

# Review on the Treatment Method to Improve the Strengthening of Recycled Aggregate Concrete

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**ABSTRACT** - In order to explore the effective method of strengthening recycled concrete coarse aggregate, improve the effective utilization rate of recycled concrete, respond to the development requirements of green buildings and green building materials. By reading a large number of existing research methods and documents, the advantages and disadvantages of various strengthening methods for recycled concrete coarse aggregate in recent years are analyzed and summarized. The main strengthening methods of reclaimed coarse aggregate are physical strengthening, chemical strengthening and gradation strengthening through comparative analysis, more effective strengthening methods are not single, but a combination of two or more methods. Effectively combine gradation strengthening and chemical strengthening, can better improve the mechanical properties of recycled concrete coarse aggregate and durability. There is little research on the failure mechanism of transition zone and strengthening the interface transition zone of recycled concrete, and there are few literatures about harmless treatment of chemically strengthened slurry. These two aspects can be explored and analyzed in the future research.

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## 1.0 INTRODUCTION

At present, the world economy is developing rapidly. Along with economic growth, construction, transportation, municipal services, water conservancy systems and other supporting facilities are also born around the world. New buildings and structures are built out of necessity, Figure 1 old buildings and structures need to be demolished because they do not meet planning requirements or have reached the expiry date, and waste products from prefabricated parts plants [1], or because of various natural disasters: Earthquake damage (Figure 2), floods, typhoons, etc. Human factors: discarded concrete caused by war, impact, etc. Read relevant literature, In China, the Average annual growth in construction waste of around 3.5 billion tonnes in recent years [2]. How to deal with the increasing amount of waste concrete, is a major headache for countries around the world, although many countries have gained some experience in disposal, such as the development of industrial building systems, the application of prefabricated building [3], in most countries, the main disposal method is mostly landfill disposal, which cannot solve the degradation of waste concrete, pollute the environment and occupy a lot of lands.



Figure 1. Demolition of an old residence block



Figure 2. Houses damaged by the earthquake

With the increasing international advocacy of green buildings and green building materials, concrete materials, as one of the most used building materials in the construction industry, must meet the development requirements of green building materials. How to deal with waste concrete, many international scholars have long carried out a variety of research, the emergence of recycled concrete. Recycled concrete is waste concrete that has been crushed, separated, cleaned, screened and other procedures, production of recycled aggregates of different particle sizes, concrete formed by partial or total replacement of natural aggregates with recycled aggregates [4].

The difference between Figure 3 recycled concrete and Figure 4 ordinary concrete lies in the difference of aggregate, recycled concrete aggregate is characterized by a high-water absorption rate, large porosity, high crushing index, and small apparent density due to its raw materials and processing process and micro-cracks caused by impact crushing during production [5]. The performance characteristics of recycled concrete aggregate directly affect the mechanical properties and durability of recycled concrete. To improve the performance of recycled concrete, we can first consider improving the performance of recycled aggregate. The improvement of aggregate performance belongs to basic research, literature reading, and domestic and foreign researchers for this basic research is mainly divided into the physical strengthening method, chemical strengthening method, and gradation strengthening method. In this paper, the strengthening methods of recycled concrete coarse aggregate are summarized and analyzed, finally, some suggestions are put forward for the research and development of strengthening technology of recycled coarse aggregate.



Figure 3. Recycled coarse aggregate



Figure 4. Natural coarse aggregate

## 2.0 PHYSICAL STRENGTHENING METHOD

### 2.1 Mechanical strengthening method

Mechanical strengthening [6], the main is to use mechanical grinding aggregate, through the impact friction between the recycled concrete coarse aggregate, remove the cement mud attached to the surface of the coarse aggregate, and improve the particle performance and shape. Some scholar [7] studied the vertical eccentric grinding device, in-grinding method, and horizontal rotary grinding method in Japan, it found that the recovery rate of the material treated by the vertical eccentric grinding device is high, which accords with the performance standard of Japan recycled aggregate. The disadvantage is the large size of the equipment, high power requirements, wear, and so on. In recent years, many scholars have optimized and improved the mechanical strengthening method, such as particle shaping method [8]. In order to reduce equipment wear, some researchers improved the strengthening method and removed the old mortar attached to the surface of the reclaimed aggregate through mutual collision and friction between the reclaimed concrete coarse aggregate [9]. The coarse recycled concrete aggregate is put into a concrete mixer for mixing, so that the mortar attached to the surface can be taken out. After the screening, the coarse recycled concrete aggregate with small particle size can be taken out [10].

