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EFFECT OF FLY ASH ON THE STRENGTH OF CONCRETE MADE FROM RECYCLED AGGREGATE BY PULSED POWER

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ABSTRACT: The performance of concrete made from recycled aggregate that produced by pulsed power technology due to the use of fly ash has been studied. Pulsed power technology has been proven to reproduce high quality recycled aggregate. Concrete made from 100% recycled coarse aggregate by pulsed power discharge can reach similar compressive strength to natural coarse aggregate concrete. The use of JIS type II fly ash as cement replacement of 25% and 50% mass without adjustment of water to cement ratio can reduce the compressive strength of concrete. However, with the same fly ash percentage, in 28 day of age, concrete made from recycled aggregate by pulsed power technology results better strength by 10.0% and 15.8% compared to natural aggregate concrete for 25% and 50% of fly ash, respectively. In addition, mixing method using two-stage mixing approach (TSMA) has been applied to improve concrete strength. This method in making recycled aggregate concrete can improve the strength of fly ash concrete made from recycled aggregate concrete up to 4.7%. Replacing 25% of cement mass with fly ash for concrete made from recycled aggregate by pulsed power technology has shown preferable result in strength, and can be improved by using TSMA method in mixing process.

Keywords: Recycled Aggregate, Pulsed Power Technology, Fly Ash, Two Stage Mixing Approach

1. INTRODUCTION

Nowadays, more than 20 billion tons of concrete has been consumed annually in the world and become the most widely used construction material [1], [2]. Along with this fact, the use of concrete as construction material also causes environmental problems such as CO2 emission due to cement production, resource depletion and waste problem.

Since aggregate is the most material needed to produce concrete, concrete recycling in producing aggregate is one of the keys to support environmental conservation. It can reduce the use of natural resources and waste disposal, as 40% of all industrial waste is construction and demolition waste [3].

Many studies on the use of recycled aggregate in concrete production have been attempted. It is well reported that recycled aggregate concrete has lower quality compared to natural aggregate concrete in strength and durability [4]-[10]. Recycled aggregate contains mortar from the original concrete which made it more porous and absorptive than many natural aggregates. Therefore, the use of recycled aggregate is mainly confined to low-grade applications [11]-[13]. Whereas in Japan, from 2006, 98% of concrete waste has been recycling to be reused as recycled aggregate for road sub-base, underground stabilization and non-structural concrete [14], [15].

The technology to reproduce high quality recycled aggregate from concrete waste has been developed using pulsed power discharge. It can remove the mortar from the aggregate thoroughly. It was found that the coarse aggregate reproduced by electric pulsed discharged energy of 640 kJ has sufficient qualities of the density in oven dry condition and the water absorption to satisfy the JIS (Japan Industrial Standard) regulation class H (A5021) [14], [16], [17]. Therefore, the application of recycled aggregate concrete by pulsed power technology is found to be promising.

In addition, it has been reported that the production amount of coal ash in Japan exceeded over 10 million tons. This amount is expected to increase due to new construction and expansion of coal-fired power station. However, the relative amount of fly ash in use for concrete is low as compared with the case used for raw material in the cement manufacturing process [18], [19]. Fly ash as cement replacement positively impacts the durability and workability of concrete [20]-[23]. As partially cement replacement, high volume of fly ash decreased the 28 day strength of concrete, but improved at age over than 90 days [24]. Moreover, the use of fly ash in recycled aggregate concrete significantly improves the resistance to chloride ingress [25]. Utilization of fly ash as a supplementary cementitious material can promote sustainable construction by reducing the CO_2 emission of cement production.

