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A Brief Review on Recycled Aggregate Concrete

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

This paper briefly introduces the recycling and regeneration preparation of waste concrete, as well as the crushing and screening process of waste concrete blocks. The properties of crushed aggregate and the physical and mechanical properties of recycled concrete were analyzed, and the research status of compressive strength and splitting tensile strength of waste concrete at home and abroad was summarized and analyzed. Factors such as water-glue ratio, water absorption, apparent density of recycled coarse aggregate, state of recycled coarse aggregate and strength of virgin concrete will affect the strength of recycled aggregate concrete. This paper also summarizes the relationship between the splitting tensile strength of recycled aggregate concrete and the compressive strength of the cube.

Keywords: Recycled aggregate concrete; compressive strength; splitting tensile strength.

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1. INTRODUCTION

1.1 Recycled Aggregates and their Basic Properties

1.1.1 Recycling of waste concrete

Usually, there are four main sources of waste concrete [1]: 1) buildings are demolished due to reaching their service life or due to aging; 2) demolition of municipal projects and the renovation of major infrastructures produce waste concrete blocks; 3) waste concrete produced by commercial concrete factories; and 4) waste concrete blocks are produced due to accidental causes such as earthquakes, typhoons, floods and other causes of the collapse of the building. Due to the complexity of the source, waste concrete blocks are inevitably mixed with various impurities such as steel, wood, plastic fragments, glass and construction gypsum, etc. Therefore, the performance of waste concrete varies greatly, and the cost of recycling part of the waste concrete is high, and it is not recycled due to economic considerations. Xiao Jianzhuang [2] and others classified waste concrete into two categories, one is recyclable waste concrete and the other is non-recyclable waste concrete, based on its source, use environment, exposure conditions, and degree of carbonation.

“With the rapid development of urbanization in China, the continuous demolition of old urban buildings has generated a large amount of construction waste” [3]. At present, the utilization rate of construction waste in China is low, and only a small part of construction waste is recycled in roadbed and non-load-bearing structures, and most of it is disposed of in the traditional way of stacking or landfilling in the suburbs, which has caused great pollution to the environment [4]. Recycled concrete [5] is a process in which ordinary concrete is crushed and screened to make recycled coarse aggregate to replace natural coarse aggregate, which can not only solve the problem of stacking and utilization of construction waste, but also conform to the green and sustainable development advocated by the state, and has great economic and social significance [6].

1.1.2 Recycled aggregate processing

The process method of producing recycled aggregate is an important part of our utilization of waste concrete, good quality recycled aggregate is more convenient for us to apply to the actual project, the following describes the process of producing recycled aggregate at home and abroad.

Construction waste is currently processed in two ways around the world.

The first form is directly in the generation of construction waste construction site for processing, this method is simple and convenient, can effectively solve the problem of high transportation costs, but also saves a lot of time, to achieve the efficacy of the current use. But the construction site is generally close to residential areas, for environmental protection for the noise requirements, cannot use high-power crushing machines, and due to the simple process, cannot get a cleaner aggregate, aggregate grading is also relatively poor, in general, the quality of the aggregate is poor.

The second form is to transport the aggregate to a specialized recycled aggregate processing plant, which requires special transport trucks and then special machines to process the construction waste. The engineering cost and time cost of this method is relatively high, but it can get clean and well-graded aggregates, and can even be used as natural aggregates. The second form is used in many developed countries [7].

Japan for the disposal of waste concrete means is this: first of all, the waste concrete crushed into about 40mm ball, after 300 ℃ high temperature heating, can make the residual paste into powder after complete separation, which produces the residual powder cement can be used for the improvement of the foundation, aggregates can be used together with the natural aggregates, this practice basically achieves 100% recycling efficiency.

