Experimental Study on the Influence of Specific Factors on the Compressive Strength of Recycled Fine Aggregate Concrete

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Abstract. In this test, the waste concrete is pulverized, and the particles of appropriate diameter are selected as the recycled fine aggregate to replace the natural fine aggregate. Meanwhile, the test materials are processed in different ways, and are finally made into recycled concrete. The processing methods of test materials include: high temperature treatment of concrete particles, partial replacement of cement with fly ash, and replacement of water with sodium silicate solution. To process the materials is to study the influence of its single factor or the multiple coexistent factors on the compressive strength of recycled concrete, and then to explore the most effective method of recycled fine aggregate use under preset conditions. The results show that: 1) When the natural fine aggregate is replaced with the recycled fine aggregate and there is only a single variable factors, the compressive strength of the recycled concrete increase most obviously after the concrete particles are processed through a six-hour-long high temperature heat at 300℃, and when the replacement rate of recycled fine aggregate is about 35%, the strength value is the maximum; 2) When there are multiple variable factors in the test, the compressive strength of the recycled concrete is lower than that of the single variable factors.

1. Introduction

With the development of social economy, the construction industry has become one of the hot industries, followed by the increasing number of construction projects. According to statistics, nearly 1 billion tons of concrete is used in construction projects every year [1]. The production of concrete consumes a lot of sandstone, resulting in a large shortage of high quality sandstone. At the same time, the abandoned concrete after the demolition of the building is piled up everywhere and is not treated in time, which not only causes waste of resources, but also causes serious damage to the environment. If these waste concrete can be reused, the total amount of concrete waste discharged can be reduced to a large extent, and the pollution to the natural environment can be reduced, and also reduce the loss of natural fine aggregate in the construction industry[2]. Therefore, many scientific studies are exploring how to reuse waste concrete. In some existing studies, the reuse of most waste concrete is to crush it into recycled coarse aggregate or recycled fine aggregate, partially or completely replacing natural aggregate to make new concrete[3]. On the basis of the above research, this experiment used waste concrete as raw material to prepare recycled fine aggregate and replaced the part of concrete with fly ash. The recycled concrete specimens with a specification of 150mm×150mm×150mm was made, and its compressive strength was tested and
analyzed. In the end, a more effective way to make recycled concrete from waste concrete was explored. The results can provide a theoretical basis for the application of recycled concrete in practical engineering.

2. Experiment Details

2.1. Experiment Material
The ordinary Portland cement with a strength rating of 42.5R and the Fly Ash made by Hong hua gang power plant were used in this experiment. In addition, the material also included B85 instant solid sodium silicate powder. The coarse aggregate was made of continuous grade natural gravel with a particle size of 5mm~31.5mm. And the recycled fine aggregate was made of waste concrete that was crushed with a particle size of 0.16mm~5mm. The fine aggregate grading was shown in the table 1. The water that was used to mix and maintain the concrete specimens was the tap water.

| Sieve pore/mm | 5.00 | 2.50 | 1.25 | 0.63 | 0.32 | 0.16 | Fitness modulus |
|---------------|------|------|------|------|------|------|-----------------|
| Recycled fine aggregate cumulative sieve residue/% | 0.1  | 19.9 | 44.4 | 63.4 | 74.0 | 82.8 | 2.84            |
| Natural fine aggregate cumulative sieve residue/% | 0.5  | 15.3 | 38.1 | 65.1 | 83.7 | 95.0 | 2.96            |

2.2. Specimens Preparation
In this experiment, three groups of recycled concrete specimens were prepared. The recycled fine aggregate was used to replace different proportions of natural fine aggregate. The replacement rates of fine aggregate were 0%, 30%, 60%, 100% respectively[5]. The first group was to directly replace the natural fine aggregates with different proportions of recycled fine aggregate without special treatment. The second group is a single variable group, the recycled fine aggregate was heated and dried by high temperature (type DHG-9140 electric heating constant temperature blast drying oven heated at 300 °C for 6 hours), and the water was substituted with 5% sodium silicate solution, and 5% of the cement was replaced with fly ash. The third group is a multivariable group. On the basis of replacing 5% cement with fly ash, the recycled fine aggregate was replaced by high temperature heat drying recycled fine aggregate and the water was replaced by 5% sodium silicate solution. The mix proportion of each group in this experiment are shown in table 2, table 3 and table 4 respectively.