In order supporting utilization of recycled aggregate which has low quality, Tam et al. proposed a two-stage mixing approach (TSMA) for improving the strength and rigidity of recycled aggregate concrete [26]. The principle process for the TSMA is initially coating the recycled aggregates with cementitious paste to improve the uniformity and strength of the interfacial transition zone. Mixing process is divided into two parts with required water proportionally split and added at different mixing time. Initial water used for formation of thin layer of cement slurry on the surface of recycled aggregate and fill up old cracks and voids [26]-[28]. It is reported that around 25-40% of recycled aggregate substitution provides optimum strength using TSMA [12]. Furthermore, deformation and permeability of recycled aggregate concrete can be enhanced by adopting TSMA and proved to be an effective method for increasing durability of recycled aggregate concrete [27]. Following up the study on TSMA, several researchers have reported that the workability of recycled coarse aggregate concrete is similar to the natural aggregate concrete and compressive and splitting tensile strength of the recycled aggregate concrete which are specifically required in the construction of airfield concrete pavements [29]. Moreover, initial moisture states of recycled aggregate strongly give influence to the strength and shrinkage of recycled aggregate concrete with two-stage mixing method [30].

To support the environmental conservation in creating sustainable construction and improving the performance of recycled aggregate concrete, research on the strength of concrete made from recycled aggregate by pulsed power technology due to the use of JIS type II fly ash as cement replacement and different mixing approach were conducted.

2. PRODUCING RECYCLED AGGREGATE BY PULSED POWER TECHNOLOGY

These recent years, pulsed power technology has been developed to reproduce a high quality recycled aggregate from concrete waste. In this method, pulsed electric discharges are generated inside concrete underwater. The concrete waste is placed on the hemisphere mesh of 5mm as low voltage electrode and discharged by high voltage electrode [14]. Fig. 1 illustrates the process of crushing the concrete waste by pulsed power discharge method.

This technology crushes the concrete by dielectric breakdown of gas contained in concrete. The gas in concrete is ionized and changes state to plasma when pulsed electrical discharges are generated inside of concrete, since the dielectric breakdown level of the gas is lower than liquid and solid. Hence the cracks occur principally in the interfacial transition zone along each aggregate particle. The shock wave is generated by the volume expansion of changing to plasma at the same time. The shock wave propagates in concrete and divided into reflected wave and the penetration wave at the boundary of coarse aggregate and mortar. The tensile stress is generated by the penetration wave and the reflected wave which delaminate mortar from aggregate. After several times of discharge, this breakdown phenomenon of concrete waste generates recycled aggregate that completely separated from the mortar [14], [16], [17].

The quality of coarse aggregate reproduced by electric pulsed discharged energy of 640 kJ has sufficient oven dry density and water absorption rate to satisfy JIS (Japan Industrial Standard) regulation class H (A5021) [14]. The concrete consisted of recycled coarse aggregate also has enough compressive strength and Young's modulus to utilize as the construction material [16], [17].

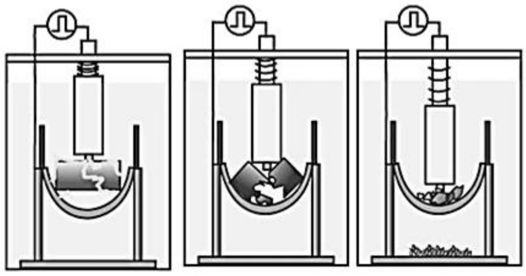

Fig. 1 Process of crushing the concrete waste by pulsed power discharged method

3. MATERIAL AND METHOD

3.1 Material

3.1.1 Aggregate

To investigate the performance of concrete made of recycled aggregate concrete, natural coarse aggregate, recycled coarse aggregate, and natural fine aggregate were used in concrete mix proportion. The natural coarse aggregate was used in concrete mix proportion as controlled specimen.

The recycled coarse aggregate were reclaimed from concrete waste by pulsed power technology. In this study, the discharge energy was set to 6.4 kJ with 180 times of discharge. The total discharge energy was 1152 kJ for 10 kg of concrete waste, or 115.2 kJ/kg. Fig. 2 shows the recycled coarse aggregate concrete used in this research.

Fig. 2 Appearance of recycled aggregate concrete by pulse power discharge.

The material properties of natural coarse aggregate and recycled coarse aggregate produced by pulsed power discharge used in the experiment are listed in Table 1. According to JIS (Japan Industrial Standard) regulation class H (A 5021) about recycled aggregate for concrete, the oven dry density is not less than 2.5 g/cm^3 and the water absorption is not more than 3%. Hence, the quality of recycled coarse aggregate used in the experiment has satisfied JIS (Japan Industrial Standard) regulation class H (A 5021) for high quality recycled aggregate, even though it was degraded by substances of mortar, paste and powder.

