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Effect of Different Fiber Content on Mechanical Properties of Recycled Concrete

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Abstract. In this paper, the effects of different steel fiber and polypropylene fiber on the mechanical properties of recycled concrete were studied. The empirical formulas for the axial compressive strength, splitting tensile strength, flexural strength and fiber content of each recycled concrete are given. The results show that the mechanical properties of recycled concrete are improved to different degrees, and the increase of splitting tensile strength is the most significant. When the steel fiber content is 2%, the increase of splitting tensile strength and flexural strength are the most significant, which are 44.8% and 34.0%, respectively; when the steel fiber content is 1.5%, the axial compressive strength has the most significant increase is 19.4%. When the polypropylene fiber content is 0.8kg/m³, the axial compressive strength, splitting tensile strength and flexural strength have the most significant increase, which are 15.8%, 40.5% and 39.6%, respectively.

1. Foreword
At present, China's economy is in the transitional stage of low-carbon sustainable development. Recycled concrete is widely recognized by contemporary society as a recyclable building material. However, the strength of recycled concrete under the same ratio is lower than that of ordinary concrete, and its performance is also worse than that of ordinary concrete. Therefore, there are some performance problems in the application of recycled concrete [1]. During the failure of concrete, the aggregates will produce some micro-cracks due to the load, resulting in reduced strength of recycled aggregates. Therefore, recycled aggregates are generally not suitable for the preparation of ultra-high-strength concrete [2]. The incorporation of proper amount of fiber into recycled concrete can effectively improve and improve the performance in terms of strength and durability. Therefore, it is a trend to replace ordinary concrete with fiber recycled concrete. Many domestic and foreign scholars have carried out relevant experimental research [3-5].

2. Test overview
2.1 Test raw materials
Cement: P.O42.5Jidong brand ordinary Portland cement. The fineness is 1.96%, the initial setting and final setting are 2:05h and 6:10h, and the 28d measured strength is 51.2Mpa. Coarse aggregate: natural coarse aggregate (NAC) and recycled coarse aggregate (RAC), the particle size is 4.75mm~26.5mm, the gradation is good, the main properties of coarse aggregate are shown in Table 1.

| Tab.1 Main performance of coarse aggregate |
|------------------------------------------|
| Coarse aggregate type | Apparent density/kg·m⁻³ | Water absorption/wt% | Crush index /wt% | Residual mortar content/wt% |
|----------------------|--------------------------|----------------------|-----------------|---------------------------|
| NA                   | 2720                     | 0.8                  | 10              | —                         |
| RCA                  | 2510                     | 1.76                 | 15.20           | 8.99                      |

Steel Fibre: shear wave fiber, length 28 mm, tensile strength = 634 MPa, specific gravity 7.9g/cm³. Polypropylene fiber (PF): bundled monofilament fiber, length 12 mm, fiber diameter 18~48 μm, tensile strength >358MPa, elastic modulus E>3.5GPa, tensile limit greater than 15%, specific gravity 0.91g/cm³. Water reducing agent (WRA): Polycarboxylate high performance water reducer with a water reduction rate of 25% or more.

2.2 Mix ratio design

According to the "Ordinary Concrete Mix Design Specification" (JGJ55-2011) combined with EMV to prepare recycled concrete with a strength of C30, and then blended with steel fiber and polypropylene fiber, meet the fiber regeneration by adding appropriate water reducing agent and adjusting the sand rate. The working performance of concrete, the matching ratio of this test is shown in Table 2.

| Tab.2 Mix proportions of concrete mixtures |
|-------------------------------------------|
| Mix ID | Water | Cement | FA | SF | Sand | NA | RAC | Steel Fibre | PF | WRA   |
|--------|-------|--------|----|----|------|----|-----|-------------|----|-------|
| RAC    | 183   | 299    | 59 | 35 | 574  | 1013 | 196 | —           | —  | 1.180  |
| RAC-S0.5 | 183 | 299    | 59 | 35 | 574  | 1013 | 196 | 11.795      | —  | 1.180  |
| RAC-S1.5 | 183 | 299    | 59 | 35 | 574  | 1013 | 196 | 35.385      | —  | 1.180  |
| RAC-S2  | 183   | 299    | 59 | 35 | 574  | 1013 | 196 | 47.18       | —  | 1.180  |
| RAC-P0.2 | 183 | 299    | 59 | 35 | 574  | 1013 | 196 | 0.2         | 0.5| 1.180  |
| RAC-P0.5 | 183 | 299    | 59 | 35 | 574  | 1013 | 196 | —           | 0.8| 1.180  |
| RAC-P0.8 | 183 | 299    | 59 | 35 | 574  | 1013 | 196 | —           | 0.8| 1.180  |

