Int. J. of GEOMATE, Sept., 2015, Vol. 9, No. 1 (Sl. No. 17), pp. 1403-1410
Geotech., Const. Mat. and Env., ISSN:2186-2982(P), 2186-2990(O), Japan

SEPARATION OF AGGREGATE FROM ASPHALT CONCRETE USING PULSED POWER TECHNOLOGY

Rétyce Ivan Hervé Dodji Togbé Amoussou, Koichi Ishimatsu, Nobuyasu Oyama and Mitsuhiro Shigeishi

Graduate School of Science and Technology, Kumamoto University, Japan

ABSTRACT: In this paper, authors propose a pulsed power application to separate aggregate from asphalt concrete. This study aims at extracting asphalt binder from asphalt concrete specimens using pulsed power technology and evaluating the quality of the asphalt concrete recycled aggregate and residues. Pulsed power was discharged into 5% asphalt content straight and modified asphalt concrete specimens. The results demonstrate that the extraction of modified asphalt binder from asphalt concrete is more difficult than that of straight asphalt and also requires more energy to produce approximately 1% asphalt content recycled coarse aggregate. Furthermore, the results suggest that recycled aggregate quality increases with increasing pulsed power energy.

Keywords: Pulsed power technology , Asphalt concrete, Modified asphalt, Recycled aggregate

1. INTRODUCTION

1.1 Background

In Japan, a considerable amount of construction waste consists of both ordinary and asphalt concrete while only half of the total amount of asphalt concrete waste is recycled as materials for surfaces, binder, or base courses [1].

Asphalt concrete is a composite material in which a bituminous material called asphalt cement binds coarse and fine aggregate, and filler. For road construction, either straight or polymer modified asphalt concrete can be utilized as binder. In the latter case, straight asphalt is modified to improve its binding properties with rubber or polymers incorporated into straight asphalt to improve resistance to rutting and cracking [2].

Asphalt concrete recycling has been promoted to satisfy the requirements to be cost-effective, environmentally responsible, and perform well. However, asphalt concrete recycling for modified asphalt pavement has some problems and does not lead to technical establishment.

While straight asphalt concrete is easily recycled relatively efficiently, recycled modified asphalt concrete presents problems of fatigue resistance [3]. Moreover, the incorporation of different types of asphalt concrete waste from various sources and the accidental mixing of debris cause inconsistencies and unpredictable behavior of recycled asphalt mixes.

Prevention of breakdown of recycling equipment during modified asphalt concrete recycling is essential [4]. Furthermore, the recycled asphalt mixture may be unpredictable and thus less durable due to the difficulty of mix design and the quality control by the reuse of modified asphalt waste.

Hence, implementation of asphalt concrete recycling methods that enhance quality of the recycled asphalt mixture by reducing the impact of deteriorated asphalt and modified asphalt binders is essential.

For ordinary concrete, the crushing processes to make recycling aggregate have been overcome by pulsed power discharge inside ordinary concrete waste to produce high-quality recycled coarse aggregate [5]. Reference [6] defined pulsed power discharge as a technique that spatially and temporally compresses and superimposes stored energy, thereby concentrating, controlling, and transmitting a large amount of power within a small space, for only a short time. This technique was less energy consuming and resulted in good quality aggregate that was as strong as the original aggregate to satisfy the JIS regulations for recycled coarse aggregate for concrete class H [7].

Unfortunately, to date, no study has investigated the applicability of pulsed power technology to recycle asphalt concrete.

1.2 Objectives

The current study is the first step of our proposed ideal polymer modified asphalt concrete recycling which final target is to separate polymer modified asphalt concrete into decomposed polymer modifier, base asphalt, filler, and recycled aggregate. This study focuses on an application of pulsed power technology to solve problems associated with asphalt concrete recycling, notably modified asphalt concrete. The objectives of the present study are asphalt binder extraction from asphalt concrete specimens using pulsed power technology and quality evaluation of the recycled aggregate and corresponding residues.

