Concrete recycling by pulsed power discharge inside concrete

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Abstract—In Japan, most of concrete scraps wasted have been reused as roadbed materials and the recycling ratio of waste concrete has been kept over 95% since 2000. However, it is expected that the needs of concrete scraps as roadbed materials decrease, whereas the concrete scraps wasted increase due to reconstruction of buildings in the next decade [1][2][3]. As the gradual exhaustion of natural coarse aggregate resources is also becoming an environmental issue, there is an urgent need to develop methods for the recycling of waste concrete. The pursuit of new and advanced recycling technology of waste concrete is of paramount importance in Japan.

In this work, the pulsed power discharge inside concrete scraps immersed in water was used to reproduce the coarse aggregate. The Marx generator was used as the pulsed power source and the point to hemisphere mesh electrode was immersed in water. In the experiments, the pulsed voltages were applied to concrete scraps placed on hemisphere mesh and the reproduced coarse aggregates were evaluated after the repetitive discharge treatment and the concretes which were made by the reproduced coarse aggregates were evaluated. From the results, it is clarified that the repetitive discharge treatment of the concrete scraps produces the recycled coarse aggregate under Japan Industrial Standard (JIS) regulation. Furthermore, the quality of the recycled coarse aggregate was controlled by the consumption energy of the discharge treatment. In addition, the concrete made by the recycled coarse aggregate has enough strength as the construction material.

Keywords—Pulsed power, concrete, aggregate, recycle, discharge, shock wave, marx generator, environment

I. INTRODUCTION

In Japan, concrete scraps are widely reused as roadbed materials, and the waste concrete recycling ratio has remained above 95% since 2000. However, while demand for concrete scraps for such application is expected to decrease in the future, supply is expected to increase due to reconstruction of buildings over the next decade [1][2][3]. As the gradual exhaustion of natural coarse aggregate resources is also becoming an environmental issue, there is an urgent need to develop methods for the recycling of waste concrete. The pursuit of new and advanced recycling technology for this purpose is therefore of paramount importance in Japan.

Conventional approaches to concrete scrap recycling such as mechanical grinding and heating/rubbing are based on the application of mechanical stress [4][5][6][7]. However, the high levels of stress involved result in extensive destruction not only of concrete scraps but also of aggregates, and large amounts of fine powder are also generated.

Alternative techniques involving the use of pulse discharge to break down solid materials [8][9][10] and to drill wells [11] have been introduced in recent years. There is a wide range of potential uses for pulsed power technologies, including application to liquids/gases and in bioelectrics. Typical examples are found in the fields of water processing [12], air pollution control [13] and cancer treatment [14]. This study examined a new recycling technique leveraging pulsed power discharge to concrete scraps immersed in water in order to retrieve coarse aggregates.

The method involves two principles of destruction: destructive discharge paths, and shockwaves caused by heat expansion from such paths [15]. The discharges propagate into and weaken the concrete’s cement paste based on its characteristic of containing fine air bubbles where electric fields tend to concentrate. Discharge paths form readily in cement paste, and the resulting shockwaves create tensile stress boundaries between paste and coarse aggregate, thereby causing them to separate. The voltage ramp rise time is an important factor in the formation of pulse discharge paths in concrete, and must be less than 500 nsec because the breakdown electric field strengths of water and solids are reversed at this time [8].

In this work, pulsed voltages were applied to concrete scraps placed on a hemisphere mesh. The retrieved coarse aggregates were assessed after repetitive discharge treatment, and the concretes which were made by the reproduced coarse aggregates were evaluated. This paper outlines the basic research conducted, which confirmed the effectiveness of pulsed power in concrete recycling.