Note: RAC means that both steel fiber and polypropylene fiber added to recycled concrete are 0; RAC-S0.5, RAC-S1.5, RAC-S2 respectively indicate that steel fiber is 0.5%, 1.5%, 2% by volume. It is incorporated into recycled concrete; RAC-P0.2, RAC-P0.5, and RAC-P0.8 respectively indicate that polypropylene fibers are blended into recycled concrete at 0.2 kg/m³, 0.5 kg/m³, and 0.8 kg/m³.

3. Test results and analysis

The test results are shown in Table 3, in which the axial compressive strength is \( f_c \), the splitting tensile strength is \( f_{st} \), the bending strength is \( f_{sb} \), and the elastic modulus is \( E_c \).

| Tab.3 Fiber recycled concrete mechanical properties test results |
|---------------------------------------------------------------|
| Mix ID | \( f_c \)/MPa | \( f_{st} \)/MPa | \( f_{sb} \)/MPa | \( E_c \)/MPa |
|--------|---------------|-----------------|-----------------|--------------|
| RAC    | 25.3          | 2.79            | 5.3             |
| RAC-S0.5 | 27.4       | 3.17            | 6.2             |              |
| RAC-S1.5 | 30.2       | 3.50            | 6.7             |              |
| RAC-S2  | 28.9          | 4.04            | 7.1             |              |
| RAC-P0.2 | 27.0       | 3.00            | 6.1             |              |
| RAC-P0.5 | 27.9       | 3.41            | 6.8             |              |
| RAC-P0.8 | 29.3       | 3.92            | 7.4             |              |
3.1 Axial compressive strength

It can be seen from Fig. 1 that the axial compressive strength increases first and then decreases as the steel fiber content increases. When the steel fiber content is 0.5%, 1.5%, 2%, respectively, the axial compressive strength increases by 8.3%, 19.4%, 14.2%, and the steel fiber content is 1.5%, the axial compressive strength reaches the maximum. Figure 2 shows the results of Origin fitting. The relationship between axial compressive strength and steel fiber content is:

\[ f_{s,c} = (1 + 0.14493\alpha + 0.06851\alpha^2 - 0.0527\alpha^3) f_c \quad (R^2=1) \]  

(1)

In the formula, \( \alpha \) - steel fiber content, %; \( f_{s,c} \) - steel fiber recycled concrete axial compressive strength, MPa; \( f_c \) - recycled concrete axial compressive strength, MPa.

3.2 Splitting tensile strength
It can be seen from Fig. 5 that the splitting tensile strength is positively correlated with the steel fiber content. When the steel fiber content is 0.5%, 1.5%, 2%, respectively, the splitting tensile strength increases by 13.6%, 25.4%, and 44.8%, respectively. When the steel fiber content is 2%, the splitting tensile strength reaches the maximum. Figure 6 shows the results of Origin fitting. The relationship between the splitting tensile strength and the amount of steel fiber is:

$$f_{ss} = (1 + 0.42951\alpha - 0.38471\alpha^2 + 0.14098\alpha^3)f_{ts} \quad (R^2 = 1) \quad (3)$$

In the formula, $f_{ss}$ — steel fiber recycled concrete split tensile strength, MPa; $f_{ts}$ — recycled concrete split tensile strength, MPa.

It can be seen from Fig. 7 that the splitting tensile strength is positively correlated with the polypropylene fiber content. When the fiber content is 0.2kg/m$^3$, 0.5kg/m$^3$ and 0.8kg/m$^3$, respectively, the splitting tensile strength increases by 7.5%, 22.2%, 40.5%, and the polypropylene fiber content is 0.8kg/m$^3$. The splitting tensile strength is maximized. Figure 8 shows the results of Origin fitting. The relationship between the splitting tensile strength and the amount of polypropylene fiber is:

$$f_{ps} = (1 + 0.32748\beta + 0.25129\beta^2 - 0.03475\beta^3)f_{ts} \quad (R^2 = 1) \quad (4)$$

In the formula, $f_{ps}$ — polypropylene fiber recycled concrete split tensile strength, MPa.