### 2.2 High-temperature treatment method

After the waste concrete is broken, it is heated to 300°C~400°C, after mechanical processing, under the action of mechanical force, the old cement mortar on the surface is removed to produce high-quality recycled concrete aggregate, which is the heating grinding method [11]. Heating can make the old cement mortar on the surface of recycled concrete coarse aggregate embrittle. After mechanical grinding, the old mortar on the surface can be better removed, and the performance is close to that of natural coarse aggregate. The properties of coarse recycled concrete aggregate are affected by different heating temperatures and grinding times. When the temperature rises from 20°C to 600°C, the content of cement can be reduced by 7 times, and the apparent density increases by 5.4%; When the grinding time increased from 5min to 25min, the content of reclaimed coarse aggregate cement was reduced by 3 times and the apparent density was increased by 12.6% [12]. Under the interaction between heat and mechanical force, the water absorption of reclaimed concrete aggregate is close to that of natural aggregate [13].

### 2.3 Wet treatment enhancement method

Wet treatment intensification is the pre-treatment of water for recycled concrete aggregates, High quality reclaimed coarse aggregate can be obtained by separating and removing impurities such as mud, steel wire, and broken brick in reclaimed concrete aggregate [14]. This method has been used in recent years in Europe and the USA to strengthen recycled aggregates. Pre-wetting of the recycled concrete coarse aggregates prior to casting generates recycled concrete with favourable effects on water absorption, water resistance, and 28-day compressive strength, but no effect on the apparent density of the recycled concrete [15].

Used ultrasonic water washing technology to treat recycled aggregates, obtained to remove loose particles from the surface of recycled concrete aggregates with a weaker matrix, enhancing the bond between the recycled concrete aggregate and the new cement paste [14]. Difficult multiple flushing processes, and high-water consumption, result in wasted water, The amount of water used for the pre-wetting of recycled concrete affects the compressive strength of recycled concrete, the compressive strength increases with the amount of pre-wetting treatment of recycled concrete [16].

### 3.0 CHEMICAL ENHANCEMENT METHOD

#### 3.1 Slurry strengthening method

Through a variety of polymers, high-efficiency waterproof agent, cement grout, cement grout mixed with fly ash, cement grout mixed with silica fume, cement grout mixed with Kim powder etc, Soak, wash and air dry, to fill cracks in the recycled concrete coarse aggregate, reduce the porosity of recycled concrete coarse aggregate [17]. Tam et al used the two-stage mixing method to prepare reclaimed concrete, so that a thin layer of cement slurry was formed on the surface of reclaimed concrete coarse aggregate, penetrates into the pores where the mortar is attached, filling some of the gaps and pores, improve the defects of loose porous adhesion mortar [18]. Cement grout mixed with fly ash strengthens regenerated coarse aggregate, Soaking, airing, and other treatments, can effectively reduce the cracks and porosity of recycled coarse aggregate and improve the compressive strength, etc. [17]. Pass treated recycled aggregate by soaking it in PVA solution, it was confirmed, that the water absorption rate of reclaimed coarse aggregate after PVA treatment was significantly reduced, and the strength increased, the performance of the generated recycled concrete is significantly improved [19]. Some researchers treated the surface of recycled aggregate with a silica fume solution, the surface of reclaimed aggregate is covered with a layer of wollastonite particles, to improve the interfacial transition zone between reclaimed aggregate aged mortar and cement slurry. The wollastonite solution fills micro-cracks in the surface mortar layer, improves the surface compactivity, and improves the compressive strength of reclaimed concrete [20].

Soaked, and dried reclaimed aggregate with cement pulp, Kim powder mixed grout, cement silica powder grout, and cement fly ash grout, it was found that the strength of reclaimed aggregate after strengthening was improved to a certain extent [21], Kim powder added to cement can significantly improve the compressive strength of recycled concrete [22]. China scholar showed that: after modified treatment of reclaimed coarse aggregate, the basic properties have been improved, and the best modification effect is a 3% concentration of the hydrochloric acid solution, followed by silicone waterproof agent, cement silica slurry, water glass, micro-expansion efficient crack waterproof agent, the working performance and compressive strength of recycled concrete, formed by the modified recycled coarse aggregate have been improved to varying degrees [23]. Inorganic compound alkaline activator and organic compound acid ester activator are used to strengthen the regenerated coarse aggregate, chemical grout infiltrates into the regenerated coarse aggregate, fills micro-cracks, or reacts with the chemical composition of cement mortar, and the product fills pores or grout to make the regenerated coarse aggregate micro-cracks bonding, so as to reduce the water absorption rate of the regenerated aggregate, reduce the crushing index, Increase the apparent density et al [24].

#### 3.2 Nanomaterial strengthening method

As a relatively new technology, the application of nanomaterials is gradually increasing with the gradual maturity of nanomaterials technology, and the research on the use of nanomaterials to strengthen recycled concrete aggregate has also attracted more attention, with nano-silica being the most studied [25]. Nano-silica can improve the compressive strength of recycled concrete, which will have adverse effects on fluidity and later mortar strength [26].