Table 2. The mix proportion of the first group. (kg/m$^3$)

| No. | Cement | Coarse aggregate | Fine aggregate | Water |
|-----|--------|------------------|----------------|-------|
| CN01 | 624.7  | 1298.7           | 0              | 575.3 | 216.0 |
| CN02 | 624.7  | 1298.7           | 172.6          | 402.7 | 221.2 |
| CN03 | 624.7  | 1298.7           | 345.2          | 230.1 | 233.8 |
| CN04 | 624.7  | 1298.7           | 575.3          | 0     | 250.1 |

Table 3. The mix proportion of the second group. (kg/m$^3$)

| No. | Cement | Coarse aggregate | Fine aggregate | Water | Fly ash | Sodium silicate |
|-----|--------|------------------|----------------|-------|---------|-----------------|
| CNC01 | 593.5  | 1298.7           | 0              | 575.3 | 227.2   | 31.2            |
| CNC02 | 593.5  | 1298.7           | 172.6          | 402.7 | 234.6   | 31.2            |
| CNC03 | 593.5  | 1298.7           | 345.2          | 230.1 | 204.9   | 31.2            |
| CNC04 | 593.5  | 1298.7           | 575.3          | 0     | 259.3   | 31.2            |
After the mixture was uniformly stirred, the two layers were placed in a test mold, and the thickness of each layer was approximately equal, and the layers were tamped with a tamper, and finally the surface was smeared with a spatula to prepare a test piece. After the specimen was naturally cured for 2 days, the mold was removed and placed in water at 20±2 °C for 7 days[6]. In the end, the natural conservation was carried out until the age of 28 days. Three specimens were made for each group of experiments, and the test piece size was 150mm×150mm×150mm cube.

2.3. Data Processing
The test for the compressive performance of recycled concrete is carried out in accordance with the GB/T50081-2002. The test is carried out by a microcomputer-controlled constant-pressure helium pressure tester model YAW-2000D, and every specimen was tested. Then the load values that each specimen can be withstood were measured.

The data is processed according to the GB/T50082-2009 and the GB50164-2011. The data processing methods of each test group are as follows.

The size of the specimen is 150mm × 150mm × 150mm, and the compressive strength calculation expression is \( fc = F / A \). Among them, \( fc \) is the cubic compressive strength of concrete; \( F \) is the test piece failure load; \( A \) is the cross-sectional area of the test piece. The mean value of the measured values of the three specimens in each group is used as the strength value of the specimens in each group. And the difference between the minimum or maximum value of the three measured values and the intermediate value shall not exceed 15% of the intermediate value. If one of them exceeds 15% of the intermediate value, the minimum and maximum values should be rounded off at the same time, and the intermediate value is taken as the compressive strength of the test piece; if they both exceed 15% of the intermediate value, then the test results of this group are invalid.

3. Results and Discussion

3.1. Effect of Fine Aggregate Replacement Rate on Compressive Strength of Recycled Concrete
When we replace the natural fine aggregate with the recycled fine aggregate without special treatment,
the recycled concrete specimens after standard curing for 28 days are tested for compressive strength, and the intensity distribution curve of the recycled concrete made under different alternative ratio is shown in figure 1. When the replacement rate was 0%, the compressive strength of the specimen is 30.35 MPa. It is the compressive strength of the standard concrete specimen and we take it as the control group of the whole experiment. As the replacement rate increases to 30%, the compressive strength increases rapidly. When the replacement rate is 35%, it peaks. When the replacement rate of the recycled fine aggregate exceeds 35%, with the replacement rate increases the compressive strength continuously decreases. This suggests that the appropriate proportion of recycled fine aggregate can exert the cohesiveness of each material of recycled concrete, thereby improving the compressive strength of it, and the most desirable replacement rate is 35%.

Figure 1. Recycled concrete compressive strength when recycled fine aggregate replaces natural fine aggregate.

3.2. Influence of Single Factor on Compressive Strength of Recycled Concrete
In this group, the compressive strength of recycled concrete is studied under the condition of replacing the natural fine aggregate with the recycled fine aggregate with high temperature treatment, 5% sodium silicate solution instead of water and fly ash instead of 5% cement. After 28 days of maintenance, the results are shown in figure 2, figure 3 and figure 4 respectively.

Figure 2 gives that with the increase of the replacement rate of the recycled fine aggregate, the compressive strength rises first and falls later, and the trend of rising and falling is relatively large. When the replacement rate reaches about 35%, the compressive strength reaches the peak. According to the analysis, the main reason is that the high temperature heating can rupture the smoother cement slurry on the surface of the recycled fine aggregate, thereby increasing the specific surface area and roughness of the recycled fine aggregate and improving the cohesion with the new cement slurry. However, the recycled fine aggregate itself has high porosity and low compressive strength. Therefore, if the replacement rate is too high, it has a limitation on the compressive strength of the recycled concrete.

