International Journal of GEOMATE, Nov., 2020, Vol.19, Issue 75, pp.66-75
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2020.75.84833
Geotechnique, Construction Materials and Environment

QUALITY EVALUATION OF PULSED POWER RECYCLED SAND BY ELECTRICAL RESISTIVITY METHOD

*Rahimullah Habibzai[1] and Mitsuhiro Shigeishi[2]

[1,2] Faculty of Advanced Science and Technology, Kumamoto University, Japan

*Corresponding Author, Received: 10 April 2020, Revised: 20 June 2020, Accepted: 16 July 2020

ABSTRACT: Construction and Demolition (C&D) wastes, inclusively concrete, establishes a major portion of total solid wastes produced in the globe. Regeneration of recycled aggregates from concrete wastes is a promising technique to mitigate the over-exploitation of natural sand and make waste concrete as a source for aggregates. This study mainly discusses the production of recycled fine aggregates from concrete wastes by electric pulsed power discharge method and it's evaluation with other natural and artificial fine aggregate. Specimens were prepared from both pulsed power recycled sand and virgin sand. The water absorption of pulsed power recycled sand was tested regarding virgin Fine Aggregates (FA) by the electrical conductivity method. The water absorption of recycled sand progressed rapidly during the initial stage of the water absorption test. Besides the pulsed power recycling technique, it is more effective compared to other recycling methods, it produced high-quality fine aggregate with a reduced amount of powder. The compressive and tensile strengths of the mortar produced from pulsed power recycled sand were also approximately identical to mortar made of virgin sand. The mechanical properties of mortar made from pulsed power sand are satisfied and relevant to be utilized in the construction industry. It was confirmed in the pulsed discharge method, that the recovered aggregate could be reduced by giving a large number of discharges, but the cement paste portion could be almost removed.

Keywords: Recycled aggregate; Recycled fine aggregate; Electric pulse power technology; Physical properties of recycled aggregate, Construction and demolition waste

1. INTRODUCTION

Aggregate makes up to 70-80% of the total volume of concrete mix design, so the overall consumption of natural aggregate resources is rapidly increasing and produces an enormous load on the environmental ecosystem [1,2]. The protection of natural aggregates resources and the development of maintainable construction industry are very important socio-economic issues.
To achieve these goals, one of the best solutions is to reuse recycled aggregate in the construction industry. This recycled aggregate can be used as a replacement for natural aggregate to manufacture concrete [3-8].

The anticipation of expectation shows that the global demand for concrete will raise to approximately 18 billion tons (about 7.5 billion cubic meter) a year by 2050 [9,10]. The global increasing population and disposal of construction wastes are of strategic issues in the construction industry sector. The primary reasons behind this strategic issue are the extreme growth of urbanization, industrialization along with natural and man-made disasters.

Construction and Demolition (C&D) waste inclusively concrete, establishes a major portion of total solid waste produced in the world. Recycling of waste and demolished concrete contribute to reducing the total environmental burden of the infrastructure sector. Reduction of the natural sand and over-exploitation, as well as disposal of construction and demolition wastes, have a negative impact on the sustainability of the construction industry. Therefore, effective recycling technology is highly significant to generate recycled aggregates from concrete waste. To make waste concrete as a source of aggregate for the production of mortar, concrete, and various application in the construction industry.

Regarding mitigating the amount of wastes, a larger fragment of these materials could be recycled into making concrete and mortar. This mechanism not only reduces landfills, but preserve the natural resources too [11-16]. Concrete industry consumes around 36.071 million tons of solid and liquid materials all together. An immense quantity of construction and demolishing wastes are produced throughout the entire duration of a building. Building wastes and demolition occupies 20-40% of the city's total waste [17].

The existing raw materials are vastly consumed by the construction industry. The utilization rate is almost 50%. Besides, construction activities create 50% of total solid waste and consume 40% of total energy [18]. The building industry substantially affects the environment in terms of unstable waste production, depletion of natural resources along with potential sewage and energy consumption [19].

One of the key reasons for recycling waste concrete is re-utilization of the concrete rubble as aggregate in concrete [20,21]. It is estimated that millions of tons of waste concrete are produced every year around the globe. The demolition of old structures and the destruction of buildings during natural and man-made disasters generate an enormous amount of solid waste. Removal of useless concrete from structures, buildings, and road pavements generates concrete waste. The testing of concrete cylinders and prisms specimens is another source of concrete waste [22,23].

Demolished concrete is normally transported to landfills for disposal, but because of larger environmental awareness, the concrete is being recycled for re-use in concrete works. There are multiple advantages in recycling waste concrete rather than dumping or burying it in a landfill. Keeping concrete debris out of landfills saves the space. They can be used as local product sources, to mitigate truck traffic and substitute to a non-renewable resource. Other benefits are cost savings and no need for disposal fees [24,25]. Concrete recycling is coordinated and often mandated in Japan, Canada, and Europe [26].

Recycled aggregate has some undesirable properties such as higher water absorption value, less impact resistance as well as crushing strength, and specific gravity compared to virgin aggregates.

