Effect of polypropylene fiber content on compressive and flexural performance of recycled concrete

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Abstract. Recycled concrete was a kind of green, environmental protection and energy-saving building material, and its mechanical properties can be improved by adding polypropylene fiber. Taking the polypropylene fiber content as a parameter, experiment of cube compressive strength and bending strength on polypropylene fiber recycled aggregate concrete (PFRAC) and natural aggregate concrete were done, among which the PFRAC has 50% replacement rate of recycled aggregate. Through the comparison of strength and fracture mode of specimens, the influence of polypropylene fiber content on the pressure resistance and fracture resistance of recycled concrete were studied, and the recycled concrete’s appropriate amount of polypropylene fiber which strength can reach to natural aggregate concrete were obtained. The results were as follows: the compressive strength and bending strength of recycled concrete with polypropylene fiber were obviously intensified and the strength continuously intensifies along with the adding of fiber content. The compressive strength and bending strength of PFARC exceed that of natural aggregate concrete when fiber content was up to 1.0kg/m³. The recycled concrete with polypropylene fiber can still maintain the property of crack without breaking after damage, and the brittle fracture morphology wouldn’t occur in it.

1. Introduction
Recycled aggregate (RA) processed from waste concrete was used to make recycled aggregate concrete(RAC), which can reduce the environmental impact from waste concrete and save nature gravel, and it was in line with the construction of sustainable development strategy, so RA processed from waste concrete was a kind of important measures for developing green ecological concrete. However, a series of defects of RAC caused by cement mortar wrapped on the surface of RC and the cracks produced from crushing, such as high porosity, high water absorption and low strength large, which deduced the strength and durability of RAC worse than natural aggregate concrete. To some extent, the defects of RAC limited its application in engineering field[1,2].

The fiber has good toughening and strengthening effect. RAC with polypropylene fiber can improve the influence of the RA’s defects on the concrete to improve RC strength[3]. This paper studies the effectiveness of polypropylene fiber content on the pressure resistance and fracture resistance of recycled concrete through comparison of strength and fracture mode of specimens, and the failure modes which is based on experiment were analyzed.

2. General Situation of Test

2.1. Raw material
Portland cement of P.O 42.5 was produced by Huaxin cement plant of Hubei. The fine aggregate was local river sand. Tap water was used to produce concrete. The coarse aggregate was composed of local natural aggregate which is made from gravel and RA which was obtained by concrete cube compressive strength test in crushing and sieving. Polypropylene fibers were bundled monofilament fibers whose main characteristics of polypropylene fiber were listed in Table 1.

Table 1. Basic properties of polypropylene fiber

| Fibre Type          | Equivalent Diameter (um) | Strength of Extension (MPa) | Elongation at Break (%) | Melting Point (℃) | Ignition Point (℃) | Density (g/cm³) | Elasticity Modulus (MPa) |
|---------------------|--------------------------|----------------------------|--------------------------|-------------------|---------------------|-----------------|--------------------------|
| Bunchy, Monofilament| 18~48                    | ≥500                       | 10~28                    | 160~180           | 580                 | 0.91            | ≥3850                    |

2.2. Test method

The design strength grades of concrete is C30 and the mix ratio were listed in Table 2. There was a reasonable 50% replacement rate of recycled aggregates which were beneficial strength considering for RAC compressive strength[4]. Therefore, the 50% replacement rate of recycled aggregate used in this experiment was to explore different fiber content on the compressive strength of RAC. The content of polypropylene fiber was taken 0kg/m³, 0.7kg/m³, 1.0kg/m³, 1.3kg/m³, 1.60kg/m³ separately.

Table 2. Concrete proportion and strength at 28 Days

| Specimen group | Water Cement Ratio w/c | Sand Ratio (%) | Dosage Of Concrete Per Cubic Meter (kg) | Average Compressive Strength (MPa) | Average Flexural Strength (MPa) |
|----------------|------------------------|----------------|-----------------------------------------|-----------------------------------|---------------------------------|
| C-0⁴           | 0.41                   | 35             | 420 632 587.5 587.5 173 0              | 38.6                              | -                              |
| R-0⁵           | 0.41                   | 35             | 420 632 587.5 587.5 173 0              | 36.2                              | 3.35                            |
| P-1⁶           | 0.41                   | 35             | 420 632 587.5 587.5 173 0.7            | 38.3                              | 3.67                            |
| P-2            | 0.41                   | 35             | 420 632 587.5 587.5 173 1.0            | 40.9                              | 3.91                            |
| P-3            | 0.41                   | 35             | 420 632 587.5 587.5 173 1.3            | 42.6                              | 4.11                            |
| P-4            | 0.41                   | 35             | 420 632 587.5 587.5 173 1.6            | 44.0                              | 4.15                            |

⁴ C was natural aggregate cement.
⁵ R was ordinary recycled aggregate.
⁶ P was Polypropylene fiber recycled aggregate concrete (PFRAC).

Because recycled aggregate was highly absorbent, so it must be prewetting processed before the test. The dry mixing method was adopted for RA will clumping together when mixed with polypropylene fiber. The dry mixing method’s was to mix the cement, sand and natural aggregate well firstly, then add and mix the polypropylene fibers, RA (prewetted to saturated but surface were dry state) and water were joined and mixed together finally. The specimens of 150 mm × 150 mm × 150 mm for compressive test and 550mm × 150 mm × 150 mm for bending test were cast. All specimens were demoulded after 24 h and cured for 28 d in standard curing tank at a temperature of 20 ℃.

