Effect of Quality and Replacement Rate on the Double Recycled Aggregate Concrete

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Abstract. Recycled aggregate can be used as a substitute for natural aggregate to produce good regenerated concrete, so the text use recycled coarse aggregate and recycled fine aggregate to substitute for natural aggregate with different replacement rates preparing double recycled aggregate concrete, and researching the effect of the quality and replacement rate of recycled aggregate on the mechanical properties of recycled aggregate systematically. The results show that the compressive strength of double recycled aggregate concrete is increased gradually with the improvement of the quality of recycled aggregate, and the effect from weak to strong is class I, class II and class III. On the other hand, the compressive strength of double recycled aggregate concrete is decreased gradually with the increase of the replacement rate of recycled aggregate, and the maximum reduction is up to 57.2%. Therefore, the simultaneous use of recycled coarse aggregate and recycled fine aggregate have an effect of “double weakening” on the compressive strength of recycled concrete, and it can be applied to the concrete products of low strength grade.

Keywords. Double recycled aggregate concrete, compressive strength, recycled coarse aggregate, recycled fine aggregate, quality, replacement rate.

1. Introduction
In recent years, the construction industry in the period of rapid development has become a pillar industry to support the national economy of our country, and the proportion of its output value and scale is also increasing. At the same time, the dosage of concrete material is huge, which will have a serious shortage of natural mineral resources [1]. Therefore, exploring new material sources to mitigate the excessive exploitation and destruction of natural resources has become the top priority. And the technology of recycled aggregate concrete prepared from construction waste is an effective way to solve this problem [2-4].

After years of basic research, now some colleges and universities, such as the Tongji University, the Chinese Academy of Architectural Sciences, and the Qingdao University of Technology have prepared recycled concrete with excellent performance using recycled aggregate produced by construction waste, and its strength grade can reach C30 and above [5-6]. However, most of the research work is focused on the single recycled aggregate, so based on the research of domestic and foreign experts and scholars [7-10], this paper uses recycled coarse aggregate and recycled fine aggregate to replace the natural aggregate at different replacement rates to prepare recycled concrete, and systematically studies the impact of the quality and replacement rate of recycled aggregate on the mechanical properties of double recycled aggregate concrete.
2. Experimental Design

2.1. Raw Material Properties
The experiment uses P•O 42.5 cement, and the fly ash uses grade II fly ash produced in a power plant, and the powder uses granulated blast furnace slag powder of S95, and the natural fine aggregate uses grade II river sand, and the natural coarse aggregate uses granitic lithotripsy with 5~25mm continuous gradation. According to the regulations of performance index of recycled aggregate in “Recycled coarse aggregate for concrete” (GB/T 25177-2010) [11] and “Recycled fine aggregate for concrete and mortar” (GB/T 25176-2010) [12], the recycled coarse aggregate and recycled fine aggregate are made of construction waste by particle shaping technology [13], which is divided into class I, class II and class III. The additive uses polycarboxylic acid high performance water reducing agent and the water uses municipal drinking water.

2.2. Test Plan
According to the regulations of the “Technical specification for application of recycled aggregate” (JGJ/T 240-2011) [14] to determine the replacement rate of recycled coarse aggregate and regenerated fine aggregate, and the strength grade of the double recycled aggregate concrete is C30. The sand rate of the concrete is 35% and the amount of polycarboxylic acid high performance water reducing agent is 1.2% of the amount of cementations material. The amount of water used during the test was determined by adjusting the slump of the concrete mixture at (180±20) mm. The effects of the following four factors on the mechanical properties of double recycled aggregate concrete were also considered in the experiment:

- The category of recycled coarse aggregate: class I, class II and class III;
- The category of recycled fine aggregate: class I, class II and class III;
- The replacement rate of recycled coarse aggregate: 25% and 50%;
- The replacement rate of recycled fine aggregate: 25% and 50%.

2.3. Test Method
The preparation, maintenance and the measurement of the compressive strength of the double recycled aggregate concrete are referred to "Standard for test method of mechanical properties on ordinary concrete" (GB/T 50081-2002). The size of concrete specimen is 100mm×100mm×100mm, and put the concrete specimen after stripping into the standard curing room with the temperature of (20±2) °C and the relative humidity more than 95% for maintenance. And then measure its mechanical properties when the curing time reaches the prescribed curing period.

