | 0.34               |
| Recycled aggregate          | 19.0                                  | 3.86                | 2.47              | 1.42               |

2. Table 1. Conch P-O42.5 cement technical indicators

| Stability | Compressive strength (MPa) | Flexural strength (MPa) | Setting time (min) |
|-----------|----------------------------|-------------------------|--------------------|
| qualified | 25.4                       | 47.6                    | 5.6                |
|           | 8.4                        | 210                     | 360                |

2. Table 2. Chemical composition and content of slag

| Chemical components | CaO | SiO₂ | Al₂O₃ | MgO | Na₂O | Fe₂O₃ |
|---------------------|-----|------|-------|-----|------|-------|
| content /%           | 46.1| 35.1 | 10.3  | 6.7 | 1.1  | 0.6   |

2. Table 3. Physical properties of natural and recycled concrete aggregates
Table 4. Aggregate grading

| Mesh size/mm | Natural fine aggregate | Natural Coarse Aggregate | Recycled aggregate |
|--------------|-----------------------|--------------------------|--------------------|
| 19           | 100.0                 | 98.1                     | 97.4               |
| 13.2         | 100.0                 | 68.5                     | 58.3               |
| 9.5          | 100.0                 | 29.5                     | 27.1               |
| 4.75         | 95.2                  | 0.8                      | 1.6                |
| 2.36         | 81.3                  | 0.2                      | 0.4                |
| 1.18         | 52.9                  |                          |                    |
| 0.6          | 26.8                  |                          |                    |
| 0.3          | 5.7                   |                          |                    |
| 0.15         | 1.8                   |                          |                    |
| 0.075        | 0.8                   |                          |                    |

2.1.3. Superplasticizer
Polycarboxylate superplasticizer was adopted by BASF, whose maximum water-reducing rate can reach 26%. The recommended dosage is 0.8~1.2%.

2.1.4. Polypropylene fiber/steel fiber
The technical indicators of polypropylene fiber and steel fiber are shown in Table 5.

Table 5. Technical indicators of polypropylene fiber/steel fiber

| Fiber type and shape | length/mm | diameter/mm | aspect ratio | density/g/cm³ | tensile strength/N/mm² |
|----------------------|-----------|-------------|--------------|---------------|-------------------------|
| Polypropylene fibers | 25        | 0.8         | 31           | 6.9           | 2200                    |
| Steel fiber          | 30        | 1.29        | 23           | 7.8           | 590                     |

2.2. Mix proportion design
The mix proportion design of different concrete is shown in Table 6, in which the dosage of cementitious material is 400 kg/m³, the water cement ratio is 0.34, the sand ratio is 0.42, and the replacement rate of recycled concrete aggregate is 0%, 30% and 50% respectively; meanwhile, the change rules of concrete properties under the conditions of slag replacing 25% cement and adding 1% polypropylene fiber/steel fiber are studied respectively. By testing the slump of different combinations, as summarized in Table 6, it is found that polypropylene fiber/steel fiber has a great influence on the slump of concrete. The slump is respectively about 200 mm and 130 mm before and after adding polypropylene fiber & steel fiber, but it can still meet the liquidity requirements of high-performance concrete construction.

Table 6. Test plan design

| serial number | cement content/Kg/m³ | slag content/Kg/m³ | sand content/Kg/m³ | natural coarse aggregate content/Kg/m³ | recycled coarse aggregate content/Kg/m³ | polypropylene fiber content/% | steel fiber content/% | water reducing agent content/% | slump/mm |
|---------------|----------------------|--------------------|--------------------|---------------------------------------|----------------------------------------|-------------------------------|------------------------|-------------------------------|----------|
| N0K0J0G0      | 400                  | 0                  | 756                | 1083                                  | 0                                      | 0                             | 0                      | 1.2                           | 210      |
| R30K0J0G0     | 400                  | 0                  | 756                | 753                                   | 325                                    | 0                             | 0                      | 1.2                           | 200      |
| R50K0J0G0     | 400                  | 0                  | 756                | 504                                   | 532                                    | 0                             | 0                      | 1.2                           | 210      |
| N0K25J0G0     | 300                  | 100                | 742                | 1052                                  | 0                                      | 0                             | 0                      | 1.2                           | 190      |
| R30K25J0G0    | 300                  | 100                | 742                | 736                                   | 316                                    | 0                             | 0                      | 1.2                           | 205      |
| R50K25J0G0    | 300                  | 100                | 742                | 501                                   | 523                                    | 0                             | 0                      | 1.2                           | 200      |
2.3. Experiment method