II. DISCHARGE TREATMENT SYSTEM FOR CONCRETE SCRAPS

A. Pulsed Power Source

Fig. 1 (a) shows the schematic diagram and Fig. 1 (b) shows the still image of the Marx generator used as pulsed power source in this work. The Marx generator consists of ten stages of capacitor and all capacitors were charged up to -40 kV in the operation. The E, R_C, C_C, S_P,
S, R_D, C_D, L and C_S in Fig. 1 (a) are with the dc power supply, the charging resistor (200 Ω), the capacitor for the reduction of the reverse voltage to E (0.2 μF), the mechanical switch for the protection of E, the mechanical switch of triggering the Marx generator, the discharge resistor (0.5 Ω), the stage capacitor of the Marx generator (0.8 μF), the inductor (100 μH) and the capacitor for stable gap switching (1 nF), respectively. For the protection of the charging circuit including E, R_C and C_C, it was separated from the Marx generator by simultaneous switching between S_P and S during the operation [16]. Fig. 2 indicates the typical waveforms of the applied voltage to and the discharge current into the concrete scrap in the experiment. The rise time of the applied voltage was less than 50 ns. The peaks of the voltage and current reached up to 400 kV and 20 kA, respectively.

B. Discharge Electrodes

Fig. 3 shows schematic diagram of the discharge reactor for the discharge treatment of concrete scraps, the point to hemisphere electrodes, which immersed into tap water, was utilized. The positive pulsed voltage from the Marx generator was applied to the point electrode and the hemisphere electrode was grounded. Especially, the hemisphere electrode was made by stainless steel 5 mm sieve. Therefore, only concretes, aggregates and mortars with over 5mm of diameter remained in the discharge electrodes and the smaller dropped from hemisphere electrode during the repetitive discharge treatment of the concrete scraps.

C. Test Piece of concrete

The test piece concretes were manufactured in our laboratory. After the production, the test pieces of concretes were cured under water for 28 days. The geometry, the dimension, the compressive strength and the Young’s modulus of the test concrete piece were the rectangular box, 150 mm to 150 mm to 75 mm, 39 N/mm² and 2,800, respectively. The coarse aggregates...
composed in the test piece concrete have 3.1 g/cm³ of the density in oven-dry condition, 0.5 % of the water absorption ratio and 6.62 of the fineness modulus, respectively.

D. Experimental Procedures

In the case of the discharge treatment, one of the test concrete pieces was placed between the point and sieve electrodes. After the setup of concrete, 128 kJ of consumption energy (20 times of the pulsed voltages) by pulsed discharge from the Marx generator were applied into the discharge electrodes continuously and then the measurements of the density in oven-dry condition, the water absorption ratio, the fineness modulus and the size distribution of the concretes, the aggregates and the mortars remained on hemisphere sieve were practiced. Totally, the cycle between the discharge treatment and the measurement was performed five times for one piece of test concrete. This means one of the test piece concretes was treated by the discharge 640 kJ of consumption energy (100 times). In the work, four pieces of test concretes were treated. Here, the concretes, the aggregates and mortars having larger diameter of 5 mm, which are produced by the discharge treatments, are defined as the recycled coarse aggregates. In the work, the recycled aggregates after the 640 kJ of consumption energy (100 times) by discharge treatments were used as the aggregates of the fresh concretes for its evaluations as construction material. After the production of the fresh concrete composing the recycled aggregates, its compressive strength and Young’s modulus are tested.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 4 shows the photos of the test piece of concrete and the recycled coarse aggregates produced by 30, 60 and 100 discharge treatments. It will be observed from Fig. 4 that the test piece concrete was fragmented with increasing the number of the discharge treatments. The recycled coarse aggregates produced by 100 discharge treatments were mostly consisted of the coarse aggregates.

A. Density and Water absorption ratio of Aggregate

Fig. 5 shows the dependence of the density in oven-dry condition of the recycled coarse aggregate on the consumption of energy. The consumption energy was calculated from the discharge energy during single discharge application and the number of the discharge applications. The higher density in oven-dry condition of aggregate is a high quality. It is seems in Fig. 5 the density in oven-dry condition of the recycled coarse aggregate improved with increasing consumption energy. At the 150 kJ of consumption energy of discharge treatment, the recycled coarse aggregates satisfied the regulation of fresh or recycled coarse aggregates under the Japanese Industrial Standard (JIS) [17][18].

