MANUFACTURING TECHNOLOGIES OF RECYCLED AGGREGATE CONCRETE

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ABSTRACT: The recycled aggregate is obtained from construction waste or waste concrete, which is then made into recycled concrete. In this paper, according to the characteristics of local raw materials, the source and processing technology of recycled aggregates is analyzed, and then the performance of recycled aggregates is analyzed by experiment, finally recycled concrete suitable for local raw materials is prepared. The working performance and mechanical properties of recycled concrete are analyzed. A more comprehensive understanding of recycled concrete is obtained, which has further promoted the practical application of environmental protection projects.

KEYWORDS: Manufacturing Technologies; Recycled aggregate; Recycled concrete

1 INTRODUCTION

Recycled aggregate is obtained by treating construction waste or waste concrete, and recycled concrete is made from recycled aggregate (Nicolas S, et al., 2016). Applied recycled concrete is applied in actual engineering project, and recycled concrete not only improves the utilization of waste concrete, but also saves a lot of natural sand. Therefore, the comprehensive utilization of waste concrete is not only an ecological economy, but also a practical implementation of the scientific development concept (LIU Jian, et al., 2018). It advocates the development of the economy on the basis of sustainable development, and fundamentally weakens the sharp contradiction between the environment and development caused by abandoned concrete, which is of great significance to the protection of limited natural resources and the protection of the ecological environment worldwide. (ZHANG Ximin, et al., 2018, XIAO Jianzhuang, et al., 2007)

During the production process of recycled aggregates, a large number of microcracks appear inside the recycled aggregate due to the accumulation of damage. Previous studies have also shown that recycled aggregates have the disadvantages of compact volume, high water absorption, high crushing index, low aggregate strength and weak bonding ability compared with natural aggregates. (CHENG Gao-Li, et al., 2018, ZHANG Haiyan, et al., 2018)

Therefore, the characteristics of recycled concrete and ordinary concrete are quite different (GUO Yuanxin, et al., 2018). Therefore, we should pay attention to the problem of recycled concrete defects and improve the quality of recycled aggregates, so that it can be more widely used in practical engineering. (SUN Bing, et al., 2018)

In order to improve the utilization rate of waste concrete, some scholars have done some analysis on recycled concrete, but the analysis is not comprehensive (ZHANG Shimin, et al., 2017). Some experimental researches have been carried out on the basic properties of recycled concrete, and some research results have been obtained. (WU Jin, et al., 2015, XU Mengbo, et al., 2018, YAN Chunling, et al., 2018)

However, due to various reasons, such as the source of recycled aggregates, the material is affected by regional influence, the test specimens are relatively small, and the research results in difference is relatively large, so further research is needed. (Comingstarful M, et al., 2015, LIU Sihan, et al., 2017, LI Fuhai, et al., 2018, LI Qian-qian, et al., 2017)

2 ANALYSIS ON RECYCLED AGGREGATE CONCRETE

In view of the advantages of recycled concrete in resource conservation, this paper conducts a
detailed investigation and conducts in-depth research, and then concludes that recycled concrete has significant social, economic and environmental benefits to the resource environment.

2.1 Social benefits

In the construction project, the amount of concrete is the largest, and the amount of aggregate in the raw materials of concrete is the first. Due to the accelerated construction of urban construction and urbanization in China, the use of concrete is getting larger and larger, and the exploitation of a large amount of sand and gravel has destroyed natural landscapes and green vegetation, which causes serious consequences such as soil erosion or river diversion. Although recycled aggregate concrete requires a series of processing and separation treatments, from the perspective of sustainable development, the application of recycled concrete can reduce the exploitation of aggregates, protect a large number of mountains and large green vegetation, which has very significant social benefits.

2.2 Environmental benefits

Recycled aggregate concrete technology is for treating waste concrete, which restores the original properties of aggregates and forms new building materials products. On the one hand, it reduces the use of limited resources, the pollution of construction waste, and is beneficial to production, life, landscape and human health; On the other hand, due to the application of recycled aggregates, natural sand and gravel mining can be reduced, which is conducive to environmental protection.