In most developing countries after the demolition of old roads and buildings, the removed concrete is often considered worthless and disposed of as demolition waste. The breaking-up process of used concrete creates Recycled Concrete Aggregate (RCA). To utilize such recycled aggregate in structural concrete, the majority of studies have mostly concentrated on the coarse fraction and ignored the fine fraction. This is principally because the extreme porosity of fine recycled materials leads to reductions in the performance of any composites containing them [27].

Various techniques are discovered to reclaim recycled aggregate from the waste concrete. Lately, revitalization recycled technologies for concrete have been developed in Japan. For example, a mechanical grinding technique, which is used to collect high quality, recycled aggregate. However, the collected, recycled aggregate is a little damaged and a huge amount of powder is generated through grinding action.

The mechanical grinding technique contains two basic demerits. First, the recycling cost of aggregate is extremely high. Secondly, the recycled operation system is complex. Meanwhile, the size of the recycled operation system is very large. Considering these key facts, the new recycling technology for waste concrete scraps is of high significance in Japan. Pulsed power has been proven to produce recycled coarse aggregate with high quality because the mortar can be separated from aggregate thoroughly [28].

In this study, based on previous research, an advanced recycling method is proposed and discussed which can separate and collect recycled aggregate from waste concrete, without deterioration of its fundamental qualities. Compared to other recycling techniques, pulse power discharge greatly reduce the amount of residual mortar adhered to the aggregate, avoids damage to the aggregate, and mitigates the problem of generation of fine dust [29].

The main goal of the current research is to investigate the quality of pulsed power fine aggregate in terms of physical properties and mechanical properties of mortar made of it. Besides, the electrical conductivity method is used to evaluate the physical properties such as water absorption in comparison to other types of sands.

The result of this study will give the scholars and readers a modern knowledge about how to reclaim medium quality recycled fine aggregates from waste concrete and coarse recycled aggregate. Particularly, how to evaluate its physical and mechanical properties. The medium quality of aggregate is described in (JIS 2012a), JIS A 5022:2012. This research paper will contribute to manage concrete debris, promote hard work and determination in the achievement of this career. This will also provide knowledge to the contractors and developers on how to promote recycling methods for sustainability and services related to the construction industry, in terms of obtaining recycled fine aggregate and their quality evaluation as well to substitute recycled concrete debris with fine aggregate in a concrete mix. They can achieve a better product performance such as promising mechanical properties and durability.

2. PREVIOUS RESEARCH ON PULSED POWER RECYCLED AGGREGATE

To utilize an alternative method, some research works have been done to generate recycled coarse aggregates for matching to current standards. They have considered the proper choice of the crushing process. Google scholar, Yanagibashi et al reported that by using an eccentric rotor mill such that the rubbing action among the aggregates is increased, the adhering mortar is more readily separated from the stone particles. Principally, it targets to reclaim the natural aggregates used in the original concrete. Recycled coarse aggregates produced in this way were found to meet the Japanese Standard JIS A 5005. Such RA requires that the particle density should not be less than 2450 kg/m^3 and water absorption not greater than 3% [30]. The quality of Recycled Aggregate (RA) concrete having 100%

coarse RCA got improved by using pozzolanic and sodium silicate solution as new treatment solutions. At 20% concentration of sodium silicate and silica fume, the compressive strength of RAC could improve up to 36% [31].

Recently in Japan, renewal recycled technologies to produce recycled aggregate from waste concrete have been developed. The coarse aggregates re-generated by using the electrical pulsed power discharge energy of 640 kJ, contains the sufficient qualities of water absorption value and dry density.

This RA fulfills the Japan Industrial Standard regulation class H (A5021). Also, their essential mechanical properties like compressive strength and Young's modulus were enough to use generated coarse recycled aggregate as construction material.

During crushing mortar and aggregate up to 5mm or less, these particles are dropped in the bottom of the water tank by pulsed discharge. These residues are categorized into recycled fine aggregate and powder. It was found that the water absorption ratio of fine recycled aggregate was high and they had low density. The pulse power technology produces a very huge amount of stored energy at once. The pulse electric discharges are generated inside of concrete underwater. With the help of the dielectric breakdown of gas and as a result, the solid concrete is crushed. In previous research for crushing waste concrete scraps the pulse power production device, Marx bank was used [32]. There were ten capacitors parallel connected and charging. The electrical pulse is discharged in series. Depending on the charge voltage and capacitor, the discharge energy is released.

Previous research investigated capacitance, generated voltage, and several pulses along with an amount of energy to consume them in pulse discharge generation devices. Consequently, optimum processing parameters to decompose concrete masses were obtained for separation and recovering high-quality RCA for concrete class H. The energy per pulse was set to 1.6 kJ, and 160 pulses were applied to the concrete mass. Recycled coarse aggregate that was recovered, satisfied the oven-dry density and water absorption quality standards for concrete class H, whereas minimizing the applied energy [33].

Another advanced concrete recycling technology for the promotion of recycling concrete has been developed. It works based on heating and rubbing method. A subsidy for high-quality recycled aggregate and a carbon tax was found to be effective ways for the development of the early introduction of the technology. A series of analysis for examining appropriate recycling system focusing on the cement and concrete industry as well as the applicability recycling technology [34].