In the processing of recycled aggregates in Russia, in view of the fact that waste concrete often contains a lot of waste metal, glass and wood and other debris, special magnet separation device is installed to facilitate the removal of impurities such as the metal part of the waste concrete, with a separator table to remove the impurities such as wood, plastic and glass. The process is also equipped with a double screen sifter, which can grade and classify the recycled aggregates, and secondary crushing of aggregates above 40 mm, which can

obtain more aggregates with a particle size of 0~40mm, as shown in Fig. 1. The process of this process is the ideal recycling process of construction waste, the disadvantage of this processing method is that there are many equipments, the investment cost in the early stage is large, and it is difficult to promote. Which the block crushing and aggregate screening in the country also has a mature process, control the sorting, sorting, clean is one of the key process technology.

China's need for recycled aggregates and not too much, all strive for convenience and cost issues, the use of simple and practical production methods, as shown in Fig. 2 below: first of all, large pieces of concrete waste, artificially crushed into the size of the jaw crusher can be put into the size of the screen with different specifications, and then sieve, take the aggregate greater than 5mm, and finally the aggregate cleaning standby, the process of attention to the removal of impurities, such as glass, metal and wood.

1.1.3 Physical and mechanical properties of recycled aggregates

1.1.3.1 Composition of recycled aggregates

“Recycled aggregate can be divided into recycled coarse aggregate and recycled fine aggregate, and it is generally considered that particles with a particle size larger than 5 mm are called recycled coarse aggregate, and particles with a particle size range of 0.16 to 5 mm are called recycled fine aggregate” [8]. “Recycled coarse aggregate mainly consists of stones with part of the cement mortar wrapped around the surface, and also includes a small portion of stones that are completely detached from the mortar as well as a small amount of cement stone particles. Recycled fine aggregate mainly consists of gravel with cement mortar attached to the surface, gravel without cement mortar on the surface, cement stone particles and a small amount of crushed stones formed after crushing waste concrete blocks. Whether the surface of recycled aggregate adheres to cement mortar

Fig. 1. Construction waste dumping

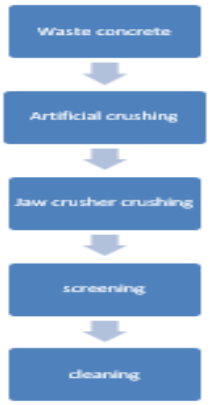

Fig. 2. Processing of recycled aggregates

and how much cement mortar adheres to it are related to factors such as the original concrete strength grade and the type of aggregate. It is generally believed that the higher the strength grade of the original concrete, the less cement mortar adheres to the surface" [9].

1.1.3.2 Apparent density

"There are many factors affecting the apparent density of recycled aggregate, mainly including: the apparent density of aggregate in the original concrete, the sand rate and water-cement ratio of the original concrete, the particle size and gradation of the recycled aggregate, the particle composition and properties of the recycled aggregate, and the water content of the recycled aggregate, etc. In general, the apparent density of recycled aggregate is smaller than that of natural aggregate. Generally speaking, the apparent density of recycled aggregate is smaller than that of natural aggregate, according to the report of B.C.S.J in Japan, the apparent density of saturated face-dry of recycled coarse aggregate is 2120~2430kg/m3 , and the apparent density of recycled fine aggregate is 1970~2140kg/m3". [10] Due to the complex composition of recycled aggregate, in the process of concrete research, it is necessary to carry out the practical Because of the complex composition of recycled aggregates, it is necessary to determine the apparent density of recycled aggregates in the process of specific research, in order to provide the necessary basis for the proportion design of recycled aggregate concrete.