### 3.3 Flexural strength
As can be seen from Fig. 9, the flexural strength is positively correlated with the steel fiber content. When the steel fiber content is 0.5%, 1.5%, 2%, respectively, the flexural strength increases by 17.0%, 26.4%, 34.0%, and the steel fiber content is 2%, the flexural strength reaches the maximum. Figure 10 shows the results of the Origin fitting. The relationship between the flexural strength and the amount of steel fiber is:

\[
 f_{s,f} = (1 + 0.49685 \alpha - 0.36477 \alpha^2 + 0.10063 \alpha^3) f_f \quad (R^2=1) \quad (5)
\]

In the formula, \( f_{s,f} \) - steel fiber recycled concrete flexural strength, MPa; \( f_f \) - recycled concrete flexural strength, MPa.

It can be seen from Fig. 11 that the flexural strength is positively correlated with the amount of polypropylene fiber. When the fiber content is 0.2kg/m\(^3\), 0.5kg/m\(^3\) and 0.8kg/m\(^3\), respectively, the flexural strength increases by 15.1%, 28.3%, 39.6%, and the polypropylene fiber content is 0.8kg/m\(^3\). The strength is maximized. Figure 12 shows the results of the Origin fitting. The relationship between the flexural strength and the polypropylene fiber content is:

\[
 f_{p,f} = (1 + 0.94598 \beta - 1.0874 \beta^2 + 0.65504 \beta^3) f_f \quad (R^2=1) \quad (6)
\]

In the formula, \( f_{p,f} \) - polypropylene fiber recycled concrete flexural strength, MPa.

3.4 Influence mechanism of fiber blending on mechanical properties of recycled concrete

The recycled concrete is brittle. When the load is applied, the micro-cracks and pores in the concrete test block gradually expand and extend until the specimen is destroyed. The proper amount of fiber is mainly used to improve the brittleness. In general, fiber plays a major role in the following three aspects in recycled concrete [7]:

1. Blocking effect. The fiber can prevent the generation of micro-cracks in the recycled concrete, and the fibers uniformly distributed in the recycled concrete can withstand the tensile stress generated by the recycled concrete during the hardening and shrinking process, preventing or reducing the occurrence of cracks.
• 2. Enhancement. The incorporation of fibers into recycled concrete can make the internal structure more compact and reduce defects such as microcracks and voids, thereby increasing the strength of recycled concrete.

• 3. Toughening effect. When the load is applied, when the recycled concrete is cracked, the fibers at the crack can still withstand a part of the stress, which makes the recycled concrete have certain toughness.

In addition, the incorporation of fibers also has a negative impact on the strength of the recycled concrete. For one thing, the incorporation of fibers reduces the bonding force between the coarse aggregate and the cement mortar, resulting in a decrease in the strength of the recycled concrete. For another thing, when the fiber content is large, the fibers are easily agglomerated during the agitation of the recycled concrete, causing the recycled concrete to be unevenly stirred, resulting in a decrease in strength.

4. Conclusion

• Steel fiber and polypropylene fiber have a good reinforcing effect on the mechanical aspects of recycled concrete. When the steel fiber content is 1.5%, the axial compressive strength reaches the maximum. When the blending amount is 2%, the splitting tensile strength and the flexural strength are the largest; when the polypropylene fiber content is 0.8 kg/m³, the recycled concrete is The axial compressive strength, splitting tensile strength and flexural strength are the highest.

• Steel fiber and polypropylene fiber have the most significant increase in the splitting tensile strength of recycled concrete, and the improvement of axial compressive strength is not obvious, and the effect on elastic modulus is small.

• From the mechanism analysis, the influence of fiber on recycled concrete is mainly the positive effect of the three aspects of cracking, strengthening and toughening, and the negative effect of excessive mixing of the fiber leading to uneven mixing.

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