Experimental study on mechanical properties of high strength concrete with solid waste

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Abstract: in order to use construction solid waste, the mix proportion tests of high-strength concrete doped construction solid waste are performed, and the influences of waste coarse aggregate replacement rate and basalt fiber on fluidity, compressive strength, elastic modulus and split strength of high strength concrete are investigated. The results show: with increase of waste coarse aggregate replacement rate, the compressive strength and elastic modulus of high strength concrete are decreased as well as slump under the same strength grade; with increase of basalt fibers, the split strength of high strength concrete increases first and then decreases, but the compressive strength of concrete is almost constant, then the suitable replacement rate of waste coarse aggregate is 30%.

1. Introduction
With the rapid development of China's economic construction and the increasing living standards of the people, more and more construction waste is produced in the city. The recovery rate of construction waste in developed countries has reached 80%, while the recovery and utilization rate of construction waste in China is still less than 5%. At present, the annual construction waste in China is up to 4 million tons, and the landfill method is a more effective method for reducing the waste. Most of our country adopts landfill disposal, but landfill not only occupies a large amount of land, destroys the environment, but also is not conducive to the utilization of waste. How to recycle building solid waste has become one of the most urgent problems to be solved.

The concrete coarse and fine aggregate formed after crushing, cleaning and grading of building solid waste is an effective way to solve construction solid waste instead of raw coarse and fine aggregate in concrete material [1, 2]. This method not only solves the problem of waste recycling, but also saves resources.

This paper aims to study the construction of solid waste impact on coarse aggregate high strength concrete mix ratio test, recovery and utilization of building solid waste concrete, waste of coarse aggregate on the original aggregate replacement rate and basalt fiber concrete fluidity, compressive strength, elastic modulus and the influence of mixing strength, splitting strength.

2. Experimental design
2.1. Experimental material
• Cement: the test selected the conch brand (P•O42.5) ordinary Portland cement.
- Fine aggregate: in this experiment, natural river sand is used as fine aggregate, and its gradation is good. Its apparent density and mud content are respectively 2.6 kg/m$^3$ and 0.2%, and fineness modulus is 2.7.
- Mineral admixture: fly ash is used in the second grade fly ash of Ningde Datang Power Plant. Adopting silica fume produced by Shanghai Shanying Environmental Protection Technology Co., Ltd., the content of SiO$_2$ is 85% ~ 95%, the average particle size of 0.10µm~0.225µm.
- Admixtures: The water-reducing agent is Fujian Jianke Polycarboxylate superplasticizer, and the water reduction rate is 25% to 35%.
- Water: Use local tap water in Fuzhou.
- Coarse aggregates: Figure 1 shows the schematic diagram of solid waste coarse aggregates, Figure 2 shows the schematic diagram of natural coarse aggregates. The coarse aggregate of solid waste is C60 high strength prestressed pipe pile. After crushing, removing impurity, sieving and grading of jaw crusher, the coarse aggregate with particle size of 7 to 13 mm is obtained. The natural coarse aggregate is a continuous gradation. According to the requirements of first-grade grading concrete, the same coarse aggregate of 7 to 13 mm is used. Table 1 below shows the basic properties of the coarse aggregates.

| Type            | Apparent density (kg/m$^3$) | Dense packing density (kg/m$^3$) | Loose accumulation density (kg/m$^3$) | Water absorption (%) | Crushing value (%) |
|-----------------|-----------------------------|----------------------------------|--------------------------------------|----------------------|--------------------|
| Natural aggregate | 2716.5                      | 1491.4                           | 1415.5                               | 0.42                 | 4.54               |
| Solid waste     | 2539.5                      | 1435.0                           | 1311.4                               | 1.83                 | 6.57               |

2.2. Experimental plan
The design match is shown in Table 2 below. For each strength grade of concrete, the replacement rate of solid aggregates as coarse aggregates was used as the study parameters, and the values were 0%, 30%, 70%, and 100%. The slumps, concrete compressive strength, and elastic modulus of each numbered high-strength concrete were measured separately. All the mix ratio tests were carried out using a 60-liter stirrer, and 13 sets of test pieces were made using 150×150×150 mm mold for
compression test and splitting test; 10 sets of test pieces were made using 150×150×300 mm molds, and the elastic molds were used. Quantity test, 3 test blocks for each test piece.