1.1.3.3 Water absorption

Natural aggregate has a low porosity, so, in general, the rate of water absorption and water absorption rate of natural aggregate is very small. For recycled aggregates, the particles are angular, the surface is rough, the composition contains a considerable amount of hardened cement mortar, the cement stone itself in the mortar body is relatively porous, and in the process of crushing, it tends to produce a large number of cracks with a certain size in its interior, so compared with the natural aggregates, the rate and rate of water absorption of recycled aggregates are much larger. In addition, Topcu [11] et al. found that "the water absorption rate of recycled aggregate with an apparent density of 2470 kg/m3 and a fineness modulus of 5.50 reached 7% after 30 minutes of immersion, which shows that recycled aggregate not only has a large water absorption rate, but also has a rather fast rate of water absorption". At the same time, Kreiiger [12] also "from a large number of test results found that the water absorption rate of recycled aggregate and its apparent density of the decreasing relationship, such as for the apparent density of 2400, 1900, 1700 and 1300kg/m3 of recycled aggregate, respectively, its water absorption rate of 3.8%, 9.7%, 12.8% and 22.2%".

In summary, recycled aggregate has a large water absorption rate compared with natural aggregate, and the rate of water absorption is fast, which should be paid special attention to in the design of the proportion of recycled aggregate concrete. In order to ensure that the recycled aggregate concrete has good workability and small dry shrinkage rate, the water absorption rate of recycled aggregate should be appropriately limited for the preparation of recycled aggregate concrete.

1.1.3.4 Crushing indicators

Natural aggregates have a hard and dense structure with low porosity, so their compressive strength is high. Relative to natural aggregates, recycled aggregates on the one hand, due to the presence of about 30% of hardened cement mortar [13][14], these cement mortars lead to the rough surface of recycled aggregates with more angles; on the other hand, waste concrete blocks have a large number of microcracks inside the recycled aggregate due to the accumulation of damages during the crushing process. Therefore, the strength of recycled aggregate is lower than that of natural aggregate. The crushing index of recycled aggregate should be determined according to the actual specific project.

1.1.3.5 Effect of recycled aggregates on the performance of recycled aggregate concrete

The influence of aggregate on the strength of concrete is twofold [15]: one is the strength of the aggregate itself; the other is the degree of interfacial bonding between the aggregate and the cement mortar. Recycled aggregate contains many microcracks, which may adversely affect the strength of recycled aggregate concrete. But at the same time, compared with ordinary concrete, recycled aggregate concrete recycled coarse aggregate surface wrapped with cement mortar, so that the difference in modulus of elasticity between recycled coarse aggregate

and new cement mortar is small, and the interfacial bond is strengthened. In this way, due to the strengthening of interfacial bond, the deterioration of the performance of recycled aggregate concrete caused by the lower strength of recycled aggregate will be compensated to a certain extent.

Combining the above two factors, the influence of recycled aggregate on the strength of recycled aggregate concrete is more complex, depending on the actual situation analysis.

2. COMPRESSIVE STRENGTH OF RECYCLED AGGREGATE CONCRETE

Many studies have been reported on the compressive properties of recycled aggregate concrete at home and abroad, Malhotra [16], Buck [17], Ravindrarajah [18], Dhir [19], Limbachiya [20], and Guptal [21] have found that the development of compressive strength with age of recycled aggregate concrete follows the same pattern as that of ordinary concrete. However, more studies have shown that the compressive strength value of recycled aggregate concrete is lower than that of normal concrete. the study of Nixon [22] showed that the compressive strength of recycled aggregate concrete is about 20% lower than that of normal concrete; the experimental findings of Liu S [23] and Tan Yishuai [24] have similar conclusions. the test of Ravindrarajah [18] found that the compressive strength of recycled aggregate concrete is 8 times lower than that of normal concrete. compressive strength was reduced by 8-24% compared to normal concrete, and the experimental results of Xing Zhenxian [25] showed that the compressive strength of recycled aggregate concrete was reduced by about 9%. Wesche [26], Buck [17], Malhotra [16] and Frondistou-Yannas [27] concluded that there is a There is a correlation between the compressive strength of recycled aggregate concrete which is 10% lower than that of plain concrete. In contrast, Hansen [28] showed that the strength of recycled aggregate concrete has a tendency to be higher than that of ordinary concrete; similar results were found in the tests of Ke Guojun [29].