3. EXPERIMENTAL PROGRAM

3.1 Materials

The recycled coarse aggregate was produced from parent concrete specimens that were manufactured in laboratory. The physical properties of concrete constituent materials and mixture design are listed in the following Table 1 and Table 2.

Table 1 Mix proportion of parent concrete

W/C (%)	62.5	Sand-2 (Kg/m^3)	260
S/A (%)	47.6	Gravel-1 (Kg/m^3)	472
Water (Kg/m^3)	183	Gravel-2 (Kg/m^3)	481
Cement (Kg/m^3)	293	Ad (Kg/m^3)	2.93
Sand-1 (Kg/m^3)	588		

Table 2 The physical properties of parent concrete constitutes

C	Ordinary Portland Cement
S1	Natural land sand, saturated surface dry density = 2.60 gr/cm^3 Water Absorption = 1.13%
S2	Natural crush sand, saturated surface dry density = 2.68 gr/cm^3 Water Absorption = 0.91%
G1	Natural crush gravel, saturated surface dry density = 2.65 gr/cm^3 Water Absorption = 0.85%
G2	Natural crush gravel, saturated surface dry density = 2.76 gr/cm^3 Water Absorption = 0.61
Ad1	Chemical admixture of water reducer

The specimens of cylinder containing 100 mm diameter and 200 height were prepared, cured, and kept wet for 28 days under the standard room temperature (20±2 ℃, relative humidity 50%). They were demoulded after 28 days for testing.

3.2 Testing

3.2.1 Discharge treatment system for concrete coarse recycled aggregate

Fig.1 shows the pulse power generator device Marx bank-type which consists of capacitors. Besides, Fig.2 illustrates the schematic diagram of the electrical pulse power system [35]. The big steel cylinder is used for crushing samples.

Fig.1 Pulse Power Marx bank-type device

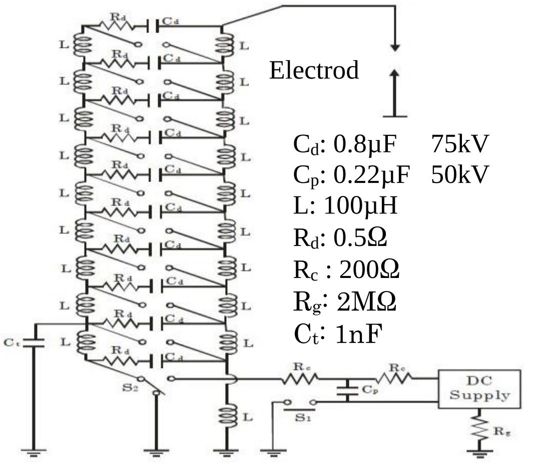

Fig.2 Schematic diagram of the pulse power system

A hemisphere mesh made of stainless steel was used as an electrode. The diameter of holes related to stainless mesh was 2.5mm and immersed in tap water as shown in Fig.3 and Fig.4. The positive pulsed voltage from the device was applied to the point electrode and the hemisphere electrode was grounded.

Fig.3 Stainless steel 2.5 mm sieve and point electrode

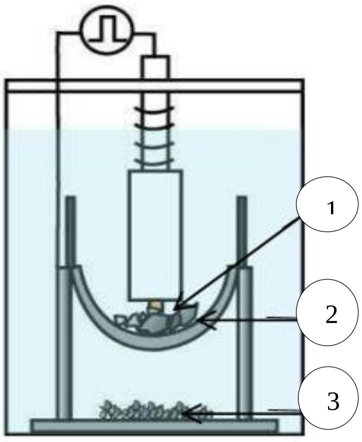

Fig.4 Schematic diagram of crushing recycled coarse aggregate over 5mm.
1. Stainless steel mesh 2.5mm in size 2. Recycled aggregate over 2.5mm and 3. Residues under 2.5mm with extracted powder.

The smaller particles and separated mortar portions smaller than 2.5mm were dropped from the hemisphere electrode and bigger ones remained during monotonous discharge treatment of coarse recycled aggregate.

3.2.2 Experimental procedure

The Pulsed power discharge is a unique technology in which energy is accumulated over a relatively long period and then discharged in short pulses with a controllable repetition rate, thus increasing its instantaneous power [36] For discharging treatment, we put each time 2 Kg of recycled coarse aggregate in stainless 2.5mm mesh and applied continuously 200 pulse shot through point electrode connected with the main device. Per shot 10 KJ energy was consumed. The dropped particles were collected for further process of the physical properties tests such as water absorption, density, and water loss. These properties were compared with natural and artificial FA. Finally, the FA was used to produce mortar.

3.3 Electrical Resistivity Test Method

For the proposed electrical conductivity test method, a cell with semi-spherical and rectangular-shaped cross-sections were used to avoid the right angles that could cause misrepresentation in the measurements. The containers were fabricated using non-absorbent insulating material. The half-spherical shape device was fabricated as an open-top with 84mm height, radius of curve portion 80 mm, and length of 164 mm, respectively. However, the rectangular-shaped device was fabricated with 100mm length, 40 mm width, and 40mm height, respectively. They were made of polyvinyl chloride (PVC), Polypropylene with 2 mm thickness. Two small copper panels with 1.5mm thickness were installed on longitudinal corner sides of the container to work as electrodes and keep the aggregate particles have enough contact.