2.3 Application Analysis

In view of the remarkable characteristics of recycled concrete for resource conservation and environmental protection, recycled concrete can be applied to the following situations.

(1) Infrastructure construction projects and greening environment improvement projects in mountainous areas or tourism areas.

Mountainous areas and tourist areas are purifiers for the natural environment, and resource conservation issues are particularly acute. In order to meet the resource and environmental conditions of the mountainous or tourism area projects and the requirements of the greening environment improvement project, the recycled aggregate concrete can be applied to the slope support, road pavement works, parking lots, toilets, supporting facilities, the basis of environmental protection facilities, etc.

(2) Roads and infrastructure projects in countryside.

The construction of beautiful countryside in China is advancing in an all-round way. The biggest problem in rural construction is the state of resources and environment and the problem of basic farmland protection. The research results of recycled concrete are mainly applied to the rural road pavement engineering and the trenches and trench cover works which are used in rural water supply and drainage, basic farmland irrigation projects, sewage treatment projects.

(3) Other items.

Recycled aggregate concrete can be applied in many fields, such as, subgrade and pavement engineering, municipal facility, subsidiary structure, base cushion and filling area, etc. These projects characters of large scale, large amount of concrete and large consumption of resources.

The application of recycled aggregate concrete can achieve the purpose of saving resources and environmental protection. Improving the quality of recycled concrete can expand the range of applications of recycled concrete.

2.4 Analysis of recycled aggregate concrete test

Making full use of the precious resources of recycled aggregates is one of the ways to ensure the sustainability of concrete. At present, the environmental, economic and social benefits of recycled concrete have attracted full attention in China and all over the world. Therefore, it is very necessary to study the performance of recycled concrete. This provides a powerful way to promote the application of recycled concrete in civil engineering, and provides the necessary experimental basis for its application in practical engineering.

The experiment consists of two parts: the first part is the experimental research on the processing technology, basic physical properties and mechanical properties of recycled coarse aggregate; the second part is the experimental study on the physical properties and working performance of recycled concrete and ordinary concrete.

The work steps of this article include:

(1) The sources of construction waste and waste concrete are investigated and analyzed.

(2) Waste concrete is collected and raw materials are prepared for recycled concrete. In this paper, waste concrete is collected from the demolition site of concrete and waste concrete.

(3) Exploring the processing technology of recycled coarse aggregate, crushing the original concrete, and processing the recycled coarse aggregate.
(4) The basic physical properties and mechanical properties of the original aggregate and the recycled coarse aggregate are analyzed by experiment.
(5) Determine the concrete mix ratio for the test through investigation, trial matching, etc.
(6) Determination of the physical properties and workability of recycled concrete and ordinary concrete of the same mix ratio.
(7) Engineering applications.

3 RAW MATERIAL PROPERTIES

3.1 Cement
Hebei Dingxin brand ordinary Portland cement (42.5) is used in this paper. The physical properties of cement are shown in Table 1.

<table>
<thead>
<tr>
<th>Apparent density (kg/m³)</th>
<th>Fineness (≤10)</th>
<th>Flexural strength</th>
<th>Compressive strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>3100</td>
<td>1.8</td>
<td>3d</td>
<td>28d</td>
</tr>
</tbody>
</table>

Table 1. Physical and Mechanical properties of cement

The cement has good stability, and initial setting and final setting time meet the standard requirements.

3.2 Natural aggregate
(1) Coarse aggregate-gravel
Gravel is from Hebei Mancheng, which has continuous grading with a particle size of 5 ~ 20mm, good gradation. The apparent density and bulk density are 2788 kg/m³ and 1558 kg/m³, respectively.
(2) Fine aggregate-sand
Hebei Mancheng River sand is a medium sand, good grade. The apparent density and bulk density are 2,700 kg/m³ and 1,573 kg/m³, respectively, the mud content was 1.2%, and the void ratio was 40%.

