Study on Present Situation of Active Stimulation of Recycled Fine Powder

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Abstract. The text describes the current research status of activation technology of recycled fine powder. The influences of all excitation methods on recycled fine powder are introduced. Based on the analysis of the advantages and disadvantages of the existing excitation methods, the paper puts forward suggestions for energy-saving improvement of mechanical grinding, searching for new chemical activators, controlling temperature and humidity and so on, so as to further promote the recycling of recycled fine powder in China.

1. Introduction
With the rapid development of China's urbanization level and the rapid expansion of construction scale, the annual concrete output in China has exceeded 20 billion cubic meters, which consumes a large number of raw materials while generating a lot of powder, SO2 and other gases. Meanwhile, China needs to demolish many old buildings, which generates a large number of construction waste. However, at present, the resource utilization rate of construction waste was less than 10% in China[1]. Irregular stacking and burying have caused earth resources problem and environmental protection problems.

In the reuse of construction waste, foreign scholars started early and a large number of researches had focused on the resource utilization of recycled aggregates [2]. Germany had been paying attention to the treatment of waste concrete. At present, the use of recycled concrete in Germany was mainly in highway pavement [3]. Because of its small land area and construction waste resource scarcity, Japan had been attached great importance to the research and development of regeneration technology. As early as in 1970s, Japan had started to study in the reuse of waste concrete. In 2005, the total utilization rate of construction waste in Japan had exceeded 85%, and most of them were used on road substrates [4]. Katrina McNeil et al.[5] showed that the use of recycled aggregates instead of natural aggregates can reduce the tensile strength of concrete, and the concrete’s modules of rupture were lower than that of ordinary concrete. It may be caused by the weakening of the interfacial transition zone of residual mortar. China started late in the reuse of construction waste, and has gotten progress in recent years. In 2013, Debin Company independently developed a dedicated and efficient disposal equipment and processing technology based on the disposal plan of regenerated fine sand and recycled fine powder as the main products to complete ‘Nantong Construction Waste Resource Utilization Franchise (BOT) Project Franchise Agreement’. The signing marked the formal start of China's first
construction waste resource BOT project \[6\]. At the end of 2017, China's industry standard ‘Recycled powder for concrete and mortar’ officially began to be compiled.

In the process of waste concrete processing, a large number of fine powder with particle size less than 0.16mm is recycled, accounting for 15% of waste materials, resulting in dust pollution and other environmental problems \[7\]. And the particle size meets the index of inhalable particulate, having harmful effect on human health. The recycled fine powder itself has a certain activity, which can be replaced by the corresponding activation method to stimulate its potential activity. Effectively reducing the amount of cement while using recycled fine powder is an important task in the process of seeking the way to reuse waste concrete. Now the researches on recycled fine powder in China are still not mature. The preparation technology, activation method and the performance of recycled products are the main concerns of most scholars in this field in China. To prove the activation performance of recycled fine powder, physical activation, chemical activation and thermal activation are generally supplemented.

2. Mechanical grinding of recycled fine powder

The waste concrete and waste brick fine powders were active in the particle size range of 40 to 100μm \[8\]. The mechanical grinding method was to grind the recycled fine powders and change the crystal silicon in SiO\(_2\) to the amorphous silicon which owned unstable lattice structure \[9\]. The length of the grinding time and the species of grinding equipments will influence the fineness of recycled fine powder. The smaller the particle size, the larger the specific surface area, the better the activity, and the faster the hydration reaction speed.

2.1 Planetary ball mill

The main reason for the increase in specific surface area of recycled fine powder after milling was to affect the activity by grinding to remove the attachments of unhydrated particles on its surface, so that the atoms on the surface were in an unbalanced state of internal and external forces, owning higher activity \[10\]. Zhang Ping et al.\[11\] used YXQM-4L Planetary ball mill to grind the recycled fine. With the increase of the grinding time, the particle size of the recycled fine powder decreased and the specific surface are became larger, which can enhance its activity. The mortar strength increased first and then decreased, and gradually became stable. Although grinding has a certain positive effect on the activity of recycled fine powder, it is necessary to comprehensively consider its energy dissipation and economic benefits. There was no significant difference in the fitness of fine powder after 60min and 90min grinding, so the optimal grinding time is 60min.

Sun Yan’s experiment\[12\] found that after 150min ball mill grinding, the passage rate factor of the fine powder which particle size is less than 0.075mm was 78%. When the grinding time exceeds a specific value, the particle size will not have a significant change and the screen residue rate will be saturated. Liu Dong\[13\] and other authors’ experiments found that the recycled fine powder had the best effect after 4h ball grinding.

