Experimental Study on Mechanical Properties of Recycled Concrete with Different Length of Waste Hybrid Fibers

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Abstract. The mechanical properties of concrete are reduced due to the defects of recycled aggregate itself. In this paper, the fluidity, compressive strength, splitting tensile strength, flexural strength and modulus of elasticity of recycled concrete with hybrid waste fibers were tested by changing the length combination of waste polypropylene fibers and basalt fibers. The test results show that the hybrid fibers can reduce the fluidity, compressive strength and elastic modulus of recycled concrete, and 19 mm waste polypropylene fibers and basalt fibers can significantly improve the splitting tensile strength, flexural strength, brittleness and crack resistance of recycled concrete.

1. Introduction

With the rapid development of Chinese construction industry, a lot of old buildings are facing abandonment and demolition, resulting in a lot of construction waste. At present, the main treatment methods of construction waste are landfill or dump, which not only occupies a large amount of land resources, but also causes serious environmental pollution. In order to reuse these wastes, many scholars at home and abroad use waste concrete to mix recycled concrete partly or totally instead of natural aggregate. However, due to the defects of recycled aggregate such as cracks, the mechanical properties of recycled concrete are seriously reduced [1]. In addition, with the development of textile industry, textile consumption has increased rapidly, and a lot of textile wastes have been produced. A large part of these wastes is made of polypropylene (The main ingredient is polypropylene), which is difficult to degrade and seriously pollute the environment. According to the literature, polypropylene fibers have the advantages of good elasticity, high strength, acid and alkali resistance. The addition of low content of polypropylene fibers in concrete matrix can reduce the micro-cracks and plastic shrinkage of concrete caused by water reduction and bleeding in the initial setting stage, thereby improving the frost resistance, impermeability and impact resistance of concrete [2]. Therefore, in order to enhance the mechanical properties of recycled concrete and improve the utilization rate of recycled resources, this paper will change the different length combinations of waste polypropylene fiber and basalt fiber, analyze the basic mechanical properties of recycled concrete, and provide technical reference for expanding the utilization of recycled resources.

2. Materials and methods

2.1. Test scheme design

In this test, 20% fly ash is used to replace part of cement, 30% recycled coarse aggregate is used to replace natural aggregate. The water-binder ratio is 0.35, the sand ratio is 0.45, and the water reducer content is 1% of the total mass of cement. Five groups of test groups were designed by changing the
length combination of basalt fibers (18 mm) and waste polypropylene fibers (6 mm, 12 mm, 19 mm, 30 mm). In the test, basalt fibers and polypropylene fibers were mixed at a volume ratio of 1:1, and the total mixing ratio was set at 0.3% (the proportion in the total volume of concrete). After concrete mixing, slump and expansion of concrete are tested under plastic state, and compressive strength, splitting tensile strength, flexural strength and elastic modulus of concrete are tested under hardening state at specified age. The mix ratio of concrete used in this test is shown in Table 1.

### Table 1. Mix ratio of recycled concrete (kg/m³)

|                | Cement | Fly ash | Water | Natural sand | Natural coarse aggregate | Recycled coarse aggregate | Water reducer | Basalt fibers | Waste polypropylene fiber |
|----------------|--------|---------|-------|--------------|--------------------------|---------------------------|---------------|---------------|--------------------------|
|                | 356    | 89      | 178   | 813.8        | 561.6                    | 244.1                     | 2.23          | 3.45          | 1.37                     |

#### 2.2. Test materials

The cement used in this experiment is P.O 42.5 ordinary Portland cement of a factory in Yanbian Korean Autonomous Prefecture, with a density of 3150 kg/m³. Fly ash is produced by a power plant in Yanji City, Jilin Province, with a density of 2180 kg/m³. The fine aggregate originated from natural yellow sand in Yanji City is medium sand with good gradation and density of 2610 kg/m³. The recycled coarse aggregate is crushed by jaw crusher with strength is 40 MPa-50 MPa waste concrete blocks, particle size of crushed recycled aggregate is 5 mm-20 mm, density is 2550 kg/m³ and water absorption rate is 4.8%. The natural aggregate is produced in Yanji area. The size of gravel is 5 mm to 25 mm and its density is 2650 kg/m³. The length of basalt fibers used in this experiment is 18 mm and the length of waste polypropylene fibers is 6 mm, 12 mm, 19 mm and 30 mm. The superplasticizer used in this experiment is a pale yellow liquid Polycarboxylate superplasticizer produced by a company in Yanji City, with a solid content of 40%.