Table 1 Recycled coarse aggregate physical properties

Properties	Recycled coarse aggregate	Natural coarse aggregate
Oven-dry density (gr/cm^3)	2.73	3.01
Water absorption (%)	2.64	0.63

The size distribution of the recycled coarse aggregate used in this study is given in Table 2. The fineness modulus of the recycled coarse aggregate produced by pulsed power technology reached 6.44.

Table 2 Sieve analysis of recycled coarse aggregate

Sieve size (mm)	Passing (%)
25 mm	100.0
20mm	97.4
15 mm	90.8
10 mm	57.4
5 mm	1.1

To compare the effect of using recycled coarse aggregate in concrete, the natural coarse aggregate was set to have similar size distribution as recycled coarse aggregate which consisted of 82% of fine gravel and 18% of gravel.

3.1.2 Cement and fly ash

Portland blast-furnace slag cement qualified for JIS R 5211 Type B was used in the experiment. Fly ash which satisfied JIS type II was used in this study as partial cement replacement. The properties of the fly ash are listed in Table 3.

Table 3 Properties of fly ash

Properties	Measurement value
SiO_2	56.6%
Hygroscopic moisture	0.2%
ig. Loss	1.2%
Density	2.36 g/cm^3
residue on sieve of 45μm	3%
specific surface (by Blaine)	4190 cm^2/g
percent flow	106%
Activity index (at 28 day)	92%
Activity index (at 91 day)	105%
methylene blue absorption	0.22 mg/g

3.2 Experimental Procedures

3.2.1 Mix proportion and mixing approach

The mix proportion and mixing approach in this experiment are described in Table 4. Since the recycled coarse aggregate in this study has satisfied the JIS regulation for high quality recycled aggregate Class H (A5021), therefore, the recycled coarse aggregate replaced the use of natural coarse aggregate by 100% with the maximum aggregate size of 20 mm. The water-cement ratio used in the experiment was 0.55 in all mixtures.

The percentages of fly ash used in the experiment to replace cement were 0%, 25%, and 50% by mass.

To compare the effect of different mixing approach to the performance of concrete, two types of mixing approach were used. Normal Mixing Approach (NMA) is the common mixing approach used to make concrete, where cement, sand, water and gravel are mixed in one stage. While Two-Stage Mixing Approach (TSMA) divides the addition of water in two steps. In this approach, fine aggregate and coarse aggregate are mixed with half of the water, and in the next stage, cement and the remained water are mixed.

Table 4 Concrete mix proportion and mixing approach

Mix ID	Water (kg/m^3)	Fly ash (%)	Cement (kg/m3)	Fly ash (kg/m^3)	Gravel (kg/m^3)		Sand (kg/m^3)	Mixing Approach
					NCA	RCA		
NCA-NMA-0	186	0	338.1	0	1061.8	0	741.7	NMA
NCA-NMA-25	186	25	253.6	84.5	1061.8	0	741.7	NMA
NCA-NMA-50	186	50	169.0	169.0	1061.8	0	741.7	NMA
RCA-NMA-0	186	0	338.1	0	0	959.5	741.7	NMA
RCA-NMA-25	186	25	253.6	84.5	0	959.5	741.7	NMA
RCA-NMA-50	186	50	169.0	169.0	0	959.5	741.7	NMA
RCA-TSMA-0	186	0	338.1	0	0	959.5	741.7	TSMA
RCA-TSMA-25	186	25	253.6	84.5	0	959.5	741.7	TSMA
RCA-TSMA-50	186	50	169.0	169.0	0	959.5	741.7	TSMA

Notes: NCA = Natural Coarse Aggregate; RCA = Recycled Coarse Aggregate; NMA = Normal Mixing Approach; TSMA = Two Stage Mixing Approach

3.2.2 Specimen casting and curing

Cylinder specimens with diameter of 100mm and height of 200 mm were made to investigate the compressive strength according to ISO 1920-8:2009 (E) [31]. 24 hours after casting, the specimens were removed from the mold and cured according to ISO 1920-3:2004 (E) [31]. The cylinder specimens were cured in water at temperature 20^{o}C ± 2^{o}C before their compressive test conducted.

