EXPERIMENTAL RESEARCH ON BASIC PROPERTIES OF RECYCLED CONCRETE

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Abstract

It is a hot potato problem to dispose more and more scrap concrete and need settle urgently for the government of each country. In the paper, for crushing and grading the waste concrete blocks, according to a certain percentage of mixed aggregate called by the recycled aggregate or recycled concrete aggregate, and recycled aggregate as part or all of the preparation of recycled aggregate concrete is recycled concrete aggregate effective way to use one. Waste concrete used in structural engineering must be tested throughoutly by the of regeneration of a solid experiment and reliable theoretical basis, the need to strengthen the structure of the regenerative properties of concrete. This paper will research the mechanics performance of recycled concrete material in compression, cleave-tensing, elastic modulus etc base on the dates of experiment.

Keywords: recycled concrete, mixed ratio design, compressive strength, splitting tensile strength, elastic module, mechanics performance

1. INTRODUCTION

The properties of recycled concrete are closely related to the properties of recycled concrete aggregates and microstructure of recycled concrete. Due to the internal transverse cracks that produced from breaking concrete, poriness of recycled concrete aggregate and the poor particle granular composition, impurities, sulphate and chloride which mixed in recycled concrete aggregate, the weak combining area that between cement slurry adhered to recycled concrete aggregates and recycled aggregates, result in the high variability of recycled concrete quality. Compare with the natural aggregate concrete for the same mix proportion, whether short-term performance such as the strength of concrete, workability, or long-term performance such as durability, the recycled concrete is worse than the natural aggregate concrete. Surface treatment for recycled aggregate and add superplasticizer admixture and
ultra-pulverized coal ash into the recycled concrete system, can effectively improve the performance of recycled concrete. The paper studies the basic performance of material of recycled concrete.

2. MATERIAL OF RECYCLED CONCRETE

2.1 Main characteristics of this article use the recycled aggregate

The test uses renewable sources of aggregate for Hunan city university laboratory test concrete structure, the broken, its main size into 0～5mm recycled fine aggregate, 5～20mm, 20～30 and 30mm～40mm three kinds of recycled coarse aggregate, as shown in figure 1.

![Recycled aggregate (size)](image)

Fig. 1: Recycled aggregate (size)

When the aggregate gradation is better, between aggregate pore filling slurry need less, which can reduce the dosage of cement. In order to make recycled coarse aggregate gradation and ordinary concrete of similar size, after three of the scope of recycled coarse aggregate proportional to the combination of combination of bulk density, after one of the biggest gradation as required. According to the building materials applied technical specification through the test, when using, as shown in the table 1 gradation, its cumulate density is maximum[1].
Table 1: Gradation table of recycled coarse aggregate

<table>
<thead>
<tr>
<th>SIZE RANGE (MM)</th>
<th>5~20MM</th>
<th>20~30MM</th>
<th>30~40MM</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROPORTION (%)</td>
<td>50</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

This experiment table 1 gradation according to specification through the test found the cumulate density and apparent density respectively 1290kg/m³ and 2340 kg/m³, and natural coarse aggregate of cumulate density and apparent density respectively 1453 kg/m³ and 2600 kg/m³. Regeneration aggregate dibulous rate is 4%, natural regeneration dibulous rate is 0.4%, thus dibulous rate is greater than natural aggregate dibulous rate. This major caused by recycled coarse aggregate surface part of cement mortar, and the big void ratio. Recycled coarse aggregate crush respect to 15.2 ,and natural aggregate crush respect to 4.04. apparently recycled coarse aggregate crush higher than the natural one, all about four times, but it still can satisfy "the ordinary concrete proportioning design rules"(JGJ55-2000), which C30 configuration of index of concrete rubble needed to crush the requirements (crush index≤16).

According to paper [1], through the test recycled aggregare and natural aggregate renewable aggregate flakiness content of particles are 6.2% and 4.8% respectively. The silt content of recycled coarse aggregate and natural coarse aggregate are 4.0% and 1.8% respectively. Due to the regeneration of the aggregate flakiness content and silt content are greater than natural aggregate, it will lead to the decline of regenerate aggregate concrete strength and the increase of shrinkage, influence of recycled concrete performance.

2.2 Recycled concrete mixing

2.2.1 Test materials

Cement: 32.5 R Panfeng brand ordinary silicate cement which produced by Hunan xiangxiang country building materials industry limited company.

Fine aggregate: Natural fine aggregate is accord with the JGJ92 – 52 requirement about river sand; recycled fine aggregate come from hunan city university concrete structures by artificial laboratory test after crushing, screening for 0~5mm particle regeneration of fine aggregate.

