Study on Effect of High Voltage Pulse Electrode Spacing on Broken Concrete Physical Performance

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Abstract. In order to study on effect of high voltage pulse electrode spacing on broken concrete physical performance, through four electrode spacing in the concrete crush test, analysis of electrode spacing effect on water absorption and loss rate of aggregate, particle size distribution, crushing value and surface roughness. The test results show that after concrete crushed by the pulse, crushed aggregate mainly assumes three kinds of apparent form; With the electrode spacing increasing, concrete crushing grain group present diversity, continuous graded aggregate gradually formed; The water absorption rate of large particle size assumes the albeit slowly trend compared the small one, on the whole, within 1 hour, aggregate absorbent ability quickly reach the maximum, grain group for 5-20 mm and 16-31.5 mm compare 0.16 hours increased by 25.53% and 12.86% respectively, to 24 hours, only increased by 18.82% and 3.02% compared the early time(one hour)condition respectively; For water loss, large and small particle size both show the increase trend; The aggregate particle size mass within the scope shows the tendency of increase after the first reduce overall.

1. Introduction
The concrete crushing technology is inspired from the waste concrete demolition work of civil building, public road, bridge and tunnel. With the high-speed global economic development, the quantities of civil engineering construction are increasing year by year. Accordingly, as concrete being the current major engineering material, its annual output and the amount of concrete waste are enormous. The total annual output of concrete is about 3.5 billion m³ in the globe, among which the total concrete output (about 1.4 billion to 1.5 billion m³) in China accounts for 45%[1]. Under mass production of as placed concrete, the amount of the generated waste cement concrete is huge for all kinds of reasons. As the laws and regulations regarding environmental protection and construction waste management are enacted and put into effect in China, the untreated waste cement concrete will no longer be disposed by stacking in suburban outdoor areas or landfilling[2-4]. Therefore, the recycling of waste cement concrete has become a problem in need of urgent solutions at the moment. Pulsed high-voltage discharge concrete crushing is considered as an economical, environmentally friendly, safe and efficient method differentiated from the traditional crushing method in recent years [5-7].

 Scholars from colleges and universities both inside and outside China have conducted extensive research on the application of the pulse crushing technology. Eric[8] studied the microcracks and fractures generated during the electrical pulse crushing process, and pointed out that the number of cracks after the pulse treatment was 4 times of that before the treatment, the ores experiencing high-voltage pulse treatment had lower mechanical strength than conventional crushing products, hence
saving 24% energy in the later ore grinding process. Tamsyn Parker[9] studied the surface chemical properties of porphyry copper deposits after high-voltage pulse pretreatment via XPS, and found that the high-voltage pulse discharge results in the oxidization of copper pyrite and the surface chemical changes and contributes to the separation of pyrite and arsenopyrite. Kathy[10] treated a large quantity of superhigh-performance fine metal fiber reinforced concrete with high-voltage pulse, and the results showed when the fiber reinforced concrete was treated respectively under input energy of 5.0 kWh/t and 13.4 kWh/t, the fine metal fiber recovery rate of the concrete test block reached 30% and 60%, respectively. The study of electrical pulse has a late start in China. Diao et al.[11] found that the waste circuit board was dissociated along the interface between copper foil and base material and that between copper foil and fire-retardant layer due to high-voltage electrical pulse, and the dissociation was gradually extended inside the interfaces with the increase of pulse number; Zhou[12] found that the microstructure existing in the coal and rock mass was redeveloped and expanded because of electrical pulse. Three crack propagation forms existed in the coal mass under the action of electrical pulse stress wave, i.e., opening mode crack, sliding mode crack and tearing mode crack.

From the abovementioned studies, it is not difficult to find that the pulse application in waste concrete crushing has been scarcely studied, and the extensive exploration of the pulse concrete crushing technology could hardly be realized due to the lack of related theories and a small test data size, etc. Therefore, the influence of five parameters (water absorption, water loss rate, particle size, crushing value and roughness) on the physical properties of concrete materials were studied under the pulse electrode spacings of 31.5 cm, 93 cm, 157.5 cm and 283.5 cm in the hope of providing a scientific basis for the pulse concrete crushing technology.

2. Test

2.1. Test raw materials
The test raw materials were stair step concrete members collected from an abandoned civil industrial factory building located in Shenbei New District, Shenyang City, Liaoning Province, with a dimension of 20 × 35 × 126 cm³. Without steel bars, the members were in plain concrete structures as shown in Figure 1. According to the design drawings provided by China Northeast Architectural Design & Research Institute, the waste concrete grade was C20, which was verified through the actual compressive strength test. The chemical composition of cement and concrete mixing proportion are seen in Table 1 and Table 2.