Fig. 6 shows the dependence of the water absorption ratio of the recycled coarse aggregate on the consumption of energy. The lower water absorption ratio of aggregate
is a high quality. It is seems in Fig. 6 the water absorption ratio of the recycled coarse aggregate improved with increasing consumption energy. At the 320 kJ of consumption energy of discharge treatment, the recycled coarse aggregates satisfied the regulation of fresh or recycled coarse aggregates under the JIS [17][18]. Therefore, the 320 kJ of consumption energy of discharge treatment is necessary to satisfy the both the density in oven-dry condition and the water absorption ratio by the JIS [17][18].

At more than 512 kJ of consumption energy, the both density in oven-dry condition and the water absorption ratio trended to saturate. This result indicate that the coarse aggregates damaged by the discharge treatment.

B. Size distribution and Fineness module of Aggregate

Fig.7 shows comparison of the size distribution of the original coarse aggregate and the recycled coarse aggregate that is treated with each the consumption of energy. The size of distribution represents the size of the aggregate, significantly affect the workability. Better size distribution of recycled coarse aggregates is close to the size of distribution of the original coarse aggregates. It will be observed from Fig. 7 that the recycled coarse aggregates was grained refining with increasing the consumption energy. At between the 256 kJ and 384 kJ of consumption energy of discharge treatment, the recycled coarse aggregates approached the original coarse aggregate. This result conformed to the result of the consumption energy which is required to satisfy the JIS [17][18].

Fig.8 shows the dependence of the Fineness module of the recycled coarse aggregate on the consumption energy. The lower Fineness module of aggregate is a fine grain. It will be observed from Fig. 8 that the curve of the Fineness module has slopes of two types. The Type1 and Type2 in Fig.8 define the slope of the first half and slope of the second half. Slope of the Type1 is greater than slope the Typ2. At the Type1, the mortars were aggressive separated from the aggregates by the discharge inside mortars. At Type2, the mortars also
were separate from aggregates at the same time as the crushing of aggregates. Because separation advances enough at Type1, and there become decrease of quantity of adherent mortar.

These straight lines of the two types are intersectional at about the 320 kJ of consumption energy. In addition, this consumption energy conformed to the consumption energy which is required to satisfy the JIS. Furthermore, a value of original aggregate almost accords with a value of this point. Therefore, evaluation of the fineness module can be a new and easy evaluation method for the evaluation of the recycled aggregate.

C. Evaluation of reproduced concrete

Fig.9 indicates that the compressive strength and the young’s modulus of the both concrete made by the original and the recycled coarse aggregates. From Fig.9, the compressive strength and the young’s module of the recycled concrete become smaller than that of the original concrete. However, the both values of the recycled concrete have enough level to construct the building.

IV. CONCLUSION

In this study, pulse discharge treatment was tested as a new method of recycling coarse aggregate for use as a construction material. The technique provides the advantages of producing high-quality recycled aggregate, saving space and eliminating the generation of fine powder. The study’s findings can be summarized as follows:

1. Repetitive pulse discharge treatment of concrete scraps produces recycled coarse aggregate that is confirmed under JIS regulations.
2. The fineness module can be examined as a simple new metric for evaluating aggregate.
3. Concrete made using coarse aggregate recycled in this way provides sufficient strength for use as a construction material.

For future commercialization, a high production rate and an improvement of the pulsed power supply are needed. Currently, approximately 0.05 tons of concrete per hour can be produced on a laboratory scale, but a rate of 1 ton per hour is required for practical use. To achieve this, the authors plan further research to investigate the process parameters, optimize energy input, improve processing efficiency, boost processing speed and enhance pulsed power supply reliability.

REFERENCES


Fig.9. Qualities of concretes produced by fresh or recycled aggregate