Figure 2. Recycled concrete compressive strength under high temperature heating condition of recycled fine aggregate.
Analysis of the effect of sodium silicate solution instead of water on the compressive strength of recycled concrete shows that the overall law of the strength curve is first rising, then falling and then rising, and the compressive strength is generally lower than that of recycled fine aggregate. The strength of the fine aggregates negatively inhibits the strength of the recycled concrete. It is speculated that the sodium silicate solution may react with some materials, and then produce substances that are not conducive to the improvement of concrete strength.

Figure 3. Compressive strength of under the condition of replacing water with sodium silicate solution.

The curve of the effect of fly ash replacing 5% amount of cement on the compressive strength of recycled concrete is analyzed. With the increase of fine aggregate replacement rate, the compressive strength trend of recycled concrete firstly increased and then decreased. The rate of increase is slower, and the rate of decline is relatively rapid, and peaks when the replacement rate of recycled concrete is about 60%. Overall, the replacement of some cement by fly ash has an effect on the strength of recycled concrete, but the effect is not enough obvious.

Figure 4. Compressive strength of concrete under the condition of replacing cement with fly ash.

Finally, a comprehensive analysis of the three figures shows that the strength of the compressive strength of recycled concrete by changing a single variable is basically produced by regenerating fine aggregate by high temperature treatment, while the other two groups have no obvious effect on the compressive strength enhancement and even lower it. It can be concluded that the high-pressure treatment of the recycled fine aggregate and the replacement of the natural fine aggregate by the appropriate proportion of the recycled fine aggregate can enhance the compressive strength of the recycled concrete.

3.3. Influence of Combination Factors on Compressive Strength of Recycled Concrete

In this group of experiments, in the case of replacing 5% amount of cement with fly ash, the recycled fine aggregate is treated at a high temperature and the water is replaced with 5% sodium silicate solution. The natural fine aggregate is replaced with the recycled fine aggregate. The compressive
strength was shown in figure 5 and figure 6.

Figure 5 shows that the compressive strength rises first with the increase of the recycled fine aggregate replacement rate. The compressive strength reaches the maximum when the replacement rate is 30% and it is the smallest when the replacement rate is 100%.

Figure 5. The compressive strength of concrete under the condition of replacing cement with fly ash and high temperature treatment of the recycled fine aggregate.

When replacing 5% amount of cement with fly ash and replacing water with 5% sodium silicate solution, the compressive strength curve is shown in figure 6. With the increase of replacement rate, its compressive strength also increases constantly.

Figure 6. The compressive strength of concrete under the condition of replacing water with 5% sodium silicate solution and replacing cement with fly ash.

Although the trends of the two experiment are different, it can be found through the vertical comparison of their respective curves that when there are combined factor variables, the compressive strength of recycled concrete is basically less than the compressive strength when there is only a single variable factor. So it can be inferred that the combination factors may affect each other and are not suitable for improving the compressive strength of recycled concrete. And by comparing all the experimental data, it can be found that the recycled concrete has the largest compressive strength value if only the recycled fine aggregate is subjected to high temperature treatment instead of about 35% of the cement.

4. Conclusions
Through the analysis of the above test data and curve graphs, the conclusions are as follows, which can be used as theoretical support for the reuse of recycled concrete.

First, when there is only a single variable, the experimental study found that when the recycled fine aggregate is subjected to high temperature treatment, the compressive strength of the recycled concrete
can be effectively improved. And when the 5% sodium silicate solution is used instead of water, it will be lowered. When 5% amount of cement is replaced by fly ash, the compressive strength is also lowered.

Secondly, when there are more than a single variable, such as replacing water with sodium silicate solution or replacing the cement with fly ash while the natural fine aggregate is replaced by the recycled fine aggregate, the compressive strength cannot be fully enhanced.

Thirdly, by analyzing all the data in the experiment, it can be found that when the recycled fine aggregate is used instead of the natural fine aggregate, the effect of improving the compressive strength of the recycled concrete is best, and when the replacement rate is about 35%, the compressive strength is maximized.

Although the experiment has achieved the expected effect, there are still some shortcomings. For example, the gradient of the replacement rate of the recycled fine aggregate is large, and the research on the replacement rate of fine aggregate is not sufficient and painstaking. For some deficiencies in the test, the test method can be improved to further study the effects of various factors on the recycled concrete.

References
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