From the above test results, it can be seen that there are some differences in the conclusions of different researchers. The reason for this is due to the large difference in the quality of recycled coarse aggregate, which causes the difference in the compressive strength of recycled aggregate concrete.

2.1 Effect of Water-cement Ratio on Compressive Strength of Recycled Aggregate Concrete

Previous test results have shown that water-binder ratio is the main influencing factor for the compressive strength of recycled aggregate concrete. Yong-Huang Lin [30] et al. conducted orthogonal tests on five factors (water-binder ratio, recycled coarse aggregate content, natural river sand substitution rate, crushed bricks content, and aggregate cleanliness, etc.) affecting the strength of recycled aggregate concrete, and each factor was divided into two classes (water-binder ratio:0.5, 0.7; recycled coarse aggregate content: 42% and 40.4%; recycled fine aggregate substitution rate: 0% and 100%; crushed brick content: 5% and 0%; aggregate cleanliness: unflushed, flushed). The test results show that the degree of influence on the strength of recycled aggregate concrete is in the following order from high to low: water-cement ratio, substitution rate of natural river sand, aggregate cleanliness, recycled coarse aggregate content, and crushed brick content.

2.2 Effect of Water Absorption on Compressive Strength of Recycled Aggregate Concrete

“The higher the water absorption of recycled coarse aggregate indicates the higher the content of attached mortar, the greater the porosity, the greater the strength loss of the formulated recycled aggregate concrete will be. The effect of recycled coarse aggregate water absorption on recycled aggregate concrete is also visualized in the recycled aggregate concrete. Reduction of workability. To minimize the loss of workability of recycled aggregate concrete, it is often necessary to pre-wet the coarse aggregate or increase the mixing water consumption. The higher the water absorption of recycled coarse aggregate, the greater the increase in the amount of water required, making the more shrinkage of recycled aggregate concrete, the greater the probability of early cracking of recycled aggregate concrete. In view of the unfavorable effect of water absorption of recycled coarse aggregate on the performance of recycled aggregate concrete, many countries and regions have restricted the water absorption of recycled coarse aggregate to no more than 10%” [31-33].

2.3 Influence of the State of Recycled Coarse Aggregate on the Compressive Strength of Recycled Aggregate Concrete

Differences in the wet state of recycled coarse aggregate can also cause variations in the strength of recycled aggregate concrete, M Barra de Oliveira and E. Vazquez [34] investigated the effect of the wet state of recycled coarse aggregate (dry, saturated face-dry, and semi-saturated face-dry) on the compressive strength of recycled aggregate concrete, and concluded that the semi-saturated face-dry state of recycled coarse aggregate was the most favorable for the increase in compressive strength, especially for the increase in flexural strength. It was concluded that the half-saturated and face-dried condition of recycled coarse aggregate was the most favorable for the improvement of compressive strength, especially for the improvement of flexural strength. However, C.S. Poon [35] and others showed that “when the recycled coarse aggregate was in air-dry state, the recycled aggregate concrete formulated with it showed higher compressive strength, and when the recycled coarse aggregate was in saturated face-dry state, the compressive strength of recycled aggregate concrete formulated with it was lower, and suggested that when the substitution rate of the recycled coarse aggregate did not exceed 50%, the recycled aggregate in air-dry state could be used to formulate the same compressive strength as the normal concrete, which was the same as the compressive strength of ordinary concrete. concrete with the same compressive strength of recycled aggregate concrete”.

2.4 Effect of Apparent Density of Recycled Coarse Aggregate on Compressive Strength of Recycled Aggregate Concrete

The low apparent density of recycled coarse aggregates directly leads to a decrease in the density of recycled aggregate concrete formulated from them, which causes a decrease in the compressive strength and modulus of elasticity of the recycled aggregate concrete [36].Tests conducted by Müller [37] concluded that “there is an incremental linear relationship between the saturated face-dry apparent density of recycled coarse aggregates and the cubic compressive strength of recycled aggregate concrete”.