A representative sample from recycled fine aggregate, mountain sand, and blast furnace slag were collected of around 3 kg. They were saturated by immersion in water for 24 hours. Then, the samples were placed into the cell in two layers, compacting the first one with 10 hits and the second one with 15 hits. The tamper indicated in ASTM C128 [37] was used for compaction.
The filling procedure was completed by making the surface even and removing the exceeding material. Immediately after the electrical measurement, approximately 300 g of material from inside the cell was sampled and weighed. This sample was dried in an oven at 110 ± 5 ˚C until constant weight. The procedure was repeated for different moisture contents as the sample was progressively dried. Three electric resistance values in the surface-wet range and three values in the surface-dry range were plotted on a diagram in which the x-axis (in arithmetic scale) represents moisture content in percentage (%) and the y-axis (in common logarithmic scale) represents electric resistance in ohm (Ω). Approximately the relationship between the electric resistance and water content was a straight line for each of the surface-wet and surface-dry ranges.

The water content corresponding to the intersection point of these straight lines refers to water absorption at the saturated surface dry condition. This is because the moisture condition immediately before the upsurge in the electric resistance as the sample condition changes from wet to dry, is assumed the saturated surface dry condition.

In addition to the resistivity method, the water absorption capacity of the mentioned fine aggregate was also determined according to the ASTM C128 method. Each reported value for this method is the average of three determinations by the same operator. Fig.5 and Fig.6 show the schematic diagram of the electrical resistivity method apparatus and graphical illustration respectively.
To find the accurate water absorption ratio of recycled fine aggregate, electrical conductivity (refer to 3.3 section) and ASTM C128 methods were used. Based on previous experimental findings, the electrical conductivity technique is a relevant method for calculating the water absorption content of recycled FA [38].

The water absorption in a different interval of time was determined and plotted. To make air-dried moisture state, the produced recycled fine aggregate was placed in an incubator until the target moister state is achieved. The temperature of the incubator was 55 ˚C in constant limit. Interval of time was determined and plotted. To make air-dried moisture state, the produced recycled fine aggregate was placed in an incubator until the target moister state is achieved. The temperature of the incubator was 55 ˚C in constant limit.

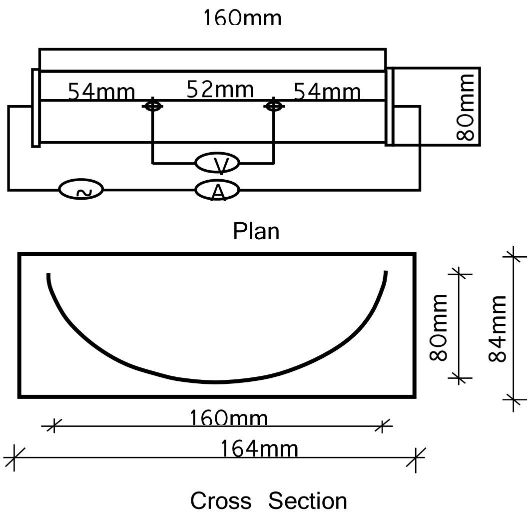

Fig.5 Schematic diagram of electrical resistivity method device

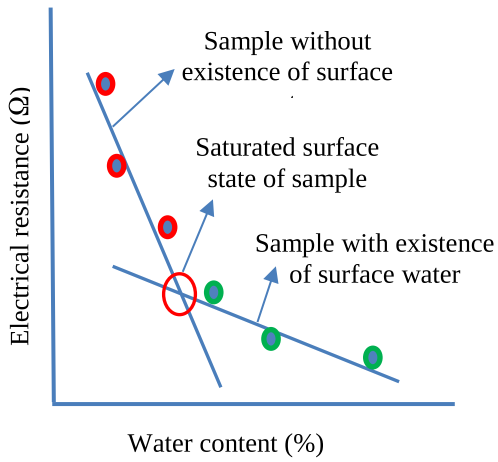

Fig.6 Graphical analysis of electrical resistivity method for fine aggregate samples

3.4 Mixture Design and Manufacturing of Mortar

The mortar mixes were prepared in two stages with the use of recycled fine aggregate and silica sand. Humid state (RHS = Recycled sand in the humid state), (SHS = Silica sand in the humid state) that was changed to a saturated surface dry state by deduction the surface water amount before mixing and air-dry, RODS (Recycled sand in the air-dry state), and SODS (Silica sand in the air-dry state). These proportions of the mortar mixes were designed using the absolute weight method. Adjustments were made according to the moisture contents and water absorption capacity of fine aggregates. Cement to sand ratio was considered 1:4, as it is a very traditional ratio for masonry construction work. The free water-to-cement (w/c) ratio was 0.55. Total 4 mortar mixes and 72 cylinders were prepared with different combinations of water in different moisture states. The cement amount was kept constant in all mixes to have equal effects on all types of specimens.

Table 3 shows a basic mixture design for mortar while Table 4 shows the modified version of mixture design. The cylinders were kept at standard room temperature (20±2 °C, relative humidity, 50%) for 28 days and then de-molded.