2.2 Superfine pulverizer

Zhao Lei\[8\] used the WZJ-Vibration Superfine Pulverizer to grind the recycled brick powder into 3 types of powder with different fineness for exams. The experimental results showed that the crushed and compressive strength of recycled brick powder cement with the fineness of 12%-30% after grinding can all reach the 80% of the standard mortar strength.

Yu Xiaoxiao\[14\] and others purposed the microstructures and phase structures of the powder with the same particle size had some differences by superfine air pulverizer and the vibration. The test found that the particle size distribution of the recycled fine powder by superfine pulverizer was more uniform, the grain shapes more regular, the activity was better and it would not have a large impact on its compressive strength.
3. Chemical additives of recycled fine powder

As shown in Table 1, the recycled fine powder contained a large number of SiO$_2$ and CaO, we can add proper chemical activator to promote its hydration, making test block and maintaining according to the code requirement. The species of additives have different effects on the performance of recycled concrete. In order to improve the activity performance of recycled powder and the strength of the recycled products, it is necessary to make a reasonable selection and incorporation of additives. Liu Dong and other scholars' research showed that we need to control the amount of alkaline activator reasonably, otherwise the excess hydroxide radical go against the hydration and it would decrease the strength.

Common activators include Ca(OH)$_2$, Na$_2$SO$_4$, NaAlO$_2$, Na$_2$SiO$_3$·9H$_2$O and so on.

Table 1. Chemical composition of recycled fine powder

| Components | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | MgO | TiO$_2$ | SO$_3$ | Loss |
|------------|---------|-------------|-------------|-----|-----|---------|-------|------|
| Content/\% | 38.87   | 11.23       | 2.29        | 25.00 | 1.11 | 0.72    | 1.24  | 9.58 |

3.1 Alkaline solution

The mechanism of the alkaline activator was to increase the concentration of OH$^-$ in the slurry and form free unsaturated active bonds. The generated gelling products can bond inner pores and improve internal structure, which can improve mechanical properties of the recycled products. Zhao Guiyun pointed out that both Ca(OH)$_2$ and Na$_2$SiO$_3$·9H$_2$O alkaline solution could play a certain activation role. The flexural strength and compressive strength of the glue sand specimens had been improved, and the effect of Ca(OH)$_2$ is better. The strong base groups can stimulate the activity of a large amount of Al and Al Oxide contained in the recycled fine powder, and the free calcium oxide in the structure is converted into layered calcium hydroxide. By comparing and analyzing the compressive strength of the glue sand specimens before and after activation, the effect was best when the concentration of NaOH solution was 3%. The reason why the concentration of the alkaline solution was too large to have a beneficial effect on the recycled products may be that the alkali aggregate reaction will cause the structure expanded and cracked, which will affect the structure of the recycled products. Qin Li pointed out that the alkaline activator can reduce the holding time of the reaction to ensure the reaction fully occur and have a higher strength in the early stage of its recycled product, and it is also higher at 90 days.

3.2 Acidic solution

The recycled fine powder is immersed fully in the hydrochloric acid solution and the hydrochloric acid reacts as the hydrated products of Portland cement to generate precipitation. After being fully soaked, the recycled fine powder will be filter out and be dried and ground. Yan Jinhai and other scholars took tests to prove that the hydrochloride has the ability to clean up the cement mortar which attached to the surface of the recycled fine powder. The method can affect the activation by improving its apparent morphology, and the test showed that its hydrophilic coefficient was significantly reduced. During the excitation process, we should control the acidic solution. If the acidity is too strong, it will generate some expansible products and cause the structure to swell and crack, reducing the strength of the recycled concrete.

3.3 Silicate solution

When the recycled fine powder is immersed in Na$_2$SO$_4$ solution, something like gypsum which has expansibility produced by the reaction play a role of filling the pores in the internal structure of the mortar. But Yue Gongbing found that this effect just only had a good activation effect on the recycled fine powder with a short soaking time. When the soaking time is more than 90 days, the recycled concrete will expand sustainably and then burst, which has an adverse effect on its mechanical properties. Liu Dong et al. observed through SEM characterization and found that the optimal content of Na$_2$SO$_4$ was 3%. The mechanism of Na$_2$SiO$_3$ activator is that calcium ion reacts with silicate to form a precipitate attached to the surface of the fine powder. Kai Wang and others
believed that carbonation products can fill the pores and combine with each other to form a dense microstructure, which helps improve the mechanical strength of recycled micronized concrete. Zhang Ping[11] and others pointed out that Na$_2$SO$_4$ activator had a better effect on improving the activity index of recycled fine powder than NaAlO$_2$ activator.