Reinforced reclaimed concrete aggregate with different dosages of nano-silica, the durability of reclaimed concrete after strengthening was studied, and the effect of 1% nano-silica content on the freezing resistance and sulfate corrosion resistance of reclaimed concrete was better [27]. Researchers studied that when only doped with nano-silica, discover with the increase of the replacement rate of reclaimed aggregate, the chloride ion penetration resistance of reclaimed concrete is better, in the case of mixed fly ash, the chloride ion penetration resistance of reclaimed concrete is significantly improved, even better than that of natural concrete [28]. Nano-silica and nano-modified mineral admixture can strengthen the regenerated coarse aggregate, the chloride ion penetration resistance of the regenerated concrete is obviously improved, and the superposition effect is good.

### 4.0 GRADING AND STRENGTHENING METHOD

Waste concrete is processed to produce aggregate of different particle sizes, and recycled aggregate of different particle sizes is screened. The gradation of aggregate with different particle sizes, can reduce porosity and improve compactness. Due to the defects of recycled coarse aggregate, good gradation strengthening can not only reduce the porosity and total area between coarse aggregate, but also reduce the amount of cement slurry, and improve the workability, compactness, and strength of recycled concrete. Gradation strengthening can effectively improve the crushing index and packing density of recycled concrete coarse aggregate, and effectively improve the compressive strength of the generated recycled concrete [29]. Under the condition that the water-cement ratio remains unchanged, the maximum particle size of reclaimed coarse aggregate decreases, and the total specific surface area of aggregate decreases, which will increase the internal cohesion of concrete and thin the slurry layer between aggregates. Therefore, the performance of reclaimed concrete will be improved with the decrease in the maximum nominal particle size of reclaimed coarse aggregate [30].

It is found that the fractal variable of aggregate gradation affects the compactness of concrete. By studied the reinforcement of aggregate gradation, and concluded that the larger the fractal variable of aggregate gradation, the better the compactness of aggregate, and the improved working performance of the generated concrete. The best fractal variable varies with different maximum particle sizes [31]. By comparing and analyzing the literature, it is concluded that when

the fractal dimension of 2.4, 2.6, and 2.8 is selected, the concrete prepared has better performance. According to GB/T14685-2011 "Gravel and Pebble for Construction", recycled coarse aggregate size is selected: 4.75, 9.5, 16.0, 19.0, 26.5, and the gradation is optimised as shown in the Table1 below.

Table 1 Grade optimization results

| Grain size (mm)       | 4.75 | 9.5  | 16   | 19   | 26.5 |
|-----------------------|------|------|------|------|------|
| Fractal dimension 2.4 | 0    | 28.5 | 59.4 | 73.8 | 100  |
| Fractal dimension 2.6 | 0    | 32.3 | 63.2 | 76.8 | 100  |
| Fractal dimension 2.8 | 0    | 26.2 | 67.0 | 79.5 | 100  |

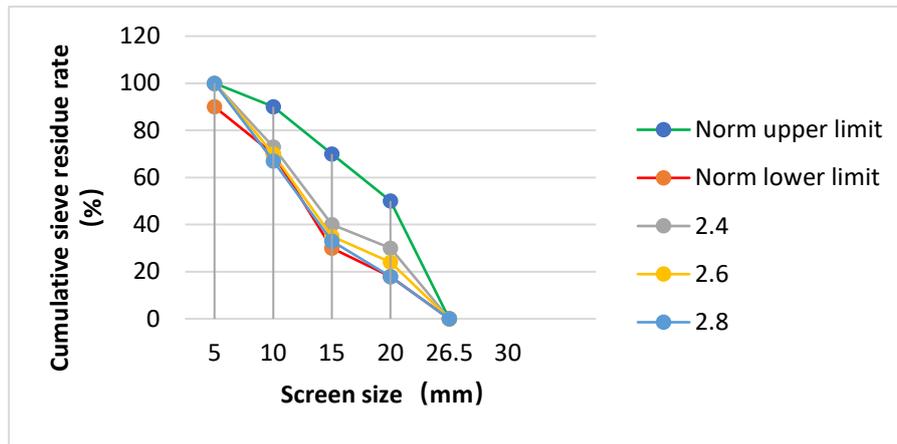


Figure 5. Optimised grading vs. specification

According to the analysis of Figure 5, the aggregate grading curve is smooth and close to the curve specification line, and the three fractal dimension values all meet the grading requirements, which can be applied to practical engineering.

### 5.0 COMPARATIVE ANALYSIS OF VARIOUS STRENGTHENING METHODS

According to the above three strengthening methods of recycled concrete coarse aggregate, comparative analysis is made in Table 2.