3. Result and analysis

3.1. Influence of Replacement Rate of Solid Aggregate on Aggregate Flow of High Strength

Table 2. Experiments mixture ratio.

| NO | W/B | Replacement Percent (%) | Material usage (kg/m³) |
|----|-----|--------------------------|-----------------------|
|    |     |                          | Water   | Cement | Sand   | Natural aggregate | Recycled aggregate | Fly ash | Silica fume | Water reducer | Basalt fiber |
| 1  | 0.32| 0                        | 175     | 382.2  | 604.4  | 1074.6           | 0                   | 109.2   | 54.6        | 6.6          | 0            |
| 2  | 0.32| 30                       | 180.9   | 382.2  | 604.4  | 752.2           | 322.4              | 109.2   | 54.6        | 6.6          | 0            |
| 3  | 0.32| 70                       | 188.8   | 382.2  | 604.4  | 322.4           | 752.2              | 109.2   | 54.6        | 6.6          | 0            |
| 4  | 0.32| 70                       | 188.8   | 382.2  | 604.4  | 322.4           | 752.2              | 109.2   | 54.6        | 6.1          | 3            |
| 5  | 0.32| 70                       | 188.8   | 382.2  | 604.4  | 322.4           | 752.2              | 109.2   | 54.6        | 6.1          | 5            |
| 6  | 0.32| 100                      | 194.7   | 382.2  | 604.4  | 0               | 1074.6             | 109.2   | 54.6        | 6.6          | 0            |
| 7  | 0.26| 0                        | 148.2   | 399    | 571.8  | 1110            | 0                   | 114     | 57          | 7.4          | 0            |
| 8  | 0.26| 30                       | 154.3   | 399    | 571.8  | 777             | 333                 | 114     | 57          | 7.4          | 0            |
| 9  | 0.26| 70                       | 162.4   | 399    | 571.8  | 333             | 777                 | 114     | 57          | 7.4          | 0            |
| 10 | 0.26| 100                      | 168.5   | 399    | 571.8  | 0               | 1110                | 114     | 57          | 7.4          | 0            |

Figure 3 shows the effect of the replacement rate of solid aggregate on the slump of high-strength concrete. It can be seen from the figure that as the substitution rate increases, the slump of high-strength concrete at each strength level shows a decreasing trend.

The coarse aggregate of the waste has a great influence on the fluidity of the high-strength concrete mixture. For each strength grade of high-strength concrete, the slump decreases by 10 to 15 mm with the increase of the substitution rate. This is because a large amount of pores and micro-cracks are generated in the coarse aggregate after the coarse aggregate of the waste is subjected to a jaw crusher.
The internal structure of the waste coarse aggregate is loose and porous, and the water absorption rate is relatively larger than that of the natural course aggregate. The coarse aggregate surface is rough and the angularity is large. During the preparation process, the friction resistance between the interiors of the concrete mixture will increase. Therefore, at the same mix ratio, with the increase of the replacement ratio of the coarse aggregate of the waste, the more water is absorbed by the coarse aggregate of the waste, thereby reducing the flowability of the high-strength concrete, manifested as the slump of the mixture. Slowing shrinking. At different strength levels, the substitution rate has a reduction effect on the slump of high-strength concrete mix, which is the same as the conclusion of document [3,4].

3.2. Influence of Replacement Rate of Crude Aggregate on Compressive Strength of High Strength

Figure 4 shows the effect of the replacement ratio of coarse aggregate on the compressive strength of high-strength concrete. For concrete with strength class C80, the compressive strength of high-strength concrete is 84.41MPa when the substitution rate is 0%; the substitution rate is At 30%, the compressive strength of high-strength concrete is 78.68MPa, and the strength is decreased by 5.73MPa; at a substitution rate of 70%, the compressive strength of high-strength concrete is 73.04MPa, and the strength is decreased by 5.64MPa when the replacement ratio is 30%; When the rate is 100%, the compressive strength of high-strength concrete is 63.07MPa. The substitution rate ranges from 0% to 100%, and the compressive strength of high-strength concrete decreases by 25.28%. For high-strength concrete with a strength class of C60, the compressive strength also showed a downward trend with the increase of the substitution rate, and the decrease trend was smaller than that of the C80.