Coarse aggregate: Natural coarse aggregate for natural gravel, maximum diameter is 20mm, continuous gradation; recycled coarse aggregate come from hunan city university concrete structures by artificial laboratory test after crushing, screening, the size of coarse aggregate for 5 ~ 40mm adopts the table 1.

Mixing water: running water.

2.2.2 The proportion of concrete and recycled concrete

Based on paper [2], Definition of recycled coarse aggregate concrete replace ratio r for quality ratio that recycled coarse aggregate divide all coarse aggregate. When r = 0 ,as the benchmark for ordinary concrete. The paper has considered the four different kinds of replace ratio: preceding 3 kinds are fine aggregate for natural yellow sand, recycled coarse aggregate replace ratio for r =0, 50%, 100%, the last 1 fine aggregate is recycled fine aggregate, recycled coarse aggregate replace ratio is r =100%, defined as a whole 100% of recycled aggregate concrete. Because of recycled coarse aggregate dibulous rate is high, need
appropriate increase in the water, which are compensated at a certain extent, the water is defined as additional water, that means make recycled coarse aggregate need additional water which attain to saturation face dry condition, the amount of water needed is according to the data of recycled coarse aggregate effectively bibulous rate (the bibulous rate is from natural drying condition to face dry state saturation) or to calculate the amount of water of recycled coarse aggregate [3]. This paper quote recycled concrete experiment results about the mixing proportion of concrete which are researched by dates of papers[4-5], who is guided by professor Deng shouchang[6-7], under different replace ratio for C30 strength grade of concrete regeneration. The concrete mixing is shown in table 2.

Table 2: Actual mix proportions of concrete (C30 concrete)

<table>
<thead>
<tr>
<th>RAC replace ratio (%)</th>
<th>W/C</th>
<th>Sand ratio</th>
<th>RAC water absorption (%)</th>
<th>Concrete materials dosage PER M³ (KG)</th>
<th>Slump (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cement</td>
<td>Sand</td>
</tr>
<tr>
<td>0</td>
<td>0.56</td>
<td>0.3</td>
<td>0</td>
<td>429.8</td>
<td>555.1</td>
</tr>
<tr>
<td>50</td>
<td>0.45</td>
<td>0.3</td>
<td>4</td>
<td>474.1</td>
<td>522.1</td>
</tr>
<tr>
<td>100</td>
<td>0.44</td>
<td>0.3</td>
<td>4</td>
<td>500.0</td>
<td>476.0</td>
</tr>
<tr>
<td>100</td>
<td>0.50</td>
<td>0</td>
<td>4</td>
<td>500.0</td>
<td>/</td>
</tr>
</tbody>
</table>

2.3 Making and curing of test specimen

Because the number of test specimen maked is not big, so use artificial stirring. In order to mix uniformly, first mix fine aggregate and cement, ready-mixed 1min, then add the coarse aggregate, ready-mixed 1min, stirring water 2min. Then shovel the mixing respectively into the 150mm×150mm×150mm cube mold trial with the same feed, insert and smash them using stir bar part three layers, special attention the four nooks. Then placing them on the vibrostand of vibrating for the same time, put test specimens into the standard curing room for maintenance at 20±1 celsius temperature degrees, relative humidity above 95%, remove after the 1d.

2.4 Test equipment for tension and compression

In the compressive strength test, we used hydraulic compression testing machines YE-5000A type produced by Jinan testing machine factory, the three measuring ranges are 5000, 2000, 1000KN, because the design strength of recycled concrete is 30MPa, so choose measuring range to 1000KN (44.4MPa), accuracy is 2KN/standard.

In the tensile strength test, we used 100 tons material testing machine WE-100 type produced by Chinese hongshan testing machine factory, the three measuring ranges are 1000, 500, 200KN, because concrete tensile strength is compressive strength of only 1/10 ~ 1/20, so choose measuring range to 200KN, accuracy is 0.5KN/standard.
3. TEST RESULTS

3.1 Compression strength

Considering the early age of recycled concrete compressive strength is low, using different compression rate in each age. Age is smaller, less compression rate. When the concrete strength below C20, compression rate is 0.1~0.5 MPa/s, namely 2.25~11.25 KN/s. When the concrete strength below C30, compression rate is 0.5~0.8 MPa/s, namely 11.25~18 KN/s. Figure 2 gives part of recycled concrete test specimens of typical failure form.