Table 3 Basic mixture design for mortar

Type of FA	W/C	Cement (gr)	Water (gr)	Sand (gr)
RHS	55	2263	1244	8951
RODS	55	2263	1244	8314
SHS	55	2263	1244	9057

Table 4 Adusted mixture design for mortar

Type of FA	W/C	Cement (gr)	Water (gr)	Sand (gr)
RHS	55	2263	1244	8951
RODS	83	2263	1878	8314
SHS	55	2263	1244	9057
SODS	62	2263	1405	8916

3.5 Compressive and Split Tensile Strength Test

The compressive and split tensile strength of the hardened mortars were determined at the ages of 7th, 14th and 28th day on cylinders with 100mm height and 50mm diameter by JIS A 1107, 1108, JIS A1113:2018 respectively. Total 72 cylinders such that three cylinders for each moisture state and tests (compressive and split tensile strength) were considered.

4. RESULT AND DISCUSSION

4.1 Physical Properties of Recycled Fine Aggregate

The results of the electrical conductivity and ASTM C128 standard methods for calculation of water absorption content related to RFA, Mountain sand, and blast furnace slag are presented in Table 5 and Table 6 respectively. The water demand for recycled sand is higher due to lower density, porous structure, and attached mortar.

Considering the dense structure of blast furnace slag sand and mountain sand, their water absorption was much lower compared to recycle sand, both in electrical resistivity and ASTM C128 standard method. Fig.7 indicates the result of the electrical conductivity method while Fig.8 shows the water absorption ratio of RFA in a different time interval. The water absorption rate was higher in the initial stage of the absorption testing process and reached a constant level after approximately one hour.

Table 5 water absorption of fine aggregate calculated by electrical conductivity method

Aggregate Type	Water Absorption (%)		
	1st	2nd	Mean
Mountain Sand	2.41	2.39	2.4
Recycled Sand	12.64	12.25	12.44
Blast Furnace Slag Sand	1.42	1.26	1.34

Table 6 water absorption of fine aggregate calculated by ASTM C128 method

Aggregate Type	Water Absorption (%)			
	1st	2nd	3nd	Mean
Mountain Sand	2.41	1.85	2.02	2.09
Recycled Sand	11.8	11.31	11.38	11.5
Blast Furnace Slag Sand	0.6	2	0.64	1.08

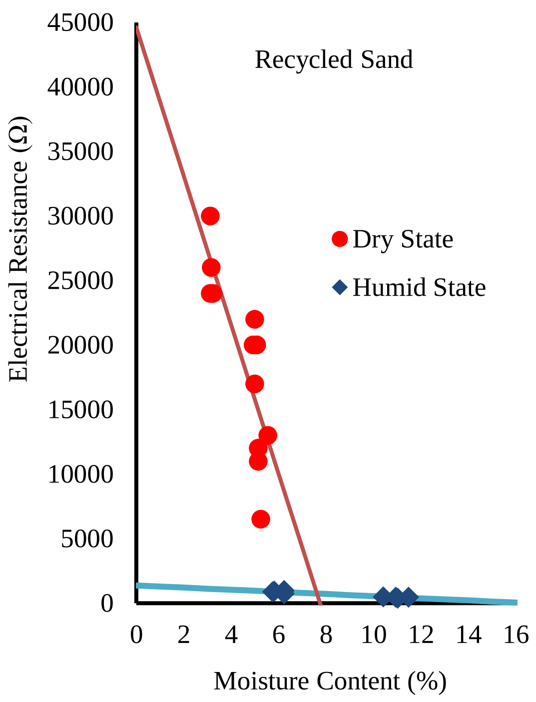

Fig.7 Electrical resistance test result for RFA

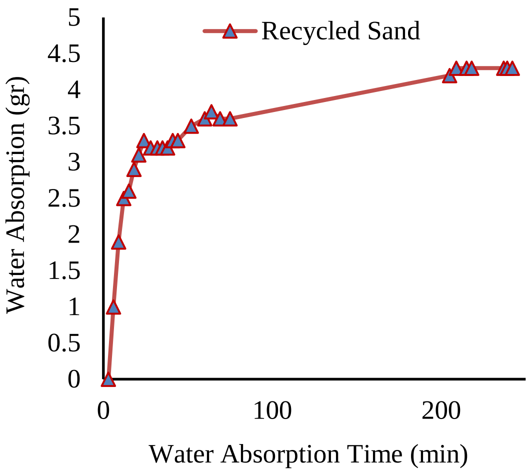

Fig.8 Water absorption of recycled fine aggregate in a different time interval

Fig.9 shows water loss (weight loss) of RFA in an incubator under 55 ˚C constant temperature. The particles started to dry soon in the startup of the drying process, which means water easily seeped out from a porous area of the interfacial transition zone (ITZ), but the water absorption in the core potion of particles was difficult to evaporate. The same phenomena could be applied to water absorption characteristics as well.