3. Effect of polypropylene fiber content on compressive resistance

3.1. Experiment and results analysis

As shown in Table 2, The compressive strength of the 50% replacement rate of recycled aggregate (R-0 group) was 6.2.% lower than that of natural aggregate concrete (C-0 group). But the compressive strength of PFRAC was improved. When RC with polypropylene fiber content were 0.7, 1.0, 1.3, 1.6kg/m³, the compressive strength of RAC were 5.8%, 13.0%, 17.7%, 21.5% higher than that of ordinary recycled concrete, which were shown in Figure 1.
Figure 1. Relationship between compressive strength and polypropylene fiber content.

It can be deduced from Figure 1 that the cubic compressive strength of PFRAC increased with the increasing of fiber content. When fiber content increasing from 0.7 kg/m$^3$ to 1.0 kg/m$^3$, the compressive strength was increased obviously. When fiber content increasing from 1.0 kg/m$^3$ to 1.3 kg/m$^3$ or from 1.3 kg/m$^3$ to 1.6 kg/m$^3$, the growth rate of compressive strength was decreased gradually. The increasing effect of compressive strength became less and less obviously.

Polypropylene fiber and recycled concrete in PFRAC formed a composite system which bearing load together. The polypropylene fiber eliminated or reduced primary fracture development by decreasing early primary cracks in concrete and reduce the number of micro cracks and scale [5].

It can be deduced from Table 2 that the compressive strength of natural concrete (Group C-0) is 38.6 MPa, while the compressive strength of RC is 38.3 MPa and 40.9 MPa with a polypropylene fiber content of 0.7 kg/m$^3$ and 1.0 kg/m$^3$ respectively. In other words, the compressive strength of RAC with a polypropylene fiber content ranging from 0.7 kg/m$^3$ to 1.0 kg/m$^3$ can reach that of natural concrete. According to the interpolation method, the RC with polypropylene fiber content that just reaches the compressive strength of natural concrete is 0.703 kg/m$^3$. Because of the large dispersion of concrete, the consideration of cost and other factors, the polypropylene fiber content is suggested to be 1.0 kg/m$^3$ in the engineering project.

3.2. Failure morphology analysis of specimens

Damaged photograph of natural concrete and PFRAC were shown in Figure 2 and Figure 3. It can be deduced from Figure 2 that the compressive failure of the natural concrete specimen was brittle failure. During the failure process, micro cracks appear on the surface of the specimen firstly. With the increasing of the load, the length, width and numbers of cracks increased continually, then expanded to the inside of the specimen finally, and external drums and flaking began to appear on the specimen’s surface. When the load reaching the ultimate compressive strength, the crack through and specimen damaged. However, PFRAC specimen didn’t broken even the cracks appeared when it reached the ultimate load which can be known from Figure 3. There wasn’t obviously spalling phenomenon and specimen remains intact except only a few cracks appeared on the edge.

Figure 2. Damaged photograph of natural aggregate concrete specimen (Group C-0).

Figure 3. Damaged photograph of PFRC specimen (Group P-1).
4. Effect of polypropylene Fiber content on bending resistance

4.1. Experiment and results analysis
The bending strength of PFRAC increased with increasing of the content of polypropylene fiber as shown in Figure 4. Compared with ordinary recycled concrete (R-0 group), RAC compressive strength with polypropylene fiber content of 0.7, 1.0, 1.3 and 1.6 kg/m$^3$ increased by 9.6%, 16.7%, 22.7% and 23.9%, respectively. The increasing of flexibility of bending strength was more obvious than that of compressive strength (5.8%, 13.0%, 17.7% and 21.5%, respectively).

When polypropylene fiber content increased from 0.7 kg/m$^3$ to 1.0 kg/m$^3$, RAC strength promote rate was 6.5%, and when the dosage of fiber increased from 1.0 kg/m$^3$ to 1.3 kg/m$^3$ or increased from 1.3 kg/m$^3$ to 1.6 kg/m$^3$, the increasing rate was 5.1% or 1.0% respectively. It showed that with the increasing of dosage of polypropylene fiber which bending strength increasing rate gradually decreased and the effect of improving is less significant.

4.2. Failure morphology analysis of specimens
The micro-cracks appeared slowly when the specimen approached the failure as the load increased during the test. A crisp sound sent out when the cracks appeared quickly, and the failure load reached at the same time. The destruction position of the specimen lied to the centerline of the specimen. As shown in Figure 5, the destructive state of ordinary recycled concrete specimen was completely disconnected, but the PFRAC specimen was not thoroughly disconnected. It can be seen from Figure 5 (c) when the specimen was destroyed, the fibers at the crack were pulled out or broken. But some fibers were still involved in the tension. In conclusion, the concrete and the fibers were tensile together after the PFRAC was stressed. Fibers provided tensile strength alone after the concrete cracks.

![Figure 4. Flexural strength of PFRAC.](image)

![Figure 5. Photograph of concrete bending damage](image)

5. Conclusions
(1) The cube compressive strength and flexural strength of ordinary recycled concrete were lower
than that of natural aggregate concrete. After adding polypropylene fiber into the recycled concrete, the compressive strength of the specimen was improved significantly.

(2) With the increasing of polypropylene content, the compressive strength and bending strength of the RAC increased gradually, with the strength increasing fast first and slow at last. The compressive strength of RC specimen with polypropylene fiber content between 0.7 kg/m³ and 1.0 kg/m³ can reach that of natural aggregate concrete. The recommended dosage was 1.0kg/m³ of polypropylene fiber concrete to replace natural concrete when PFRAC application in the engineering.

(3) The recycled concrete with polypropylene fiber can still maintain the property of crack without breaking after damage, and it wouldn’t appear the brittle fracture morphology which natural aggregate concrete usually done.

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