3.3 Water
Ordinary water.

4 PROCESSING TECHNOLOGY AND PERFORMANCE OF RECYCLED COARSE AGGREGATE

4.1 Source of recycled aggregate
On the one hand, the waste concrete collected by the test is from the abandoned ordinary concrete of several concrete companies in Hebei Province, and the test blocks were all 100 mm × 100 mm × 100 mm cubes; On the other hand, the concrete is collected from the removal of some waste concrete components which have been simply treated. These waste concrete are processed into a certain size, and the standard value of the cubic compressive strength is measured. At last, the waste concrete is classified according to the actual compressive strength. According to the test results, three levels of test blocks are found in this experiment, and the corresponding strength levels are C20, C25, and C30.

According to the source data verification and material identification of waste concrete, it is concluded that the coarse aggregate in waste concrete has two kinds of gravel and pebbles, and the sand is ordinary river sand, which belongs to medium sand; some fly ash and mineral powder in waste concrete mix a compound; a naphthalene type water reducing agent or a polycarboxylic acid water reducing agent is incorporated.

4.2 Processing technology of recycled aggregate
In the crushing process, the waste concrete test block with higher strength is more difficult to be broken, and the surface of the recycled aggregate material is crushed, and there are many fine and flake-shaped particles. The surface of the recycled aggregate is more angular and rougher. The waste concrete with lower strength grade is more easily to be broken. The fracture surface is mostly along the interface between stone and cement mortar. The shape of the stone on the surface of the recycled aggregate is more complete. For the reason of that the strength of these waste concrete is low, after the crushing process, the obtained aggregate has more adhering mortar on the surface. In order to avoid the influence of excessive mortar on the test results, in this paper, the large-sized recycled aggregate is treated with attached mortar and sieved again to obtain the reclaimed coarse aggregate that meets the requirements.
The specific production process of recycled aggregate is shown in Fig 2.

4.3 Gradation of recycled aggregates

According to the article 6.1 in the Chinese standard "Construction Pebble, Crushed Stone" GB/T 14685-2011, the test uses the aggregate gradation which is shown in Table 2.

Table 2. Aggregate graduation

<table>
<thead>
<tr>
<th>Aggregate type</th>
<th>Nominal diameter</th>
<th>Cumulative screening/%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4.75</td>
</tr>
<tr>
<td>Natural aggregate</td>
<td>5~20</td>
<td>100%</td>
</tr>
<tr>
<td>Recycled aggregate</td>
<td>5~20</td>
<td>100%</td>
</tr>
</tbody>
</table>

4.4 Apparent density of recycled aggregate

According to the provisions of the article 5.9 in the Chinese standard "Recycled Concrete for Concrete" GB/T 25177-2010, the apparent density of C20 and C25 strength grade recycled aggregates is greater than 2250 kg/m³ and less than 2350 kg/m³, so it is class II; For C30 strength grade recycled aggregate, the apparent density is greater than 2350 kg/m³ and less than 2450 kg/m³, so it is class II.

Table 3. Apparent density of recycled aggregate

<table>
<thead>
<tr>
<th>Aggregate type</th>
<th>Apparent density( kg / m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural aggregate</td>
<td>2788</td>
</tr>
<tr>
<td>Waste concrete grade</td>
<td></td>
</tr>
<tr>
<td>C20</td>
<td>2332</td>
</tr>
<tr>
<td>C25</td>
<td>2344</td>
</tr>
<tr>
<td>C30</td>
<td>2362</td>
</tr>
</tbody>
</table>

4.5 Water content and water absorption of recycled aggregate

According to the provisions of "Construction Pebble, Crushed Stone" GB/T 14685-2011 and "Recycled Concrete for Concrete" GB/T 25177-2010, the water content rate and the water absorption rate of recycled aggregate is determined. The test values are shown in Table 4.

Table 4. Water content Rate and Water absorption rate of recycled aggregate

<table>
<thead>
<tr>
<th>Nominal diameter</th>
<th>Recycled aggregate</th>
<th>Waste concrete grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C20</td>
</tr>
<tr>
<td>water content</td>
<td>1.0%</td>
<td>1.8%</td>
</tr>
</tbody>
</table>
According to the provisions of the article 5.3 in the Chinese standard of "Recycled coarse aggregate for concrete" GB/T 25177-2010, the water absorption rate of all kinds of recycled aggregates is less than 5% at 30 minutes, which belongs to class II; The water absorption rates of various recycled aggregates at 1 hour are both greater than 5% and less than 8%, which belongs to class III.