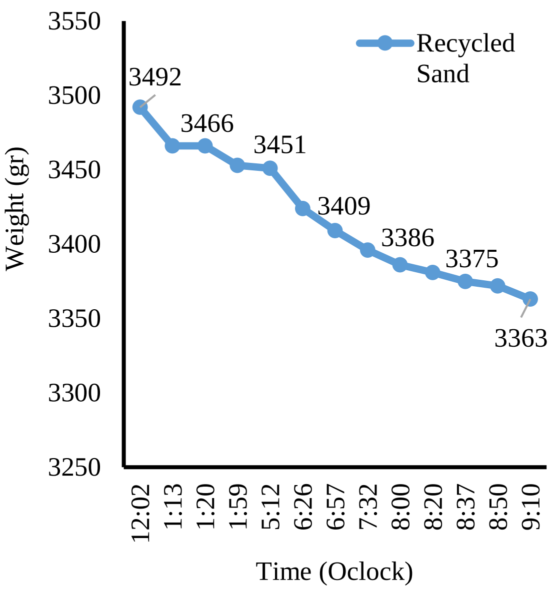

Fig.9 Water loss of RFA in a different time interval

4.2. Compressive and Split Tensile Strength

The compressive and split tensile strength of mortar mixes made of recycled fine aggregate and silica sand are shown in Fig.10, Fig.11, Fig.12 and Fig.13. The effects of the moisture states of fine recycled aggregate were different for a diverse combination of mixes. As water absorption to the core portion of the fine aggregate particle is more difficult and complex, therefore the extra added water was not absorbed thoroughly during mixing mortar and curing period of specimen.

The W/C ratio of RODS mortar was higher than RHS mortar, therefore compressive strength decreased. The mortar specimens made of high-quality dense silica sand, had higher compressive and split tensile strength compared to mortar specimens produced by recycled sand.

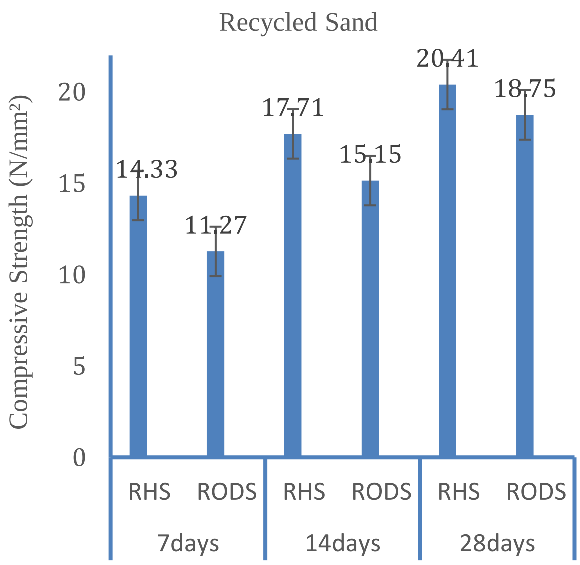

Fig.10 Compressive strength of RFA mortar at 7th, 14th and 28th days

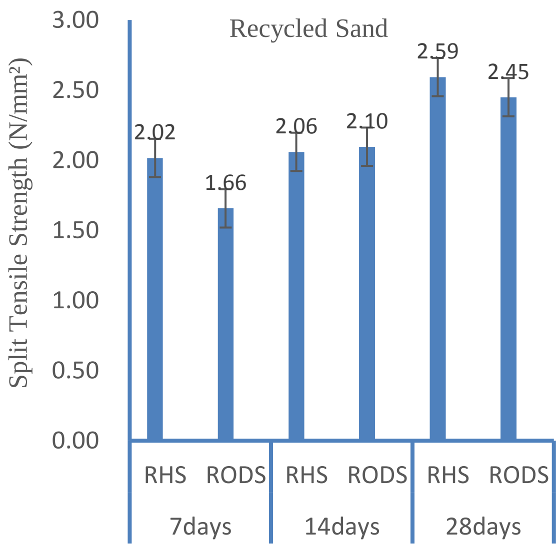

Fig.11 Split tensile strength of RFA mortar at 7th, 14th and 28th days

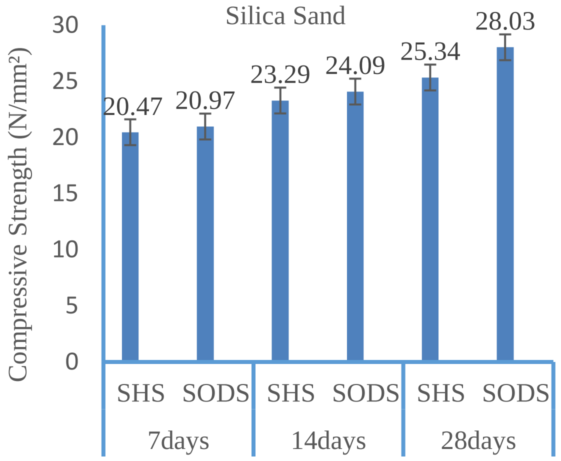

Fig.12 Compressive strength of silica sand mortar at 7th, 14th and 28th days

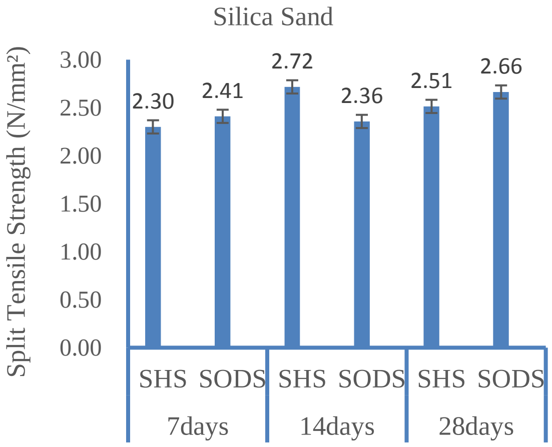

Fig.13 Split tensile strength of silica sand mortar at 7th, 14th and 28th days

The compressive and split tensile strength of SODS mortar specimens increased compared to SHS mortar specimens after 7, 14, and 28 days of curing. In contrast, the compressive strength of RODS mortar specimens decreased compared to RHS mortar specimens after 7, 14, and 28 days of curing.