3. Experimental Analyses
The 28d compressive strength of the three kinds of recycled fine aggregate concrete was measured, and its representative fracture surface after the compressive failure is shown in figure 1.

![Figure 1. Compressive failure of double recycled aggregate concrete.](image-url)
It can be seen from figure 1 that the fracture surface of compressive failure of double recycled aggregate concrete specimens is more complex, which is more coarse aggregate been crushed and more interface been damaged. When the quality of recycled coarse aggregate is class I and the replacement rate is lower, the crushing of coarse aggregate is reduced. When the quality of the recycled fine aggregate is class III and the replacement rate is higher, the damage of the interface is increased. It can be explained that the quality and the replacement rate of recycled aggregate are the important factors affecting the compressive failure of the double recycled aggregate concrete.

3.1. Effect of the Quality and Replacement Rate of Recycled Coarse Aggregate on the Compressive Strength of Double Recycled Aggregate Concrete

Under the condition of using different kinds of recycled fine aggregate, the relationship between the 28d compressive strength of double recycled aggregate concrete and the quality and replacement rate of recycled coarse aggregate is shown in figure 2.

![Graph of the relationship between quality and replacement rate of recycled coarse aggregate and compressive strength of double recycled aggregate concrete](image)

**Figure 2.** Effect of quality and replacement rate of recycled coarse aggregate on the compressive strength of double recycled aggregate concrete.

From figure 2, we can see that under the condition of using the same quality of recycled fine aggregate, the 28d compressive strength of double recycled aggregate concrete decreases gradually with the decrease of the quality of recycled coarse aggregate. The weakening effect of the quality of recycled coarse aggregate on the compressive strength of double recycled aggregate concrete from weak to strong is class I, class II and class III. On the other hand, under the conditions of using the same replacement rate of recycled fine aggregate, the 28d compressive strength of double recycled aggregate concrete decreases with the increase of the replacement rate of recycled coarse aggregate.
And when the replacement rate of recycled coarse aggregate being 25%, the compressive strength is higher than the replacement rate of recycled coarse aggregate being 50%. The compressive strength of double recycled aggregate concrete reaches the highest value that is 37.6MPa when the qualities of recycled coarse aggregate and recycled fine aggregate being class I and the replacement rate being the lowest. This is because the differences in the performance indexes of the different qualities of recycled coarse aggregate, which will lead to the compressive strength of recycled concrete has great differences. At the same time, increasing the use of recycled fine aggregate is bound to bring the weakening effect to the compressive strength of the double recycled aggregate concrete.

3.2. Effect of the Quality and Replacement Rate of Recycled Fine Aggregate on the Compressive Strength of Double Recycled Aggregate Concrete

Under the condition of using different kinds of recycled coarse aggregate, the relationship between the 28d compressive strength of double recycled aggregate concrete and the quality and replacement rate of recycled fine aggregate is shown in figure 3.

![Figure 3](image)

**Figure 3.** Effect of quality and replacement rate of recycled fine aggregate on the compressive strength of double recycled aggregate concrete.

From figure 3, we can see that under the condition of using the same quality of recycled coarse aggregate, the 28d compressive strength of double recycled aggregate concrete decreases gradually with the decrease of the quality of recycled fine aggregate. The weakening effect of the quality of recycled fine aggregate on the compressive strength of double recycled aggregate concrete from weak to strong is class I, class II and class III. On the other hand, under the conditions of using the same replacement rate of recycled coarse aggregate, the 28d compressive strength of double recycled
aggregate concrete decreases with the increase of the replacement rate of recycled fine aggregate. And when the replacement rate of recycled fine aggregate being 25%, the compressive strength is higher than the replacement rate of recycled fine aggregate being 50%. The compressive strength of double recycled aggregate concrete reaches the lowest value that is 16.1MPa when the qualities of recycled fine aggregate and recycled coarse aggregate being class III and the replacement rate being the highest, and the 16.1MPa is only 42.8% of the highest compressive strength. Therefore, the quality and the replacement rate of the recycled fine aggregate will have a great influence on the compressive strength of the double recycled aggregate concrete.