The concrete in this experiment has a low strength grade. It is only a simple treatment of the attached mortar on the surface of the recycled aggregate. It can be seen from Table 4 that the water absorption rate of the recycled aggregates with different strength grades increases with time, and the water absorption rate also increase with the increase of the strength grade of the recycled aggregates.

5 PROCESSING TECHNOLOGY AND PERFORMANCE OF RECYCLED COARSE AGGREGATE

5.1 Overview of Recycled Aggregate Concrete Mix Ratio

The calculation method of the mixing ratio of recycled coarse aggregate concrete is carried out according to the provisions of JGJ 55-2011 of "General Concrete Mixing Ratio Design Regulations". The main difference between the design of recycled concrete and ordinary concrete is the difference in water consumption per unit volume. Due to the high water absorption of recycled aggregates, the recycled concrete needs to add an additional amount of water. The amount of additional water depends on the water absorption and moisture content of recycled aggregate. This part of the water is completely inhaled by the aggregate. It does not improve the fluidity in the concrete mixture, but it will change water-cement ratio of the Concrete, that is, the hydration reaction of the concrete mixture will change. In this paper, the change of water-cement ratio caused by this part of additional water is not taken into consideration, that is, the water-cement ratio (W/C) of the concrete mixture = the calculated water consumption W in the concrete (without additional water) / gelation material usage.

At present, there are two methods of incorporation of additional water ΔW: one is to pre-wet the recycled aggregate so that it is in a saturated dry state. The advantage of this method is that the additional water weight is absorbed by the recycled aggregate, which does not have a great influence on the hydration heat reaction of the mixture. The disadvantage is that the saturated surface of the recycled coarse aggregate is difficult to control, especially regeneration. The coarse aggregate is difficult to be used in the construction promotion; the other method is to add additional water in the concrete mixing process, and add this part of the water together with the mixing water determined according to the design method of the ordinary concrete. This method is simple and easy to control. The disadvantage is that the additional water will change the water-cement ratio of the concrete mixture, and the hydration heat of the concrete will also change. In this paper, additional water is added during the concrete mixing process.

In order to facilitate the popularization and application, the water-cement ratio selected in this test is 0.48, and the concrete strength grade of this test is C30. It meets the requirements of the article 5.1.5 in the Chinese standard of "Recycled coarse aggregate for concrete" GB/T 25177-2010.

5.2 Recycled aggregate concrete mixing method

Recycled aggregate concrete is mechanically mixed. In the test of concrete, Wuxi Jianyi single-shaft forced concrete mixer is used, and the model is HJW-30. In this paper, the recycled aggregate concrete specimens are made of Wuxi Jianyi HJW60 concrete test mixer.

The mixing procedure of recycled aggregate concrete is as follows: dry mixing of cementing material for 1 min, dry addition of aggregate for 2 min, adding water 15 to 20 seconds after dry mixing, and then mixing for 2 min.

5.3 Mixing ratio and working performance of recycled aggregate concrete for test

The test combining recycled coarse aggregates from different sources in this test is combined. The strength grade of recycle coarse aggregate is C30. For the convenience of comparative analysis, five types of concrete with the same mix ratio are shown in Table 5.

In order to better reflect the influence of the amount of recycled aggregate on the performance of recycled concrete, this paper used a comparison test of recycled concrete with different aggregate replacement rates and ordinary concrete.

The replacement ratio of recycled coarse aggregate is "R=the amount of recycled coarse aggregate / the amount of coarse aggregate in concrete", that is "the amount of coarse aggregate in coagulation = the amount of recycled coarse aggregate + natural coarse aggregate". The ordinary
concrete R=0, the recycled concrete R=0.3, the recycled concrete R=0.5, the recycled concrete R=0.75, and the recycled concrete R=1.

In Table 5, W1 is the design mix ratio calculation water, and W2 is the additional water.