2.3.1. Strength. The compressive strength, splitting strength, and flexural tensile strength of recycled concrete specimens were tested respectively. The size of the specimens for compressive strength was 10cm×10cm×10cm. The specimens were cured under standard conditions and used. The compressive strength of 7 days, 28 days and 90 days was tested by a universal testing machine. The cylinder with the splitting tensile strength of φ 10cm × 20cm is used to test the splitting tensile strength of the cylinder after curing the specimen for 28 days. The box with the dimension of 10cm × 10cm × 40cm is used to test the bending strength of the specimen after 28 days.

2.3.2. Water absorption. The water absorption test was carried out in accordance with the American standard ASTM C642. The sample size is a cube of 10cm×10cm×10cm. The quality difference of the sample before and after drying is tested separately after curing the sample for 7 days, which is used as an index to evaluate the water absorption of concrete.

3. Test results and analysis

3.1. Compressive strength

The compressive strength results of different recycled concretes are shown in Figures 1 to 6. It can be concluded from Figure 1 to Figure 6 that the compressive strength of all recycled aggregate concretes increases with the extension of age. Compared with recycled aggregate concrete without adding slag, using 25% slag equivalent to replace cement has no significant impact on the compressive strength of concrete; when 1% polypropylene fiber/steel fiber is added, the compressive strength of recycled concrete increases significantly. The content of recycled aggregates has a greater impact on the strength of concrete. As the content increases, the strength decreases. When the content of recycled aggregate is 30%, the compressive strengths of recycled aggregate concrete mixed with polypropylene fiber and slag composite material for 7d, 28d, and 90d are 39.8MPa, 55.5MPa, 71.7MPa, respectively, compared with the control group Increased by 14%, 14.9%, and 21.1% respectively; the 7d, 28d, and 90d compressive strengths of recycled aggregate concrete mixed with steel fiber and slag composite materials were 42.1MPa, 58.2MPa, 73.6MPa, respectively, compared with the control group They are increased by 20.3%, 20.7%, and 24.1% respectively. It can be seen that the fiber improves the concrete performance significantly in the later stage.

When 25% slag is used to replace cement, the 7-day and 28-day compressive strength of recycled concrete decreases, while the 90-day strength increases. This is because the addition of slag can improve the cohesiveness of the cementitious material, reduce the appearance of cracks, and fill the capillary pores of the cement matrix so as to improve the performance of the interface transition zone and then increase the strength of the concrete.
Figure 1: Compressive strength of recycled aggregate concrete without admixture

Figure 2: Compressive strength of recycled aggregate concrete mixed with 25% slag

Figure 3: Compressive strength of recycled aggregate concrete mixed with 1% polypropylene fiber
Figure 4  Compressive strength of recycled aggregate concrete mixed with polypropylene fiber and slag

Figure 5  Compressive strength of recycled aggregate concrete mixed with 1% steel fiber

Figure 6  Compressive strength of recycled aggregate concrete mixed with steel fiber and slag
3.2. Splitting tensile strength and bending tensile strength

The 28-day splitting tensile strength and flexural tensile strength of different mixtures are shown in Figure 7–Figure 12.