Table 2. Comparison of three strengthening methods of recycled concrete coarse aggregate

| Reinforcement method           | Treatment measure   | Equipment requirement | Advantage  | Shortcoming  | Cost   |
|--------------------------------|---|-----------------------|--|--|--------|
| Physical strengthening method  | Mechanical grinding aggregate; High temperature processing; Wash separation           | Yes                   | Can better remove the surface of the old cement mortar | Equipment size, high power, wear, pollution                  | Higher |
| Chemical strengthening method  | The crevices of recycled coarse aggregate are filled by soaking in various grout      | No                    | Wide range of improvement                              | The residual liquid and waste liquid pollute the environment | Medium |
| Gradation reinforcement method | Coarse aggregates of different particle sizes were selected to optimize the gradation | No                    | Can better improve the compressive strength            | Single improvement effect                                    | Lower  |

Analysis Table 2, Mechanical strengthening method of physical strengthening method, is one of the most widely used methods, because of its simple principle and operation. Due to high energy consumption, serious mechanical grinding production process produces a lot of dust, serious environmental pollution, and other shortcomings, limiting the further application of this method. High temperature grinding and strengthening method, increasing the temperature grinding and strengthening of recycled aggregate, can improve the property of recycled aggregate, but requires high temperature, high energy consumption, high temperature will damage the performance of aggregate. Wet treatment, a simple process, with low energy consumption, can better improve the performance of recycled aggregate, so as to improve the related performance of recycled concrete, but the effect is limited, and water consumption is large, resulting in the waste of water resources.

The chemical grout strengthening method can improve the performance of recycled aggregate from different angles, the selection of different grout, and the amount of different, improve the effect of recycled aggregate is different, to compare and analyze the better chemical grout strengthening method through the experiment. After chemical strengthening, the disposal of residual materials and wastes can reduce environmental pollution. How to better dispose of residual materials and wastes can be a focus. Although nanomaterials can improve some of the early performance of recycled concrete, they will cause damage to other properties of recycled concrete. In addition, this material is still in the early stage of research, which is to study whether it can be combined with other materials and nanomaterials, to strengthen the recycled coarse aggregate and make up for the restriction of nanomaterials on fluidity, which is the direction of future research attention.

The gradation strengthening method, which is to optimize the gradation by selecting recycled coarse aggregate with different particle sizes, fills the internal cracks and pores of the reclaimed concrete, increases the compactness, and improves the compressive strength, but it has little influence on the shear and tensile strength of the reclaimed concrete.

Compared with the three strengthening methods, each has advantages and disadvantages. Many scholars choose one of them when studying the strengthening of recycled concrete aggregate. Based on the above analysis, one or two types or even three types can be effectively selected in subsequent studies. Based on the test objectives and on the basis of reasonable gradation, physical reinforcement, and chemical reinforcement can be effectively combined to achieve better reinforcement effects. From the current research and application status analysis, although the three strengthening methods can improve the performance of recycled coarse aggregate to a certain extent, however, there are few large-scale applications in practical engineering. How can it be applied to engineering practice at a lower cost and on a large scale, more research is needed to enrich our literature.

## 6.0 PROSPECT

This paper discusses the strengthening method of recycled concrete coarse aggregate. Some strengthening methods and research achievements in recent years are analyzed, but there are still some problems that need further study in the future.

- 1) The difference between coarse recycled concrete aggregate and ordinary concrete aggregate is that the interfacial transition zone is more complex, and belongs to the weak zone, it is affected by the material composition and water-cement ratio, because there are weak areas, that constrains the workability of recycled concrete. Therefore, the study of the damage mechanism of the transition zone and the strengthening of the interfacial transition zone of recycled concrete (Figure 6) could be a future research direction.

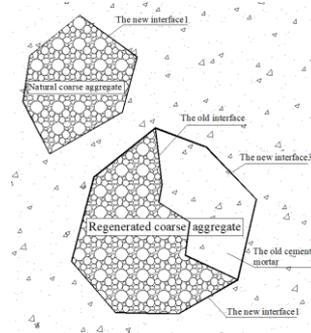


Figure 6. Recycled concrete interface transition zone

- 2) Chemically enhanced methods can solve some of the microscopic problems of recycled concrete coarse aggregates, different slurries can improve the different properties of recycled aggregates, how to better combine the application of different slurries, integrated improvement of the performance of recycled coarse aggregates, and green handling of residuals and waste materials, which is a target for later researchers to focus on.
- 3) Although there has been a lot of research into recycled concrete, it is not commonly used in practical engineering. How to promote the application of recycled concrete at a low cost is also a problem to be solved.

## 7.0 AUTHOR CONTRIBUTIONS

Zhang Li: Writing- Original draft preparation, Software, Modify.

Mohamed Nor Azhari Azman: Data curation, Reviewing and Editing, Supervision, Methodology.

Ramadansyah Putra Jaya: Software, Validation.

## 8.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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## 10.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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