2.5 Effect of Original Concrete Strength on Compressive Strength of Recycled Aggregate Concrete

Hansen and Narud [28] found that, “under the condition of other factors are basically the same, the compressive strength of recycled aggregate concrete is mainly determined by the water-cement ratio of the original concrete and the recycled aggregate concrete, and with the increase of the water-cement ratio of the original concrete, the strength of the recycled aggregate concrete basically decreases gradually”. “The strength of high-strength recycled aggregate concrete with low-strength original concrete as coarse aggregate is 39% lower than that of high-strength recycled aggregate concrete with high-strength original concrete as coarse aggregate. Moreover, the compressive strength of recycled aggregate concrete is comparable or superior to that of ordinary concrete when the water-cement ratio of the original concrete does not exceed that of the recycled aggregate concrete.The same result was found in the test of De Pauw” [38].

3. SPLITTING TENSILE STRENGTH OF RECYCLED AGGREGATE CONCRETE

Tensile strength is one of the most basic mechanical indexes of recycled aggregate concrete, which is an indispensable basis for the study of crack resistance of recycled aggregate concrete and its structural components design and calculation, and for the discussion of the destruction mechanism of recycled aggregate concrete, etc. At the same time, the appearance quality and durability of concrete are closely related to its appearance. Meanwhile, the appearance quality and durability of concrete are closely related to its tensile strength. It is well known that the tensile strength of concrete is usually determined indirectly through the determination of splitting tensile strength.

3.1 Comparison of Tensile Strength of Recycled Aggregate Concrete with Tensile Strength of Ordinary Concrete

Jau [39] et al. found that the splitting tensile strength of recycled aggregate concrete was lower than that of normal concrete, with a decrease ranging from 7.44 to 20%.Similar conclusions were reached by the experiments of Kou [40], whose test results showed that the

splitting tensile strength of recycled aggregate concrete decreased with an increase in the recycled coarse aggregate substitution rate, and that overall, the splitting tensile strength of recycled aggregate concrete was lower than that of normal concrete by 18.2%.The experimental study by Sagoe [41] et al. found that the splitting tensile strength of recycled aggregate concrete decreases with the increase of recycled coarse aggregate substitution rate. When the replacement rate of recycled coarse aggregate is 50%, the splitting tensile strength of recycled aggregate concrete is 85% of that of normal concrete; when the replacement rate of recycled coarse aggregate is 100%, the splitting tensile strength of recycled aggregate concrete is 40% of that of normal concrete. The experiments of Kheder [42] found that, when the water-cement ratio is high, the strength of recycled coarse aggregate is greater than the strength of cement paste, and the splitting tensile strength of recycled aggregate concrete is reduced by the strength of cement paste. The split tensile strength of recycled aggregate concrete is determined by the strength of cement paste; when the water-gum ratio is low, the strength of recycled coarse aggregate is less than the strength of cement paste, the split tensile strength of recycled aggregate concrete is determined by the strength of recycled coarse aggregate, and the two boundaries of the water-gum ratio is 0.5. In summary, the results show that the split tensile strength of recycled aggregate concrete is 12.9~23.5% of ordinary concrete.