In summary, the quality and replacement rate of recycled coarse aggregate and recycled fine aggregate are important influential factors on the compressive strength of double recycled aggregate concrete. Compared with the single recycled aggregate concrete, the double recycled aggregate concrete is much more complicated in the compressive failure, and there are more factors affecting the compressive strength of the concrete. However, the recycled coarse aggregate and recycled fine aggregate have great influences on the mechanical properties of recycled concrete when recycled aggregate is prepared by recycled aggregate with different replacement rates, showing a phenomenon of "double weakening". Therefore, the application of double recycled aggregate concrete to practical project must be carried out on the premise of a large number of experimental studies, and the quality of the project must be strictly ensured.

4. Conclusions

(1) The compressive strength of double recycled aggregate concrete increases gradually with the improvement of the quality of recycled aggregate. The effect of the quality of recycled aggregate on the compressive strength of double recycled aggregate concrete from weak to strong is class I, class II and class III.

(2) When the replacement rate of recycled aggregate increased from 25% to 50%, the compressive strength of double recycled aggregate concrete decreased gradually, and the biggest decline of compressive strength is 57.2%.

(3) Compared with the single recycled aggregate concrete, the double recycled aggregate concrete is much more complicated in the compressive failure. Recycled coarse aggregate and recycled fine aggregate bring a "double weakening" effect on the compressive strength of double recycled aggregate concrete.

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References
[1] Li Qiuyi, Gao Song, Xue Shan. Green concrete technology [M]. Beijing: China Building Materials Industry Press, 2014.
[2] Monalisa B, Bhattacharyya S K, Minocha A K, et al. Recycled aggregate from C&D waste and its use in concrete-A break through towards sustainability in construction sector: A Review [J]. Construction and building materials, 2014, 68: 501-516.
[3] C. Ulsen, H. Kahn, G. Hawlitschek, et al. Production of recycled sand from construction and demolition waste [J], Construction and Building Materials. 2013, 40: 1168-1173.
[4] Vlastimir Radonjanin, Mirjana Malešev, Snez´ana Marinkovic, et al. Green recycled aggregate concrete [J]. Construction and Building Materials, 2013, 47: 1503-1511.
[5] Xiao Jianzhuang, Fan Yubin, Lin Zhuangbin, et al. Experiment on compressive strength of recycled fine aggregate concrete [J]. Journal of Architecture and Civil Engineering, 2011, 28(4): 26-29.
[6] Guo Yuanxin, Li Qiuyi, Li Qianqian, et al. Experimental research on the mix proportion optimization of high quality recycled coarse aggregate concrete [J]. Journal of Shenyang jianzhu university (natural science), 2017, 33(1): 19-25.

[7] Guo Zhanggen, Chen Chen, Fan Bingjie, et al. Experiment research on mechanical behavior for concrete made of coarse and fine recycled aggregates [J]. Journal of Building Structures, 2016, 37(S2): 94-102.

[8] A.G. Khoshkenari, P. Shafigh, M. Moghimi, et al. The role of 0-2 mm fine recycled concrete aggregate on the compressive and splitting tensile strengths of recycled concrete aggregate concrete [J]. Material Design. 2014, 64: 345–354.

[9] V. Corinaldesi. Mechanical and elastic behavior of concrete made of recycled-concrete coarse aggregates [J]. Construction and Building Materials, 2010, 24(9): 1616-1620.

[10] Geng Jian, Sun Jiaying, Mo Liwei, et al. Micro-structure Characteristics of recycled fine aggregate and its concrete [J]. Journal of Civil, Architectural &Environmental Engineering, 2013, 35(2): 135-140.

[11] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of the People's Republic of China. Recycled coarse aggregate for concrete: GB/T 25177-2010 [S]. Beijing: Standards Press of China, 2011.

[12] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of the People's Republic of China. Recycled fine aggregate for concrete and mortar: GB/T 25176-2010 [S]. Beijing: Standards Press of China, 2011.

[13] Guo Yuanxin, Li Qiuyi, Wang Weiqin, et al. Research on Recycled Coarse Aggregate Quality of Enhancement Technology [J]. Concrete, 2015(06): 134-138.

[14] Ministry of Housing and Urban-Rural Development of the People's Republic of China. Technical specification for application of recycled aggregate: JGJ/T 240-2011 [S]. Beijing: China Architecture & Building Press, 2011.