![Figure 1. Dimensions of Crushed Concrete Block](image)

**Table 1. Chemical Composition of Cement (%)**

|     | SiO₂ | Fe₂O₃ | Al₂O₃ | CaO  | MnO  | MgO  |
|-----|------|-------|-------|------|------|------|
|     | 56.26| 8.96  | 16.04 | 5.98 | 0.14 | 3.61 |

**Table 2. Concrete Mixing Proportion (kg/m³)**

|     | Cement | Coarse aggregate (5-31.5mm) | Fine aggregate | Water |
|-----|--------|----------------------------|----------------|-------|
|     | 404    | 1264                       | 542            | 190   |

2.2. Testing equipment and test standard
In the actual production of concrete mixing plant at present, coarse aggregates are generally divided into 2 single gradations: 5.0 - 20.0 mm and 16.0 - 31.5 mm[13]. According to the aggregate size distribution laws after crushing, the electrode spacing was taken as 31.5 cm, 93 cm, 157.5 cm and 283.5 cm, respectively. The charging voltage of high-voltage charging capacitor was 140 kV, and the high-voltage electrical pulse was released for 30 times. The single energy storage capacity on the high-
voltage capacitor was 200 J. The aqueous medium used in the test was tap water, with an electrical conductivity of $700 \mu \text{s/cm}$.

In the test, the FZHVP-1 high-voltage pulse treatment system produced in Austria with adjustable electrode spacing was used to crush waste plain concrete members; the thermostatic drying oven and drying box were used to measure water absorption and water loss rate; the aggregate crushing value was determined via square-hole plansifter, stone crushing value tester and JYE-2000 digital display compression testing machine. The above parameter determination was in accordance with Test Methods of Aggregate for Highway Engineering (JTG E42-2005)[14].

2.3. Test process
When the discharging conditions were met with the gradual boost of capacitor, pulse waves were formed between two poles of the electrode, and a pulsing channel was immediately formed. This process was instantaneously completed, accompanied by the “bang” of concrete, the concrete was crushed by the pulse abruptly, and the crushing channel was demonstrated as seen in Figure 2. As the electrode spacing was gradually enlarged, various particle size groups existed in the concrete crushing products. The products mainly presented three morphologies: The concrete was totally crushed, the pulse wave energy broke through the interface layer between aggregate and cement-based material, and the cement mortar was stripped off the aggregate, thus forming “natural coarse aggregate” in an absolute sense; the aggregate was totally separated from the cement mortar, microcracks appeared on the interface, and the recyclable coarse aggregates were regenerated; the pulse wave only broke through the inner part of cement mortar but was not transited into the interface layer, and the mortar layer was loose and crushed at the time. Based on the engineering application practice and in consideration of the test detection accuracy, the three types of crushing products were manually vibrated and crushed again to form coarse aggregates, which were completely stones, namely the aggregate form similar to the first type of coarse aggregate.

3. Test Results and Discussion

3.1. Influences of electrode spacing on water absorption and water loss rate of crushed concrete
As the pulse crushing was conducted in a soaking environment, the concrete crushing products should be firstly dried in a 100°C drying oven for 4 h and then cooled under natural conditions for 4 h, followed by a redetermination of water absorption and water loss rate. The water absorption changes of crushed aggregates at different water absorption time are displayed in Figure 4.
Figure 4. Changes of Aggregate Water Absorption in Different Particle Size Groups

As shown in Figure 4, the water absorption of crushed concrete blocks rapidly reached the maximum value within 1 h, the water absorption rate of the particle size groups 5-20 mm and 16-31.5 mm were elevated by 25.53% and 12.86%, respectively, compared with those at 0.16 h, but after 24 h, the two numbers were increased by only 18.82% and 3.02%, respectively, in comparison with those in the initial stage (1 h). It could be found that the concrete aggregate with large particle size has a weak water absorption after 1 h, and it can be considered as not absorbing water at this point. Nevertheless, the small crushed aggregate still absorb water, because after the electrical pulse crushing under unchanged field intensity, the pulse wave expanded the pores inside the cement-based material and overcame the tensile strength. Then the water-based material underwent severe damage and formed many pores and fractures. A large quantity of micropores were formed in the small crushed blocks, while a small quantity of micropores were formed in large crushed blocks. According to the water absorbing characteristics of capillary pores, small crushed blocks had a stronger water absorbing capacity than the large ones, so the increase amplitude was great within 1 h; after 1 h, as the capillary pores were filled with saturated water solution, the concrete crushing products in small particle size groups still absorb water, while the concrete crushing products in large particle size groups lacked capillary water absorbing channels and only contained large fracture pores, rendering it hard to continue absorb water. Therefore, the concrete crushing products with large particle size almost did not absorb water after 1-24 h.