4. RESULT AND DISCUSSION

4.1 Properties of Fresh Concrete

Slump test is the most common method to determine the consistence of fresh concrete. In this study, determination of slump of fresh concrete for each case was conducted according to ISO 1920-2:2005 (E) [32]. In addition, air content was performed to measure the total air content in a sample of fresh concrete.

Table 5 Concrete fresh properties

Mix ID	Slump (cm)	Air content (%)
NCA-NMA-0	7.4	0.6
NCA-NMA-25	17.4	0.8
NCA-NMA-50	16.5	0.8
RCA-NMA-0	10.3	0.9
RCA-NMA-25	17.4	0.8
RCA-NMA-50	18.7	0.8
RCA-TSMA-0	13.7	0.9
RCA-TSMA-25	10.1	1.2
RCA-TSMA-50	13.5	1.2

Concrete fresh properties in this study are presented in Table 5. It shows that the use of recycled aggregate was not significantly influence its slump and air content compared to natural aggregate concrete. Moreover, the results of concrete slump showed that fly ash as partially cement replacement increased the workability of fresh concrete. Nevertheless, the utilization of fly ash did not show significant effect in air content of fresh concrete. Compared to concrete produced by normal mixing approach, two-stage mixing approach in producing concrete showed higher air content.

4.2 Properties of Hardened Concrete

4.2.1 Compressive Strength

The compressive strength test was performed at age 7, 28, and 56 day. Fig. 3, Fig. 4, and Fig. 5 illustrate the effect of fly ash as cement replacement to the compressive strength of concrete made from natural coarse aggregate using normal mixing approach, recycled coarse aggregate using normal mixing approach, and recycled coarse aggregate using two-stage mixing approach, respectively. The results showed that compressive strength of concrete was decreased by the use of fly ash as cement replacement in all cases.

Fig. 3 shows the effect of fly ash on the strength of natural coarse aggregate concrete. In early age of concrete, the use of fly ash as cement replacement has shown significant reduction in compressive strength of natural aggregate concrete. With 25% of fly ash to replace cement, the 28 day compressive strength was reduced by 16.6%, while 50% of fly ash significantly reduced the compressive strength by 55.8%. In the 56 day compressive strength, 25% of fly ash has shown

15.1% reduction, and the 50% of fly ash reduced its compressive strength by 49.4%.

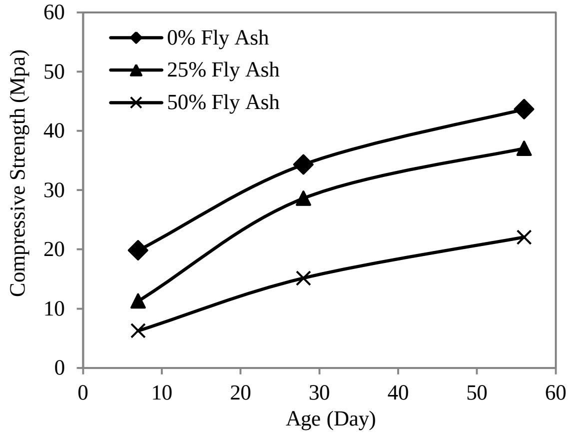

Fig. 3 Compressive strength of specimens made of natural coarse aggregate

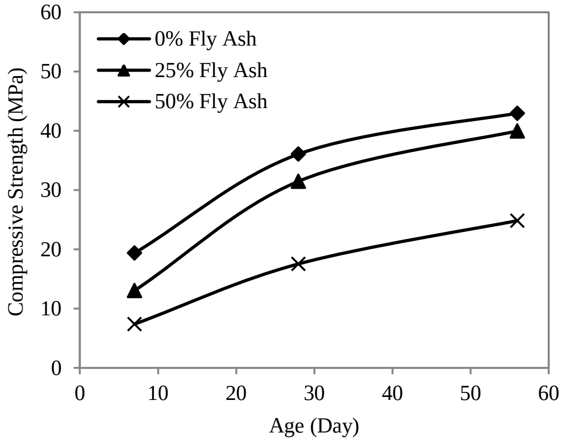

Fig. 4 Compressive strength of specimens made of recycled coarse aggregate using normal mixing approach