#### 2.3. Test methods

The uniform dispersion of fibers in concrete has a great influence on the performance of concrete. The order of feeding and mixing methods controls the uniformity of fibers in concrete. To ensure the uniformity of fibers, natural coarse aggregates, recycled coarse aggregates, natural sand, cement, fly ash and fibers are first mixed for 60 s, and then mixed with water and water reducer for 180 s. After mixing, the slump and expansion under plastic state are measured, then load trial mold and compacted on the shaking table. Then, it is maintained in standard curing room. After 24 hours, the molds are removed. After they are maintained for 28 days and the compressive strength, splitting tensile strength, flexural strength and modulus of elasticity are tested. The specimen sizes of compressive strength and splitting tensile strength are 150 mm × 150 mm × 150 mm; the specimen sizes of flexural strength are 150 mm × 150 mm × 550mm; and the specimen of elastic modulus is 150 mm × 150mm × 300mm. Specific test methods refer to "Standard for Testing Methods of Mechanical Properties of Ordinary Concrete" (GB/T50081-2002).

### 3. Test results and analyses

#### 3.1. Slump and expansion

Figure 1 and Figure 2 show the slump and expansion of recycled concrete under different length of waste polypropylene fiber and basalt fiber. From them, it can be seen that the slump and expansion of the reference group without fiber are 255mm and 564mm. The slump and expansion of concrete with fiber show a decreasing trend compared with the reference group. The main reason is that basalt fibers absorb a lot of water in the concrete mixing process, which has a great impact on the workability of concrete mixtures and a great loss of fluidity. Because of its small fibers, large aspect ratio and large specific surface area, waste polypropylene fibers will absorb a large number of cement slurry wrapped, so that the viscosity of concrete increases and slump decreases [3]. Among them, B₁₈P₃₀ group
decreased the most, slump decreased by 15.7%, expansion decreased by 19.9%. The reason is that the waste polypropylene fibers of B_{18P30} are too long to disperse in concrete, and the aggregated fibers encapsulate a large number of cement pastes, which reduces the slump and expansion of concrete.

3.2. Compressive strength
Figure 3 shows the 28-day compressive strength of recycled concrete with different lengths of waste polypropylene fiber and basalt fiber. Firstly, the compressive strength of the reference group concrete is 45.1 MPa, while the compressive strength of the concrete of the test groups decreases in varying degrees with the addition of fibers. That is to say, the compressive strength of recycled concrete in B_{18P6}, B_{18P12}, B_{18P19} and B_{18P30} groups decreased by 40.8%, 30.5%, 17.8% and 18.7% compared with the reference group. The strength of B_{18P6} group with 6 mm length of waste polypropylene fiber decreased the most, mainly because the waste polypropylene fiber was too short to form a fiber network with basalt fiber to prevent the development of concrete cracks, resulting in a sharp decrease in the compressive strength of concrete mixed with 6 mm polypropylene fiber and basalt fiber. With the increase of the length of waste polypropylene fibers, the compressive strength of waste polypropylene fibers increases gradually. When the length of waste polypropylene fiber is 19 mm, its strength decreases least. The reason is that the length of waste polypropylene fiber is very close to that of basalt fiber. When concrete cracks develop, effective bridging effect is formed to prevent the continuation of cracks, which conforms to the "fiber spacing theory" [4]. When the length of waste polypropylene fiber reaches 30 mm, the compressive strength of waste polypropylene fiber decreases slightly compared with that of 19 mm. The reason is that the length of waste polypropylene fiber is too long to disperse in concrete.

3.3. Splitting tensile strength
Figure 4 shows the 28-day splitting tensile strength of recycled concrete with different lengths of waste polypropylene fibers and basalt fibers. From Figure 4, it can be seen that the splitting tensile strength of reference group is 2.33 MPa. After adding fibers, the splitting tensile strength of recycled concrete shows a trend of decreasing first and then increasing. The splitting tensile strength of B_{18P6} and B_{18P12} groups decreased by 45.5% and 33.9%. Compared with the reference group, the splitting tensile strength of B_{18P19} and B_{18P30} groups increased by 13.3% and 8.1%. This is due to the suitable length of the two groups of waste fibers, the random distribution of fibers in concrete, and the formation of "support network structure", which can effectively alleviate the stress concentration around cracks, reduce the generation and development of cracks, and effectively inhibit the micro-cracks in concrete. As a result, the splitting tensile strength of concrete is increased [5].
3.4. Flexural strength