With the increasing discharge electrode spacing, the water absorption of small particle size group presented a slowly declining trend, while that of large particle size group presented a sharp declining trend. The reason has been partly mentioned in the previous section: due to the capillary pores and air exposed natural surface area characteristics, natural water was exposed on the external surface with a larger surface area, and thus most part of natural water was air dried and evaporated. In small particle size groups, the micropore channels gradually lost water, the moisture flow gradient was generated in the pore channel due to pressure difference, so gradual water loss happened. Hence, the two groups were obviously different in water absorption rate.

The changes in water loss rate of crushed aggregates after air drying under natural conditions are displayed in Figure 5.

Figure 5. Changes of Aggregate Water Loss Rates in Different Particle Size Groups

From Figure 5, the effective water loss generally took place within 24 h, the water loss rates in particle size groups 5-20 mm and 16-31.5 mm were elevated by 2.73 times and 4.2 times in
comparison with those at 0.16 h, but after 24 h, they were averagely increased by 63.01% and 51.85%, respectively, compared with those at 24 h. Therefore, it could be considered that the water loss process was basically completed within 24 h, while what happened within 1-30 d was just that the residual moisture in the pore channel of the cement-based material vanished, and this process was the result of collaborative action of water evaporation generated by air drying and pressure difference in gaps. Furthermore, the water loss rate in concrete crushing products with small particle size was higher than that in the large particle size group, and the reason was the same as the previous water absorption analysis, so it would not be described here repeatedly.

As the discharge electrode spacing was enlarged, the water loss rates in both large particle size and small particle size groups were gradually increasing. The charging voltage of capacitor was guaranteed as 140 kV, and after it released high-voltage pulse for 30 times, the concrete test blocks could be effectively crushed. The crushed concrete particle size was gradually transformed from small particle size group into large particle size group, and consequently, the moisture disappeared fast and the water loss was accelerated. The change of water loss rate is consistent with the influence analysis result of specimen size effect on water loss rate obtained by Professor Yan from Tsinghua University[15].

3.2 Influence of electrode spacing on crushed concrete particle size

In the test, the particle size distributions of regenerated coarse aggregates were demarcated using screen mesh size in accordance with Test Methods of Aggregate for Highway Engineering (JTG E42-2005)[16], namely, 2.36 mm, 4.75 mm, 9.5 mm, 16.0 mm, 19.0 mm, 26.5 mm and 31.5 mm. According to the actual production status of concrete mixing plant, the mass ratios (%) of electric shock crushed aggregates falling into the continuous grading intervals were determined, as shown in Figure 6.

![Figure 6. Mass Distributions of Different Particle Size Groups](image)

With the increasing particle size of crushing products under unchanged pulse electrode spacing, the mass ratio of aggregates falling into the corresponding particle size groups firstly increased and then decreased. Under four electrode spacings, the aggregate particle size groups corresponding to the maximum mass ratio were 2.36-4.75 mm, 2.36-4.75 mm, 16-19 mm and 16-19 mm, respectively. The reason for the above changes was explained as follows: under narrow electrode spacing, the concrete crushing area was only restricted within the electrode spacing, while the maximum crushing particle size was approximate to the electrode spacing, so the particle sizes of the crushing products were all partially small, and the mass ratio was high; when the electrode spacing was no smaller than 157.5 mm, as the electrode spacing could cover multiple large aggregate sizes, the pulse wave was ensured to run through the internal base of concrete, thus generating many large crushed concrete aggregates, most of which were concentrated within 16.0-19.0 mm and 19.0-26.5 mm.

As the pulse electrode spacing was enlarged, the mass ratios of aggregates within the corresponding particle size groups has firstly increased and then declined as a whole. It could be found in the test process that with the increase of electrode spacing, the mass ratio of crushed aggregates within 2.36-4.75 mm was gradually reduced, because the aggregates with small particle size did not prevail, but with the increasing electrode spacing, more aggregates with large particle size were
gradually formed during the crushing process, so as to form multi-grade mass distributions, so in other
words, the mass ratio of small particle size group was reduced.

4. Conclusions
(1) With high crushing speed in the plain concrete crushing process, the electrical pulse crushing
method can remarkably improve the aggregate particle size group screening in the concrete. Moreover,
this method integrates the merits of low noise, cleanliness and non-pollution.

(2) The particle size groups are diversified after concrete crushing with the increase of electrode
spacing, and then continuous aggregate gradation is formed. The water absorption rate of large particle
size groups is reduced at an accelerated speed. On the whole, the water absorption of crushed
aggregates rapidly reaches the maximum value within 1 h, and those in the particle size groups of 5-20
mm and 16-31.5 mm are increased by 25.53% and 12.86%, respectively compared with those at 0.16 h.
However, after 1 h, they are increased only by 18.82% and 3.02%, respectively, in comparison with
those in the initial stage, and it can be considered that the aggregates in large particle size groups
almost do not absorb water after 1 h.

(3) The water loss rates in large and small particle size groups are gradually rising with the increase
of electrode spacing.

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