However, the test results of Mostafa [43] showed that the splitting tensile strength of recycled aggregate concrete was higher than that of plain concrete. Similar conclusion was reached by Gupta [21] whose test results showed that the splitting tensile strength of recycled aggregate concrete with a high water-to-cement ratio was greater than that of plain concrete. Tests conducted by Jahnston [44] found that the type of recycled coarse aggregate was the most important influencing factor. The more cement mortar adhered to the surface of recycled coarse aggregate, the higher the split tensile strength of recycled aggregate concrete and the lower the compressive strength for each water to cement ratio. Jahnston's study concluded that the bond strength of the coarse aggregate to the cement mortar had a greater effect on the split tensile strength of recycled aggregate concrete and a lesser effect on the compressive strength. Mansur [45] studied the split tensile strength of recycled aggregate concrete formulated with waste bricks as coarse aggregate and the compressive strength of recycled aggregate concrete formulated with waste bricks as coarse aggregate. recycled aggregate concrete splitting tensile strength. Their test results showed that the splitting tensile strength of brick aggregate recycled aggregate concrete was higher than that of normal concrete by 12%.

In addition, some researchers believe that the splitting tensile strength of recycled aggregate concrete is similar to that of normal concrete. The experimental results of Ravindrarajah [18] showed that the splitting tensile strength of recycled aggregate concrete is similar to that of normal concrete. The experimental results of Ryu [46] found that the type of recycled coarse aggregate has little effect on the splitting tensile strength of recycled aggregate concrete when the water-cement ratio is 0.55 The splitting tensile strength of recycled aggregate concrete with a water-cement ratio of 0.25 depends on the quality of the old and new interfaces of the recycled coarse aggregate. When the quality of the new interface is inferior to the quality of the old interface, the splitting strength of recycled aggregate concrete depends on the water-cement ratio; when the quality of the new interface is superior to the quality of the old interface, the splitting strength of the recycled aggregate concrete depends on the strength of the recycled coarse aggregate. Tests conducted by Ravindrarajah [18] investigated the relationship between the splitting tensile strength of the recycled aggregate concrete and that of the original concrete, and the results showed that The splitting tensile strength of recycled aggregate concrete was within 15% of the splitting tensile strength of virgin concrete. RILEM [47] developed various mechanical property indexes for recycled aggregate concrete, in which the design value of splitting tensile strength was set at 1 MPa.

3.2 Relationship between Split Tensile Strength and Cubic Compressive Strength of Recycled Aggregate Concrete

The study of Kou [40] showed that “the ratio of split tensile to compressive strength of recycled aggregate concrete is lower than that of normal concrete”. Li Jiabin [23] collected the splitting tensile strength of recycled aggregate concrete obtained by different researchers f_{sp} and compressive strength f_{cu} test values from

different researchers and analyzed them by regression analysis, and concluded that the conversion relationship between splitting tensile strength and compressive strength of recycled aggregate concrete isf_{sp} =$f_{cu}^{0.65}$ Tests by Mansur [45] showed that “the higher the compressive strength of recycled aggregate concrete, the higher the splitting tensile strength and gave the conversion relationship between splitting tensile strength and compressive strength of recycled aggregate concrete as .$f_{sp} = 0.63(f_{cu})^{0.5}$" Kheder [42] analyzed “the test results and concluded that the relationship between splitting tensile strength and compressive strength of recycled aggregate concrete is given by$f_{sp} = 0.5676(f_{cu})^{0.4988}$" Jau [39] et al. analyzed the regression analysis of the test data and concluded that the conversion relationship between the splitting tensile strength and compressive strength of recycled aggregate concrete is given by$f_{sp} = 1.75(f_{cu})^{0.5}$ Jau [39] et al.

4. CONCLUSION

Summarizing the above research results, it can be seen that, so far, the material properties of recycled aggregate concrete have been extensively studied at home and abroad, and many important results have been obtained. However, it is worth pointing out that most of these research results are based on the test results of single-source recycled aggregate concrete, and there is little research on the basic mechanical properties of recycled aggregate concrete from different sources. In practical engineering, due to the wide range of sources of waste concrete, there are more influencing factors on the mechanical properties of recycled aggregate concrete formulated from it, resulting in a large difference between the mechanical properties of recycled aggregate concrete from different sources and those of single-source recycled aggregate concrete. Therefore, in order to promote the application of recycled aggregate concrete, the research on the above work needs to be further developed.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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