As load increases, stress in the recycled concrete test specimen increases ceaselessly, test specimen begin to crack. At first crack close to the profile and surface, the crack along the vertical direction in the test specimen’s central, and develop along oblique upward and downward, until reach the loading surface and then swerve the corner of test specimen, form two coterminous "eight" words. As the load increases gradually to develop new cracks to the inside, surface concrete begin to outward convex and spalling, and eventually form coterminous quadrangular pyramid. From the destructive pattern, recycled concrete’s destruction are basically cohesive destruction between coarse aggregate and cement gel, had not been found case about splitting of coarse aggregate, so the destructive pattern that between recycled concrete and ordinary strength of natural concrete is approximate[6]. We can know the compressive strength of the recycled concrete cube test specimen value from table 3.
Table 3: Recycled aggregate concrete cube: $f_{cu}$ (Mpa)

<table>
<thead>
<tr>
<th>Days</th>
<th>Natural</th>
<th>RCA replace ratio R is 50%</th>
<th>RCA replace ratio R is 100%</th>
<th>Completely regenerated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (D)</td>
<td>9.6</td>
<td>7.0</td>
<td>7.5</td>
<td>10.3</td>
</tr>
<tr>
<td>2 (D)</td>
<td>11.1</td>
<td>16.0</td>
<td>17.6</td>
<td>13.5</td>
</tr>
<tr>
<td>3 (D)</td>
<td>13.8</td>
<td>19.0</td>
<td>17.4</td>
<td>17.3</td>
</tr>
<tr>
<td>4 (D)</td>
<td>14.1</td>
<td>20.3</td>
<td>20.3</td>
<td>19.0</td>
</tr>
<tr>
<td>7 (D)</td>
<td>18.7</td>
<td>26.0</td>
<td>26.3</td>
<td>22.0</td>
</tr>
<tr>
<td>14 (D)</td>
<td>23.4</td>
<td>31.4</td>
<td>30.6</td>
<td>27.7</td>
</tr>
<tr>
<td>28 (D)</td>
<td>28.9</td>
<td>37.1</td>
<td>36.8</td>
<td>36.1</td>
</tr>
</tbody>
</table>

3.2 The compare of compressive strength between recycled concrete and ordinary concrete

The four groups of recycled concrete compressive strength, we can know their growth curves on the basis of age from Fig. 3.

![Fig. 3 the growth curves of concrete compressive strength-age](image)

From the Fig. 3, concrete compressive strength increase along with time, and early growth faster. Recycled concrete test specimen compressive strength higher than ordinary concrete test specimen, the reason is a part of mixing water absorbed by recycled coarse aggregate in the mixed process will be released along with cement hydration, so as to promote the development of recycled concrete compressive strength. Recycled concrete strength compare to ordinary concrete compressive strength in the seventh day, improve $17.6\% \sim 40.6\%$, improve $29.0\% \sim 32.2\%$ after 28 days.
3.3 The displacement of relationship between recycled concrete compressive strength and coarse aggregate

When the recycled coarse aggregate of displacement ratio is 50%, the recycled concrete compressive strength is highest, it may be due to the gradation that form between recycled coarse aggregate and natural coarse aggregate is better, also may be due to the randomness of the test results. This phenomenon is to be further studied from microcosmic angle. With the conclusion that might apply only to the test conditions.

3.4 The relationship between recycled concrete compressive strength and fine aggregate's displacement

The recycled coarse aggregate of displacement ratio is 100%, compressive strength of natural sand for fine aggregate is greater than the compressive strength of recycled coarse aggregate rate of 100%, the fine aggregate is recycled fine aggregate's compressive strength of completely recycled concrete, it may be due to the gradation that form between recycled coarse aggregate and natural sand is better, also may be due to the randomness of the test results. This phenomenon is to be further studied from microcosmic angle. With the conclusion that might apply only to the test conditions [7-9].

4. TENSILE STRENGTH

The tensile strength of concrete is lower, only is the compressive strength of concrete $1/10 \sim 1/20$, the tensile strength of recycled concrete also have the same rules [10-12], and the tensile strength of recycled concrete is smaller than the tensile strength of ordinary concrete.

There are three methods to detect the tensile strength of concrete, direct tension test, splitting tensile strength test and flexural strength test. Using the direct tensile test in this paper, that is to say fixing the prismoidal test specimen at both ends, then exerting tension until destroy the test specimen, the tensile strength is that destructive load divide sectional area. The size of prismoidal test specimen is $150\text{mm} \times 150\text{mm} \times 450\text{mm}$, making three prismoids using each proportioning, test results from the average value. We can see four groups of recycled concrete tensile strength from table 4.