Figure 5 shows the 28-day flexural strength of recycled concrete with different lengths of waste polypropylene fibers and basalt fibers. It shows that the flexural strength of reference group is 2.95 MPa. After adding fibers, the flexural strength of recycled concrete decreases first and then increases. Compared with reference group, the flexural strength of B_{18}P_{6} and B_{18}P_{12} groups decreases by 15.25% and 22.03%, showing a "negative hybrid effect" [6]. The flexural strength of B_{18}P_{10} group was 22.37% higher than that of the reference group. When the length of waste polypropylene fibers is 30mm, that is B_{18}P_{12} group, the mixing of waste polypropylene fibers and basalt fibers has little effect on the flexural strength of concrete, only increased by 2.03%.

3.5. Elastic modulus

Figure 6 shows the 28-day elastic modulus of recycled concrete with different length of waste polypropylene fibers and basalt fibers. It can be seen from Figure 6, compared with the reference group, the elastic modulus of recycled concrete with waste fibers mixed with hybrid fibers is reduced; the elastic modulus of B_{18}P_{6} group is lowered by 31.30%, the reason is that the length of waste polypropylene fibers is too short to be compared with basalt fibers. The elastic modulus of B_{18}P_{12} and B_{18}P_{19} groups decreased by 26.7% and 21.8% compared with the reference group, as the length of waste polypropylene fiber increased. The elastic modulus of B_{18}P_{30} group showed a downward trend. The main reason may be that the elastic modulus of waste polypropylene fibers is low and the toughness is high. After mixing with concrete, the deformability of concrete increases [7].
3.6. Ratio of elastic modulus to strength

The ratio of elastic modulus to strength is one of the most widely used indexes to evaluate the crack resistance of concrete. The smaller the ratio of elastic modulus to strength is, the better the crack resistance of concrete is. Figure 7 shows the ratio of elastic modulus to compressive strength of recycled concrete under different length changes of waste polypropylene fiber and basalt fiber. It shows that the elastic strength ratio of reference group is 724, the B_{18}P_6 group reaches the maximum value of 840, which is 16.02% higher than that of reference group. With the increase of the length of waste polypropylene fibers, the B_{18}P_{19} and B_{18}P_{30} groups decreased by 4.83% and 4.56% compared with the reference group, and their crack resistance was higher than that of the reference group.

![Figure 7. Ratio of elastic modulus to strength of hybrid fiber recycled concrete with different lengths](image)

![Figure 8. Tensile-compression ratio of hybrid fiber recycled concrete with different lengths](image)

3.7. Tension-compression ratio

Tension-compression ratio is one of the indexes to evaluate the brittleness of concrete. The lower the tension-compression ratio is, the greater the brittleness of concrete is. Figure 8 shows the ratio of tensile strength to compressive strength of recycled concrete under different lengths of waste polypropylene fibers and basalt fibers in 28 days, i.e. tension-compression ratio. From Figure 8, it can be seen that the tension-compression ratio of base group is 0.0512, and B_{18}P_6 group decreased by 7.03%. Thereafter, with the increase of the length of waste polypropylene fibers, the tension-compression ratio of B_{18}P_{12} group is 0.0499. There was no significant difference between the reference group. The B_{18}P_{19} group with an increase of 39.26% compared with the reference group, while the B_{18}P_{30} group showed a downward trend, but an increase of 34.38% compared with the reference group. Generally, the brittleness of concrete can be significantly improved when the length of hybrid fibers is suitable.

4. Conclusion

In this paper, the workability and mechanical properties of recycled concrete are analyzed by mixing different length combinations of basalt fibers and waste polypropylene fibers into recycled concrete, and the following conclusions are obtained.

1. The fluidity of recycled concrete decreases with the addition of hybrid waste fiber, and the fluidity of concrete decreases with the increase of the length of waste polypropylene fiber.

2. The compressive strength and elastic modulus of recycled concrete are decreased with the addition of hybrid waste fiber. When the length of waste polypropylene fiber is 6 mm, it will decrease most, and then increases with the increase of the length of waste polypropylene fiber. The compressive strength and elastic modulus increase slowly, but they are still lower than those of the reference group.

3. When the length of waste polypropylene fiber is 19 mm and 30 mm, the splitting tensile strength and flexural strength of recycled concrete can be improved significantly.
(4) When the fiber length of the waste polypropylene fiber is 19 mm and 30 mm, the mixed waste polypropylene fiber and the basalt fiber can obviously improve the brittleness and the cracking resistance of the recycled concrete.

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