Figure 7 28-day splitting tensile strength of recycled aggregate concrete without fiber

Figure 8 28-day splitting tensile strength of recycled aggregate concrete mixed with 1% polypropylene fiber

Figure 9 28-day splitting tensile strength of recycled aggregate concrete mixed with 1% steel fiber

Figure 10 28-day flexural tensile strength of recycled aggregate concrete without fiber
It can be seen from Figure 7-9 that with the increase of the content of recycled aggregates, the 28-day splitting tensile strength of high-performance recycled concrete gradually decreases. When the content of recycled aggregates is 30% and 50%, the splitting strength reduces by 5.2% and 10.5% respectively. When 25% slag is used to replace the cementitious material, the splitting strength of recycled concrete does not change much. When polypropylene fiber is added, the splitting strength of the mixture is significantly improved. When the content of recycled aggregate is 30% and 50%, the splitting tensile strength is increased by 49% and 58.4%, respectively; when steel is added after fiber, there is also a significant increase, but the increase is 20.9% and 25%, respectively. This is because polypropylene fiber has high tensile strength, elastic modulus, and effective anchoring mechanism, which inhibits the expansion of macroscopic cracks in concrete; Figure 10-12 shows that concrete flexural and tensile strength exhibits similar laws.

3.3. Water absorption
The water absorption rate of recycled concrete was tested, and the test results are shown in Figure 13. It can be seen from Figure 13 that adding slag to concrete can significantly reduce its water absorption. The addition of polypropylene fiber has a significant impact on the water absorption of concrete. Adding 1% of polypropylene fiber can reduce the water absorption of concrete by 29%. The water absorption rate of recycled aggregate concrete with 1% polypropylene fiber is 23% lower than that of recycled aggregate concrete without polypropylene fiber. This may be because the slag can improve the microstructure of the cement matrix, reduce the pore size, and interrupt the connection of the pores. In addition to the pozzolanic activity of the slag, due to the small particle size of the slag, its filling effect will also reduce the water absorption. Therefore, the addition of polypropylene fiber limits the formation and expansion of cracks in the concrete structure, thereby reducing its permeability. It also shows that the addition of 1% steel fiber can also reduce the water absorption of concrete by 5.4%.
4. Improvement mechanism analysis

Through the mechanical properties, water absorption and drying shrinkage tests of recycled concrete, the performance enhancement effects of polypropylene fiber and slag on high-performance recycled concrete are analyzed from a macro perspective. Based on the test results, the analysis is as follows:

(1) When no mineral admixture is added, the surface of the high-performance recycled concrete mixture is rough and has holes, and the macroscopic performance is that the mixture has high water absorption and low mechanical properties. When 1% polypropylene fiber/steel fiber is added, due to the multi-dimensional random distribution of the fibers in the concrete, the high-performance concrete is bonded into a solid whole, and its mechanical properties such as compressive strength are significantly improved. Because the fiber and cement paste are bonded as a unified whole, the internal compactness of the concrete is improved to a certain extent, and the intrusion channel of external moisture is blocked. Macroscopically, the water absorption rate is reduced.

(2) After adding slag, due to the large specific surface area of slag, it can promote the hydration of cement to a certain extent, improve the internal structure of concrete, and make the interior of recycled concrete denser, which is manifested in the improvement of mechanical properties and shrinkage properties on a macroscopic scale. Due to the high activity of the slag, the hydration of the cement paste is more sufficient, and the product can fill the concrete structure to a greater extent, which is also the reason for the decrease in water absorption. The composite modification of fiber and slag can significantly improve the performance of high-performance recycled concrete.

5. Conclusion

(1) Slag can improve the compressive strength of recycled concrete. After replacing cement with the equivalent of 25% slag, the early strength of high-performance recycled concrete will decrease, while the later strength will increase.

(2) Adding polypropylene fiber can significantly increase the split tensile strength and flexural tensile strength of recycled concrete; slag as a mineral admixture has little effect on the split tensile strength and flexural tensile strength of concrete.

(3) Fiber and slag can significantly reduce the water absorption of recycled concrete, and fiber and slag as a composite modified material can improve the water absorption of high-performance recycled concrete the most significant.
(4) Adding fiber and slag composite modified materials can promote the hydration of cement slurry and improve the compactness of concrete. Macroscopically, it can be expressed as an increase in mechanical properties and a decrease in water absorption.

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