The effect of fly ash on the strength of concrete made from recycled aggregate by pulsed power technology is shown by Fig 4. Similar to natural aggregate concrete, in early age of concrete, the use of fly ash has shown significant reduction in compressive strength. With the increasing of concrete age, the use of fly ash in recycled aggregate concrete showed a decrease in strength reduction. In 28 day of age, compressive strength of recycled aggregate concrete with 25% of fly ash was reduced by 12.7%, and continued decreased to 7.0% in 56 day of compressive strength. These results were contrast with the recycled aggregate concrete using 50% of fly ash as cement replacement. It significantly decreased the strength by 51.3% in 28 day of age, and 42.2% in 56 day of concrete age.

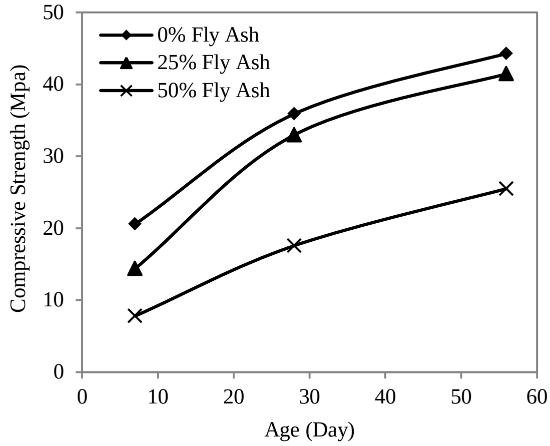

Fig. 5 Compressive strength of specimens made of recycled coarse aggregate using two stage mixing approach

Fig. 5 shows the effect of fly ash on the strength of recycled aggregate concrete using TSMA method. Although at early age of concrete showed significant reduction in strength, TSMA has shown less reduction in strength compared to NMA in producing recycled aggregate concrete. By replacing 25% of cement mass with fly ash, the compressive strength was reduced by 8.1% in 28 day of concrete age, and 6.4% in 56 day of concrete age. However, 50% of fly ash to replace cement shown similar results to recycled aggregate concrete with NMA method. It reduced the compressive strength by 51.0% and 42.4% in 28 day and 56 day of concrete age, respectively.

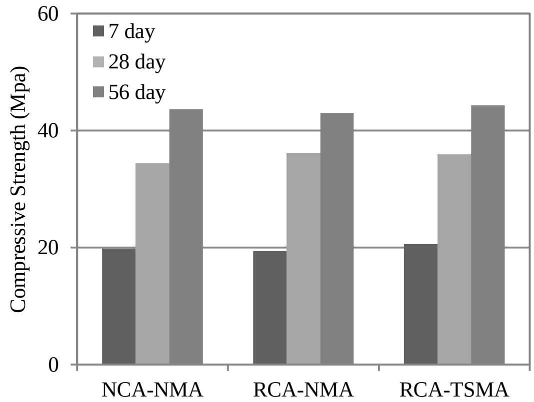

Fig. 6 Compressive strength of specimens without fly ash

Fig. 6, Fig. 7, and Fig. 8 illustrate the effect of different mixing approach to the compressive strength of concrete. Fig. 6 shows that the compressive strength of concrete made from

100 % recycled aggregate by pulsed power technology was not significantly differ from the concrete made from natural coarse aggregate without fly ash. This figure emphasizes that pulsed power can produce high quality recycled aggregate. Fig. 6 also indicates that TSMA in producing recycled aggregate concrete was not significantly affect the compressive strength of concrete made from recycled aggregate by pulsed power technology without fly ash.