The water absorption rate of the recycled aggregate is 5.7% of the water absorption of the recycled aggregate of C30 strength grade.

The working performance of ordinary concrete and recycled concrete is measured, which is shown in Fig 3.

5.4 Cube compressive strength of recycled concrete

The cubic compressive strength of recycled concrete is determined by standard tests, which is shown in Table 7. It can be seen from the test results that with the replacement ratio of the recycled aggregate increasing, the cubic compressive strength decreases. When the recycled aggregate replacement ratio R=1, the cubic compressive strength is about 0.637 time than that of ordinary concrete (R=0).

<table>
<thead>
<tr>
<th>Concrete type R</th>
<th>W/B</th>
<th>Natural aggregate</th>
<th>Recycled aggregate</th>
<th>Sand</th>
<th>Cement</th>
<th>W1</th>
<th>W2</th>
<th>Sand rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>R=0</td>
<td>0.48</td>
<td>1089</td>
<td>0</td>
<td>726</td>
<td>410</td>
<td>196.8</td>
<td>0</td>
<td>40%</td>
</tr>
<tr>
<td>R=0.3</td>
<td>0.48</td>
<td>762.3</td>
<td>632.7</td>
<td>726</td>
<td>410</td>
<td>196.8</td>
<td>18.3</td>
<td>40%</td>
</tr>
<tr>
<td>R=0.5</td>
<td>0.48</td>
<td>544.5</td>
<td>544.5</td>
<td>736</td>
<td>410</td>
<td>196.8</td>
<td>30.49</td>
<td>40%</td>
</tr>
<tr>
<td>R=0.75</td>
<td>0.48</td>
<td>272.25</td>
<td>816.75</td>
<td>726</td>
<td>410</td>
<td>196.8</td>
<td>42.47</td>
<td>40%</td>
</tr>
<tr>
<td>R=1</td>
<td>0.48</td>
<td>0</td>
<td>1089</td>
<td>726</td>
<td>410</td>
<td>196.8</td>
<td>56.63</td>
<td>40%</td>
</tr>
</tbody>
</table>

Table 6. Working performance of concrete tested

<table>
<thead>
<tr>
<th>Concrete type</th>
<th>Slump</th>
<th>Cohesiveness</th>
<th>Water retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>R=0</td>
<td>70mm</td>
<td>good</td>
<td>No bleeding</td>
</tr>
<tr>
<td>R=0.3</td>
<td>76mm</td>
<td>good</td>
<td>No bleeding</td>
</tr>
<tr>
<td>R=0.5</td>
<td>76mm</td>
<td>good</td>
<td>No bleeding</td>
</tr>
<tr>
<td>R=0.75</td>
<td>90mm</td>
<td>good</td>
<td>No bleeding</td>
</tr>
<tr>
<td>R=1</td>
<td>110mm</td>
<td>good</td>
<td>No bleeding</td>
</tr>
</tbody>
</table>

Table 7. The cube compressive strength test results

<table>
<thead>
<tr>
<th>Concrete type</th>
<th>Compressive strength fcu/MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7d</td>
</tr>
<tr>
<td>R=0</td>
<td>36.7</td>
</tr>
<tr>
<td>R=0.3</td>
<td>29.3</td>
</tr>
<tr>
<td>R=0.5</td>
<td>28.9</td>
</tr>
<tr>
<td>R=0.75</td>
<td>26.5</td>
</tr>
<tr>
<td>R=1</td>
<td>25.8</td>
</tr>
</tbody>
</table>

6 CONCLUSION

This paper starts from the problem that if the waste concrete is not treated properly, it will bring serious harm to the resources and environment. Recycled concrete can reduce the use of limited resources and reduce construction waste. In order to facilitate the widespread promotion of recycled concrete, this paper starts from the local resources of Hebei Province, China, with experimental determination and theoretical analysis as the supplement. The performance characteristics of recycled aggregates are obtained. When the recycled aggregate replacement ratio R=1, the cubic compressive strength is about 0.637 time than that of ordinary concrete (R=0).

7 ACKNOWLEDGEMENTS

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