Experimental Study and Design Method of High-Performance Recycled Aggregate Concrete

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Abstract

In this paper, high performance of recycled aggregate concrete (HPARC) between concrete strength grade C40 and C50 is made by the using high-quality mineral admixtures and super-plasticizer pairs of mixed technology. The key parameters including concrete cube compressive strength, elastic modulus and tensile strength etc, are studied through a series of experiments of HPRAC. A formula on the uniaxial stress-strain curves of HPRAC is suggested. It has a very good agreement between calculated and experimental results. It showed that the proposed HPRAC has good mechanical properties and durability. The proposed design method can be used in engineering practice.

Keywords: High performance recycled aggregate concrete; experiment; design method; mechanic behaviour.

1. INTRODUCTION

Recycled Concrete Technology can be used in waste concrete disposal and save natural gravel. It also brings about societal, economic and environmental benefits. It is considered as green concrete, which is one of the main measurement in building resources and environment to achieve sustainable development. Recycled concrete has been studied by some scholars in Japan, Germany, and America, when buildings and facilities were damaged seriously and waste concrete increased significantly. The international conferences on the use of recycled concrete have been held in three times. However, it is lack in studying recycled aggregate concrete in China. In recent years, the Chinese government paid attention to utilization of the waste recycling. Some universities and institutes have carried out the experiments and analysis of recycled concrete, but the recycled concrete generally is used as pavement materials in roads. The coarse aggregate replaced by recycled concrete for the members in building structures is rare.
High performance of recycled concrete (HPRAC) is a new high-tech concrete, recycled aggregate that is from concrete block that is discarded after a certain process of production, and use it instead of natural aggregates to prepare high performance concrete, which has good mechanical properties, durability and as well as economic benefits. High performance of recycled concrete with the characteristics of low consumption, low power consumption, can be recycled using is considered an important direction of concrete structure in the future development. Research on the recycled concrete with the strength below C30 in China and worldwide have been undertaken in large scale, but research on the recycled concrete with the strength above C40 is rare. This paper describes a serial of experiments of HPRAC to obtain concrete cube compressive strength, elastic modulus and tensile strength etc.

2. EXPERIMENTAL SCHEME

2.1 Composition of HPRAC

The tested recycled aggregate is originated in the waste concrete from Huangshan road in Hefei. The diameter of the coarse aggregate is about 20-30mm, the maximum diameter up to 50mm, as shown in Figure 1. Waste concrete block is dense and few carbonation. It was broken down by machines into becoming recycled aggregates (see Figure 2). Recycled aggregate has more angularity and surface roughness, low-intensity, and poor wear resistance. The apparent density is also significantly less than the natural coarse aggregates, but water absorption is higher than natural aggregates. Cement of strength grade 52.5MPa used in specimens is produced from Wuhu Hailuo Cement Company. In order to satisfy the requirement of slump, additional high-range water reducer (HRWR) from Hefei was used.

![Fig. 1 Recycled aggregate](image1.png)  ![Fig. 2 Jaw crusher](image2.png)

2.2 Mix design

Water absorption of recycled aggregates is greater than that of natural aggregates, and it is therefore a problem to control the water-cement ratio. Water-cement ratio is a key parameter of the concrete and significantly affects the property of concrete. This paper compared the test results of three water-cement ratios of 0.48, 0.50, and 0.52. Finally it is was discovered that the water-cement ratio of 0.52 was optimum. Water used in tests can be divided two parts: one part is the absorbed water measured by water absorption of coarse aggregates, and the other part is the free water. The mix proportions of the recycled aggregate concrete were as
follows: cement: 450kg/m\(^3\); blast furnace slag: 170kg/m\(^3\); water: 181kg/m\(^3\); sand: 815kg/m\(^3\); coarse aggregate: 815kg/m\(^3\); HRWR: 4.3kg/m\(^3\).

2.3 Decrepitating

Commonly there are some impurities in waste concrete, such as non-metallic materials (brick block, glass, and fiber) and metal materials (steel and aluminum). Thus it needs to be separated by machines in construction sit, and then appropriate crushing equipments are selected to produce recycled aggregates. Jaw crushers and impact crushers are popular in breaking equipments used. In the tests, the jaw crusher was adopted to break recycled aggregate blocks. The fine aggregate, which diameter is less than 5mm, is regarded as impurity and it was removed. Due to the difficult in separating minor iron and plastic from the recycled aggregate, magnet separator and separation table are used to improve the purity of the aggregates and reduce the aggregate surface attached mortar. Various sizes of recycled aggregates are produced by a vibration screening machine or centrifugal screening machine.

2.4 Experimental equipments

The test equipments to measure the mechanical behavior of the recycled concrete includes: hydraulic pressure testing machine, airtight machine, extensometer, and vertical efficient mixer etc(see Fig. 3). Specimen production and curing were all done in Hefei municipal concrete mixing station. The tests have been done in the key laboratory for structures and material in civil engineering in Anhui province.