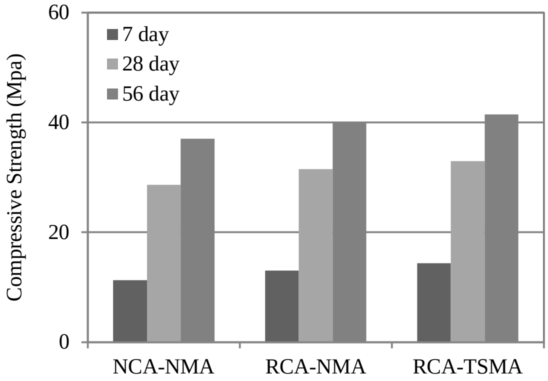

Fig. 7 Compressive strength of specimens with 25% of fly ash as cement replacement

Compressive strength of concrete with 25% of fly ash as cement replacement is shown in Fig. 7. It showed that by using fly ash, concrete made from recycled aggregate by pulsed power indicated higher compressive strength by 10.0% compared to natural coarse aggregate concrete. Moreover, two-stage mixing approach improved 4.7% strength of recycled aggregate concrete in 28 day of concrete age and performed highest compressive strength. In 56 day of age, the recycled aggregate concrete showed 7.9% higher compressive strength than that of natural aggregate concrete, and improved by 3.7% by using TSMA. It clarifies that TSMA improved the compressive strength of recycled aggregate concrete.

Comparing the compressive strength of concrete made from recycled aggregate and using TSMA method, Fig. 8 has shown same trend as Fig. 7. By 50% of cement mass replacement with fly ash, concrete made from recycled coarse aggregate by pulsed power technology performed higher compressive strength by 15.8% compared to that of natural aggregate concrete, and slightly improved by the using TSMA method by 0.1% in 28 day of concrete age. While in 56 day of age, the recycled aggregate concrete showed 12.6% higher compressive strength than that of natural aggregate concrete, and improved by 2.6% by using TSMA.

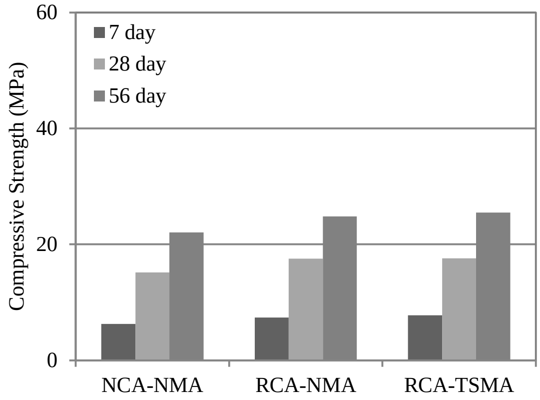

Fig. 8 Compressive strength of specimens with 50% of fly ash as cement replacement

5. CONCLUSION

Compressive strength of recycled aggregate concrete produced by pulsed power technology were investigated to characterize the effect of JIS type II fly ash as cement replacement and different mixing approach to the performance of concrete. The following conclusions are drawn from the test result:

1. Pulsed power technology has been proven to reproduce high quality recycled aggregate. Concrete made from recycled coarse aggregate can reach similar compressive strength to that of natural coarse aggregate concrete without fly ash. While in using fly ash as cement replacement, concrete made from recycled aggregate by pulsed power technology showed higher compressive strength by 10.0% and 15.8% in 28 day of age for 25% and 50% of fly ash, respectively, compared to that of natural aggregate concrete.
2. The use of fly as cement replacement increased the workability of concrete but shown insignificant effect in air content of fresh concrete. The utilization of fly ash without adjustment in water to cement ratio reduced the compressive strength of concrete.
3. Two stage mixing approach has shown an improvement in compressive strength of the recycled aggregate concrete with fly ash. It improved the compressive strength of fly ash concrete made from recycled aggregate by 4.7% and 3.7% in 28 day and 56 day of concrete age, respectively, for the use of 25% fly ash for cement replacement. While in 50% of fly ash percentage, it showed less

improvement of 0.1% and 2.6% in 28 day and 56 day of concrete age, respectively.

4. Replacing 25% of cement mass with fly ash for concrete made from recycled aggregate by pulsed power technology has shown preferable result in strength, and can be improved by using TSMA method in mixing process.

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