Concrete is made of three-phase composite materials. Due to the use of waste coarse aggregates to replace part of the natural coarse aggregate, the interface structure of concrete is complicated, and the effect of coarse aggregate on the strength of concrete is mainly in the interface transition layer. For ordinary concrete, the modulus of elasticity between the cement mortar containing high-strength concrete containing coarse aggregate and the coarse aggregate is too different. Under the action of the load, the changes of the two are different, micro-cracks occur at the interface, and these interface transition regions will become the weak points of the concrete strength. The roughness of the surface of the coarse aggregate of the waste is larger than that of the natural aggregate, and some of the stones will crack along the texture due to the force during the crushing process. This will not only increase the new rough surface but also increase the angular effect, which may cause waste. The coarse aggregate has a lower strength.

With the increase of the concrete strength grade, the more the coarse aggregate content of the waste, the greater the decrease in the strength of the concrete. The test result is the same as the conclusion in document [5].

3.3. Influence of Replacement Rate of Crude Aggregate on Elastic Modulus of High Strength Concrete

Figure 5 shows the effect of substitution rate on the elastic modulus of high-strength concrete. On the whole, the modulus of elasticity of high strength concrete decreases with the increase of the substitution rate.
Due to the existence of coarse aggregate of waste, the interface between natural coarse aggregate and old cement, the interface between the rock part of the coarse aggregate and the new cement, the old mortar and new cement in the coarse aggregate, the number of pores and micro-cracks in the interfacial surface is more than that of ordinary concrete, and the porosity is the main factor affecting the elastic modulus of the concrete. The cement mortar envelops the coarse aggregate of the waste and simultaneously exerts a transitional effect, making the new cement mortar and waste. The difference in elastic modulus between coarse aggregates decreases, but there is still a difference in strength. On the whole, the modulus of elasticity of concrete with the same strength grade decreases with the increase of the substitution rate, but it has no significant influence on the compressive strength.

3.4. Influence of basalt fiber on compressive strength of high strength concrete with waste coarse aggregate

Figure 6 shows the effect of basalt fiber on the compressive strength of high-strength concrete with coarse aggregates. After adding 3kg/m$^3$ of basalt fiber, the strength of the high-strength concrete hardly changed. After adding 5kg/m$^3$ of basalt fiber, the strength of high strength concrete decreases by 6.52MPa. This is due to the addition of basalt fiber, which causes more micro-cracks in the interior of high-strength concrete. These cracks lead to more weak interfaces in high-strength concrete and reduce the compressive strength of high-strength concrete. [6]

3.5. Influence of basalt fiber on the splitting strength of high strength concrete with waste aggregate and coarse aggregate

Figure 7 is a basalt fiber affecting splitting strength of high strength concrete diagram when the basalt fiber is 0kg/m$^3$, the splitting strength of concrete reaches 152.1MPa; when the basalt fiber content reached 3kg/m$^3$, the splitting strength increased by 23.7MPa, because of basalt fiber and inorganic cementations material to combine to form a three-dimensional fiber network structure the concrete structure is more compact. A large number of hydration products are attached, and can effectively organize the expansion of micro cracks, thereby reducing crack length, width and cracking area, absorbing and consuming energy, to a certain extent, improving the crack resistance of concrete. After increasing the basalt fiber of 2kg/m$^3$, the splitting strength decreased by 21.4MPa. It may be because the effect of the interface transition zone and the mesh structure formed by excess fiber and cement slurry is offset by each other, and the negative effect is more negative. So the fiber added to it can’t share load, absorb and consume energy. Although it is repeatedly added to the mixer for stirring, it is inevitable that agglomeration will result in the occurrence of initial defects, which can’t give full play to the role of fiber and make the strength decrease with the increase of basalt fiber.
4. Conclusions
The solid aggregates of construction solid waste have higher water absorption than natural coarse aggregates, which is reflected in the reduction of the fluidity of high-strength concrete mixes. Therefore, in the preparation of high-strength concrete using building solid waste, additional water is needed to ensure the flow of high-strength concrete.

For high-strength concrete of the same strength grade, the change of the replacement ratio of coarse aggregate in waste has an impact on the compressive strength of high-strength concrete. As the substitution rate increases, the strength of high-strength concrete decreases, and the strength grade increases. The more obvious the impact is, the higher elastic modulus of high-strength concrete also shows a downward trend with the increase of the substitution rate, but it has no obvious compressive strength.

Incorporation of basalt fiber can increase the splitting strength of high-strength concrete. However, when the content is increased to 5 kg/m³, basalt fiber will have agglomeration phenomenon in concrete, leading to a decrease in the split strength of high-strength concrete. According to the results of this experiment, the optimum amount of basalt fiber was 3 kg/m³.

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