3.4 Chloride solution
By adding an appropriate amount of CaCl$_2$ activator into the recycled fine powder, the porosity and the average pore diameter of the sample show a small state. That is because in the later period, CaCl$_2$ can not only hydrate on the surface of the recycled fine powder particles, but also into the interior of the particles to play a role of filling the internal pores. So the structure of recycled concrete was denser and the recycled concrete has the highest compressive strength[24].

4. Thermal influence of recycled fine powder

4.1 Water boiling
Yan Jinhai[21] et al. in order to solve the problem that the recycled fine powder contains a large number of unhydrated particles, they chose to boil the recycled fine powder. The specific operation was: Placing the recycled fine powder into the 100°C boiling water for 20 minutes and drying it. Grinding according to the standard, this method aims to make the activity of the recycled fine powder hydrated again by hydration reaction.

4.2 Microwave heating
Wang Jiaqie et al.[25] used the microwave heating technology to make up the shortcomings of traditional mechanical crushing method. Without impact and extrusion, the method can remove completely the mortar on the aggregates and the performance of the powder by microwave heating was better than that by traditional mechanical grinding.

4.3 Muffle furnace heating
The recycled fine powder is placed in a muffle furnace at 750°C to make a heating treatment for 2 hours, and the original moisture is dehydrated and evaporated. During the process, the C-S-H structure disintegrated and the hydration reaction occurred again. Yang Lin[26] researched that in this case, the activation was improved and its performance can meet the core requirement.

4.4 Autoclaved process
The internal structure of the recycled fine powder is affected by the temperature-change stress and the internal Si-O and Al-O chemical bonds are destroyed. So the speed of the hydration reaction is accelerated and the potential activity of the recycled fine powder is enhanced. Autoclaved treatment has a great impact on materials containing more silicon. Liu Yiyue[27] pointed out that due to the recycled fine powder contains a large number of silicon, the internal pores can be mostly filled with hydrates and the compressive strength of recycled products increased by nearly 50%.

5. Compound activation of recycled fine powder
The effect of physical or chemical excitation alone is not significant. The chemical activation of the recycled fine powder obtained by mechanical grinding has a significantly better effect than the single activation method. In the case of only chemical excitation of the recycled fine powder, the effect of the composite chemical activator is better than that of the single chemical activator. Yang Lin[26] pointed out that the best activation condition was: screening the particles which have a 10min grinding, using a 0.15mm sieve, the screened particles were ground by a ball mill for 1hour, and then calcined in a muffle furnace at 750 °C for 2h. Xian Jiabei[28] found experiments showed that 2% CaO + 1% Na$_2$SO$_4$ + 0.25% NaOH + 2% CaSO$_4$ was the optimal compound formula.
The effect of recycled fine powder under alkaline activation is not the same at different temperatures. Li Qin et al. found that the higher the temperature, the faster the rate of hydration reaction generation, resulting in the gelation products not filling the internal pores in time and unable to play a role of filling effect. He Zhimin [29] and others obtained through experiments that the incorporation of chemical activators significantly improved the compressive strength of steam-cured recycled products.

6. Conclusion and prospect
(1) Most of the active excitation methods of recycled powders are mainly physical and chemical excitations, which are aimed at improving the internal structure and mechanical properties of the powder by promoting the formation of gelling substances, and the apparent morphology, particle size, and internal structure of the powder and the recycled products have certain effects.

(2) The physical excitation method has good effect and low cost, and it is also applied most widely, but the large energy consumption is the biggest problem with this method. Therefore, the low-energy and high-efficiency physical excitation method needs further study.

(3) Chemical activators can effectively improve some properties of recycled concrete. Different types of activators have different applicability. It is necessary to choose appropriate admixtures according to the specific proportion. The addition of a single activator has certain limitations, so doping activator can be studied further.

(4) Temperature and humidity affect the excitation effect of recycled fine powder. The next step is to find the appropriate temperature and humidity of various fine powders, combined with physical or chemical excitation, to enhance its activity and fully hydrate, thereby improving the performance of recycled products.

(5) Most of the recycled fine powder comes from waste concrete. At present, China has no corresponding normative standard for the source, preparation process, use environment, age, etc. of waste concrete. The properties of different types of recycled fine powder are quite different, and the results have big differences.

(6) The government should unveil the corresponding standards to screen the performance of fine powder accurately, promoting efficient production models and the large-scale application of recycled fine powder concrete.

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