5. CONCLUSION

5.1 Implication

Prior utilization of RFA brought by the advanced electrical pulsed power technology, its physical properties such as water absorption and density, compared to other natural and artificial fine aggregate, were investigated. Additionally, the mechanical properties of mortar specimens made of recycled sand and other fine aggregates were evaluated as well.

The mechanical properties of mortar made of pulsed power RFA are satisfied and relevant to be utilized in the construction industry.

5.2 Summary

The main findings of this research could be summarized as follows

1. Using electric pulse power technology is a more effective technique compared to other recycling methods in terms of generating high-quality fine aggregate with a reduced amount of powder.
2. The water absorption and water loss of FA progressed rapidly in the initial stages of absorption and drying process.
3. According to the electrical resistivity test result, the water absorption of RFA is higher than natural mountain sand and artificial blast furnace slag sand.
4. The recovered aggregate could be reduced by giving a large number of discharges, but the cement paste portion could be almost removed.
5. In the primary crushing pulse discharge technique, the recovery rate of RFA was reduced by discharging the concrete sample at a low output voltage, but the quality of the recovered aggregate was improved. On the other hand, in the secondary and tertiary crushing, when the discharge was performed at a high output voltage, a higher recovery rate and higher quality aggregate were recovered.

5.3 Recommendation

Based on the above research outcomes, as far as pulsed power discharge technique has been used to produce high-quality recycled aggregate from waste concrete, its application is proposed to extract the remaining adhered mortar from recycled coarse aggregate to produce fine recycled aggregate.
This unique technique mitigates the environmental burden, generation of fine powder, and save more space.Mortar specimens made from RFA with air-dry state compared to the humid state, had lower compressive and split tensile strength.
Using RFA in a humid state, had promising effects on compressive and split tensile strength of mortar specimens.Therefore it is proposed to utilize recycled aggregate in the humid state while producing mortar and concrete

6. ACKNOWLEDGMENTS

This research could not be accomplished without Dr. Takao Namihira and Mikiya Matsuda's advanced knowledge of high-voltage pulse power engineering and permission to use the research facility. Also, the authors would like to cordially thank Mr. Kosuke Nouchi, Mr. Yoshinori Toda, and Ms. Arisa Hamasaki for their valuable support during our research activities.