<table>
<thead>
<tr>
<th>Recycled coarse aggregate (RCA) replace ratio R (%)</th>
<th>Compressive strength (MPa)</th>
<th>Tensile strength (MPa)</th>
<th>The reduce of tensile strength compare to ordinary concrete (%)</th>
<th>Tensile strength/compress-ive strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>28.9</td>
<td>2.40</td>
<td>0</td>
<td>1/11.8</td>
</tr>
<tr>
<td>50</td>
<td>37.1</td>
<td>2.37</td>
<td>6.67</td>
<td>1/15.6</td>
</tr>
<tr>
<td>100</td>
<td>36.8</td>
<td>2.31</td>
<td>1.25</td>
<td>1/15.8</td>
</tr>
<tr>
<td>100</td>
<td>36.1</td>
<td>2.24</td>
<td>3.75</td>
<td>1/16.7</td>
</tr>
</tbody>
</table>

From table 4, the tensile strength of recycled concrete is lowering with the increase of recycled aggregate, and the reduction of recycled aggregate concrete is lesser, the lower value of tensile strength of recycled concrete is 6.67% comparing to ordinary concrete, and tensile
strength of recycled concrete is its compressive strength of 1/16.

5. THE MODULUS OF ELASTICITY OF RECYCLED CONCRETE

In the construction of recycled aggregate concrete cube, at the same time, pouring for prismoids which used to test modulus of elasticity. Each mix proportion produced six prismoids, three of which are used to measure the compressive strength of concrete axis, other three are used to measure the modulus of elasticity, a total of 24. The size of prismoid test specimen is 150mm×150mm×450mm, pouring and conserved conditions as same as the cube test specimen. Conserve for 28 days, and then test the modulus of elasticity, take the average result. Figure 4 presents concrete prismoid test specimen typical destructive form.

![Concrete prismoids (a) r=0%, (b) r=50%, (c) r=100%, (d) complete regeneration)](image)

Fig. 4: Typical failure pattern of recycled aggregate concrete prism

According to the concrete modulus of elasticity value criterion \(^1\) formula:

\[
E_c = \frac{F_a - F_0}{A} \times \frac{L}{n}
\]  

\(E_c\) —— the concrete modulus of elasticity (MPa);
\(F_a\) —— stress for 1/3 axis when the compressive strength of the load (N);
\(F_0\) —— the initial load (N);
A — specimen pressed area (mm$^2$);
L — measuring gauge length (mm);

\[ n = \varepsilon_a - \varepsilon_0 \]

\( \varepsilon_a \) —— final load corresponding strain;
\( \varepsilon_0 \) —— data point corresponding strain.

We can know the test results from table 2.6.

<table>
<thead>
<tr>
<th>Recycled aggregate replacement ratio (%)</th>
<th>Modulus elasticity EC (GPa)</th>
<th>The reduction of modulus of elasticity compared to ordinary concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>37.6</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>28.3</td>
<td>24.7</td>
</tr>
<tr>
<td>100</td>
<td>28.0</td>
<td>25.5</td>
</tr>
<tr>
<td>100</td>
<td>24.7</td>
<td>34.4</td>
</tr>
</tbody>
</table>

We can see that recycled concrete elastic modulus lower than ordinary concrete. Recycled coarse aggregate content to 50%, 100% and complete of recycled concrete elastic modulus is lower than ordinary concrete, values respectively are 28.2%, 25.5% and 34.4%. The reason for reduce of elastic modulus is mortar attached to recycled aggregate, and these mortar of elastic modulus is relatively low. Reduce of recycled concrete elastic modulus, it cause the increases of deformation under load. Because of reduce of recycled concrete elastic modulus, when used for structural components, we need to consider the problems of increasing of deformation of structural components [13-14].

6. CONCLUSIONS

We researched recycled aggregate concrete and the basic performance of recycled concrete of in this chapter, through the research and analysis we get conclusions:

(1) The destructive process of recycled concrete and destructive mode is according to ordinary concrete mainly, and the destruction of recycled concrete basically from agglutinating destruction that from coarse aggregate and cement gel.

(2) The influence which the replacement rate of recycled coarse aggregate replacement to the compressive strength of recycled concrete is great, the compressive strength of recycled concrete is higher than ordinary concrete, the displacement ratio is the highest rate of 50%, This phenomenon is to be further studied from microcosmic angle.

(3) The influence which recycled fine aggregate to the compressive strength of concrete is little.

(4) The recycled aggregate’s bulk density, apparent density and crush index are smaller than the natural aggregate, bibulous rate is bigger than the natural aggregate, the content of impurity is higher than the natural aggregate, but basically satisfy demands for aggregate that 《quality standards and methods of detection for ordinary concrete with gravel or pebbles 》in the concrete, it is feasible used to allocate recycled concrete.
(5) The mix proportion of recycled concrete can be designed using with ordinary concrete design method of mix proportion that mentioned in 《the ordinary concrete mixture rules 》 (JGJ55-2000) , then determine the additional water of recycled aggregate, and put in mixing water and additional water at the same time, when mix recycled concrete[2-5;9-10];

(6) The compressive strength of recycled concrete is bigger than ordinary concrete, but the tensile strength of recycled concrete is smaller than ordinary concrete, and the elastic modulus of recycled aggregate concrete is smaller than ordinary concrete[15-19].

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