![Experimental equipments](image)

(a) hydraulic pressure testing machine  
(b) Airtight machine  

Fig. 3 Experimental equipments

3. TEST RESULT ANALYSIS AND DISCUSSION

3.1 Cube compressive strength test

The standard specimen size is 150×150×150mm (see Fig. 4). After the tested blocks were put in a standard curing room for 28 days, the cube compressive strength was measured. The number of recycled aggregate concrete blocks is 18. The three groups had 9 specimens. For all the water-cement ratios of 0.52, 0.50, and 0.48, the specimens were all cured for 7 days, then the compressive strength was tested, and the highest strength of a group was determined. At 28 days curing, the cube compressive strength was again measured.
The average strength of the tested specimens was 47.6MPa. The results of the compressive strength were lower than the theoretical results, mainly due to their low strength of the recycled coarse aggregates. The final failure models of the specimens of recycled concrete were the four corner cones. The destruction of recycled concrete block section was interface of natural coarse aggregate. The case of coarse aggregates splitting was not found and failure modes of common concrete are almost the same.

3.2 Elasticity modulus test
According to Specification T0555-2005 and T0556-2005, the elasticity modulus of recycled concrete under compressive loading was tested. The elastic modulus of recycled concrete was measured and corresponded to 1/3 axial compressive strength. This test was completed in hydraulic pressure testing machine with the extensometer and other instruments. 150mm×150mm×300mm prism was measured, as shown in Figure 4. The average concrete compressive elastic modulus is $31.2 \times 10^4 \text{N/mm}^2$. The elastic modulus of recycled concrete reduced. As the surface of the recycled aggregates has a large number of cement mortar attached to it, the cement mortar with low elastic modulus and larger deformation is less than that of natural aggregates. Comparing with that of ordinary concrete, the elastic modulus of cycled concrete decreases.

![Fig. 4 Elasticity modulus test](image1)
![Fig. 5 Splitting test](image2)
![Fig. 6 Bending test](image3)

3.3 Split tensile test
The splitting tensile test of standard cube specimen of recycled concrete has been done by using 9 specimens of 3 groups (see in Fig.5). The test result of recycled concrete splitting tensile strength is shown in Table 1.

The average splitting tensile strength is 3.55kN. After specimens were split, the failure of recycled concrete is the bond failure between recycled coarse aggregates and cement. It caused that most of recycled concrete were Latvia damage between the mortar and coarse aggregates, and a few of coarse aggregates were snapped. Compared with ordinary concrete, the split tensile strength of recycled concrete has a certain drop.
Table 1: Splitting tensile strength

<table>
<thead>
<tr>
<th>Number</th>
<th>days</th>
<th>Failure load (kN)</th>
<th>Failure load (kN)</th>
<th>Splitting strength (kN)</th>
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<td>T 3</td>
<td>28</td>
<td>127</td>
<td>140</td>
<td>108</td>
</tr>
</tbody>
</table>

3.4 Bending test

The bending test of recycled concrete is completed in a bending experimental device, which can able to impose uniform, continuous and controllable loads (see Fig.6). The supports and loading head of the specimen need diameter of 20-40mm, and its hard steel cylindrical length is not less than 10mm.

The prism size of recycled concrete is 150×150×550mm and span is 450mm. The specimen is subjected to 4 point loads. According to Specification GB / T 50081-2002, the final failure models are shown in Fig. 6.

The flexural strength of recycled concrete \( f_i \) (MPa) calculated by the following formula

\[
f_i = \frac{F l}{b h^2}
\]  

Where \( F \) is failure load; \( b \) and \( h \) are respectively the width and height of cross-section.

It is found that according to the results of recycled Concrete flexural strength test, the flexural strength of recycled concrete increases with the cube compressive strength under monotonic loading. For ordinary concrete, there is a certain correlation between bending strength and the square root of compressive strength. European Concrete Committee (CEB) suggested the relationship is equation (2):

\[
f_i = 0.8\sqrt{f_{cu}}
\]  

Through statistical regression, a formula of flexural strength of recycled concrete was proposed

\[
f_i = 0.68\sqrt{f_{cu}} \ (R = 0.87)
\]

4. CONCLUSIONS

Through a series of experiments and theoretical analysis of high-strength recycled aggregate concrete, some conclusions can be drawn:

(1) The failure process of recycled concrete blocks is basically similar with that of ordinary concrete, but some differences exists in the failure modes. The failure of recycled concrete is the bond failure between recycled coarse aggregate and cement.

(2) The recycled concrete compressive strength, tensile strength, and elastic modulus are less than ordinary concrete, but its flexural strength is higher than that of ordinary concrete.
(3) The tensile strength of recycled concrete is about 1/10 ~ 1/12 of the compressive strength. The relationship of stress-strain curves of recycled concrete under uniaxial compressive load similar with that of ordinary concrete.

(4) The measurement of paste wrapped in stone can significantly improve the aggregate cross-section, which can also improve its mechanical properties.

ACKNOWLEDGEMENTS
The research was supported by the Youth League Innovative Pilot Project in Hefei University of Technology.

REFERENCES