7. REFERENCES

[1] Meyer C., The greening of the concrete industry, cem concrete compos, 2009, 31 (8): pp.601-5.
[2] De Brito J., and Saikia N., Recycled aggregate in concrete: Use of industrial, construction and demolition waste. London, UK: Springer; 2013.
[3] Huda S.B., and Alam M.S., Mechanical behavior of three generations of 100% repeated recycled coarse aggregate concrete, Constr. Build. Mater. 65, 2014, pp.574-582.
[4] Pedro D., Brito de J., and Evangelista L., Influence of the use of recycled concrete aggregates from different sources on structural concrete, Constr. Build. Mater., 71, 2014, pp.141-151.
[5] Soares D., Brito J.de., Ferreira J., and Pacheco J., Use of coarse recycled aggregates from precast concrete rejects: mechanical and durability performance, Constr. Build. Mater. 71, 2014, pp.263-272.
[6] Thomas C., Setién J., Polanco J.A., Lombillo I., and Cimentada A., Fatigue limit of recycled aggregate concrete, Constr. Build. Mater. 52 2014, pp.146-154.
[7] Brand A.S., Roesler J.R., and Salas A., Initial moisture and mixing effects on higher-quality recycled coarse aggregate concrete, Constr. Build. Mater., 79, 2015, pp.83-89.
[8] Huda S.B., and Alam S.M., Mechanical and freeze-thaw durability properties of recycled aggregate concrete made with recycled coarse aggregate, J. Mater. Civ. Eng, 2015, 04015003. Concrete Structures and Materials, Vol. 4, No. 2, 2010, pp.113-118
[9] Naik T.R., Sustainability of concrete construction. Pract Periodical Struct Des Constr 2008, 13(2): pp.98-103.
[10] Mehta P.K., and Monteiro P.J.M., Concrete: microstructure, Building Materials 21, 2007, pp.1301-1310.
[11] Larrañaga M.E., Experimental study on microstructure and structural behavior of recycled aggregate concrete [thesis]. Universitat Politècnica de Catalunya; 2004.
[12] Xiao J., Xie H., and Zhang C., Investigation on building waste and reclaim in the Wenchuan earthquake disaster area. Resour Conserv Re-cycle, 2012, 61: pp.109–17.
[13] Chi-Sun P., and Chan D., The use of recycled aggregate in concrete in Hong Kong. Resources, Conservation and Recycling Vol. recycled concrete aggregates. Cement and Concrete Composites, 2010, 32(1):9 50, No. 3, 2007, pp.293-305
[14] Oikonomou N.D., Recycled concrete aggregates. Cem Concr Compos 2005; 27(2): pp.315-8.
[15] Topcu I.B., and Sengel S., Properties of concretes produced with waste concrete aggregate. Cem Concr Res 2004; 34(8): pp.1307-12.
[16] Amnon K., Properties of concrete made with recycled aggregate from partially hydrated old concrete. Cem Concr Res 2003; 33(5): pp.703-11.
[17] Xiao J.Z., Recycled Aggregate Concrete, China Architecture and Building Press, Beijing, 2008.
[18] Oikonomou N., Recycled concrete aggregates, Cement & Concrete Composites, 27, 2005, pp.315-318.
[19] Sadi K.M.A, Arham A., Sajoudi M.N., Mohd Firdaus B.M.K., Torshizi F., and Taherkhani R., Reduce, Reuse, Recycled and Recovery in Sustainable Construction Waste Management, Advanced Materials Research Vols. 446-449, 2012, pp.937-944.
[20] NSCP Section 703, Mortar and Grout, National Structural Code of the Philippines, National Bookstore, 2010.
[21] Ganiron Jr.TU.Jr., Sustainable management of waste coconut shells as aggregates in the concrete mixture, Journal of Engineering Science and Technology Review, vol. 6, no.5, 2013, pp.7-14.
[22] Ganiron Jr.T.U., An empirical investigation on end-users' acceptance of compressed lahar sediment blocks as wall panel, International Journal of ICT-aided, Architecture and Civil Engineering, vol. 1, no.1, 2014, pp.19-30.
[23] ASTM C 136-95a., Standard Test Method for Sieve Analysis of Fine and Coarse Aggregate, Annual Book of ASTM, International Standard Worldwide, 2009.
[24] ASTM C 172-90., Standard Practice for Sampling Freshly Mixed Concrete, Annual Book of ASTM, International Standard Worldwide, 2009.
[25] Ganiron Jr.TU., Sustainable management of waste coconut shells as aggregates in the concrete mixture, Journal of Engineering Science and Technology Review, vol. 6, no. 5, 2013, pp.7-14.
[26] Ganiron Jr.T.U., Waste tire as an asphalt cement modifier for road pavement, International Journal of U- and E-Service, Science and Technology, vol. 7, no. 5, 2014, pp.181-194.
[27] Evangelista L., and De Brito J., Durability performance of concrete made with fine

http://dx.doi.org/10.1016/j.cemconcomp., 2009. 9.005.

[28] Lizasa S., Shigeishi M., and Namihira T., Recovery of high-quality aggregate from concrete waste using the Pulsed Power Technology, Clean Technology, ISBN 978-1-4398-3419-0, www.ct-si.org, 2010.
[29] Shigeishi M., Separation and Collection of Coarse Aggregate from Waste Concrete by Electric Pulsed Power, Green Construction, and Engineering Education for Sustainable Future AIP Conf. Proc. 1887, 020077-1–020077-10; DOI: 10.1063/1.5003560.
[30] Kawano H., The State of Using By-products in Concrete in Japan and Outline of JIS/TR on Recycled Concrete using Recycled Aggregates"1st fib Conference, 2002. www.pwri.go.jp/eng/kokusai/conference/kawano01.pdf.
[31] Bui N.K., Satomi T., and Takahashi H., Enhancement of recycled aggregate concrete properties by a new treatment method. International journal of GEOMATE, Vol. 14, Issue 41, 2018, pp.68-76.
[32] Akiyama H., High voltage pulse power engineering., 2003.12, pp.95.
[33] Shigeishi M., Namihira T., Iizasa S., Ishimatsu K., Arifi E. and Amoussou R.I.H.D.T., Pulsed Power Application to Production of Recycled Aggregate. Third international conference on sustainable construction materials And technologies., 2013. www.claisse.inf/proceeding.htm
[34] Shima H., Tateyashiki H., Matsuhashi R., and Yoshida Y., An Advanced Concrete Recycling Technology and its Applicability Assessment through Input-Output Analysis, Journal of Advanced Concrete Technology, Vol. 3, No. 1, 2005, pp.53-67.
[35] Inoue S., lizasa S., Wang D., Namihira T., Shigeishi M., Ohtsu M., and Akiyama H., Concrete recycling by pulsed power discharge inside concrete, International Journal of Plasma Environmental Science and Technology, Vol. 6, No. 2, 2012.
[36] Hansjoachim B., Pulsed Power Systems: Principles and Applications. Berlin: Springer, 2006.
[37] ASTM C128-15, Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate, ASTM International, West Conshohocken, PA, 2015, www.astm.org
[38] JSCE-C506 (2003), Test method for density and water absorption of slag fine aggregate for concrete by measurement of electric resistance. Japanese Society of Civil Engineers, Tokyo, Japan.