2. EXPERIMENT

2.1 Asphalt Concrete Specimens

Asphalt concrete specimens produced by Showa Rekisei Industries Co., Ltd. Kumamoto Mixture Factory, Kumamoto, Japan were approximately 1.2 kg of both straight and modified type H [8] asphalt concrete specimens (Fig.1). Those characteristics are shown in Tables 1, 2 and 3.

Fig.1 Asphalt concrete specimen

Table 1 Mix proportions of asphalt concrete specimens

Coarse aggregate	Fine aggregate and Filler	Asphalt
57.60%	37.40%	5%

Table 2 Properties of virgin aggregate

Aggregate types	Surface-dried density (g/cm^3)	Water absorption (%)	Dry-density (g/cm^3)
Coarse	3.02	0.80	2.99
Fine	3.00	2.02	2.94

2.2 Pulsed Power Discharge into Asphalt Concrete

The authors have proposed a pulsed power application to extract asphalt binder from asphalt concrete. Pulsed power is a technology in which energy is accumulated over a relatively long period of time and then discharged in short pulses with controllable repetition rate thus increasing its instantaneous power [9].

Table 3 Properties of straight and modified type H asphalt

Asphalt types	Softening point (^{o}C)	Penetration (10^{-1} mm)	Ductility (cm)
Straight (S)	44.0 - 52.0	60 - 80	≥ 100
Modified H (MH)	95.0	45.0	93.0

Pulsed power energy (Eq. (1)) was discharged into both, straight and modified type H asphalt concrete specimens submerged in water (Fig.3) using a Marx generator (Fig.2 and Table 4) under the conditions shown in Tables 5 and 6.

The pulsed power discharged energy is calculated using;

$$E = \frac{1}{2}C(V)^2 \quad (1)$$

where E is pulsed power discharged energy, C is the capacitance of the Marx generator, and V is voltage across the Marx generator.

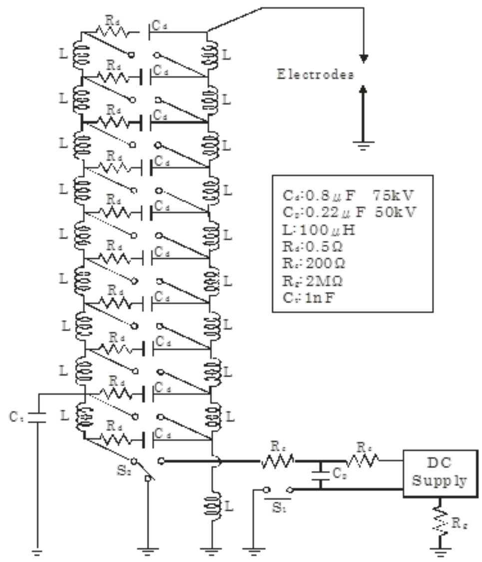


Fig.2 Marx Generator [10]

Table 4 Marx generator parameters

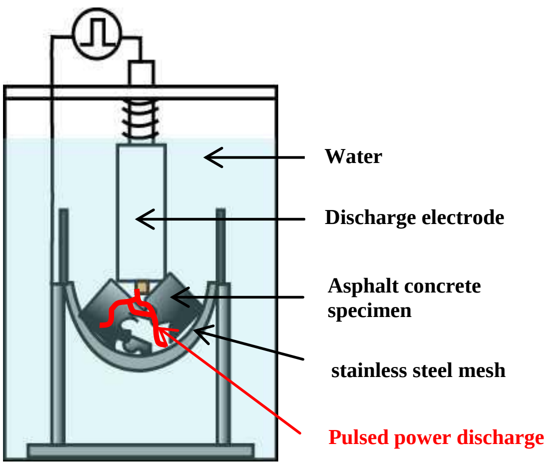
Charging voltages (kV)	30	40
Capacitance of the Marx generator (μF)	8	8

Table 5 Conditions for straight asphalt specimens

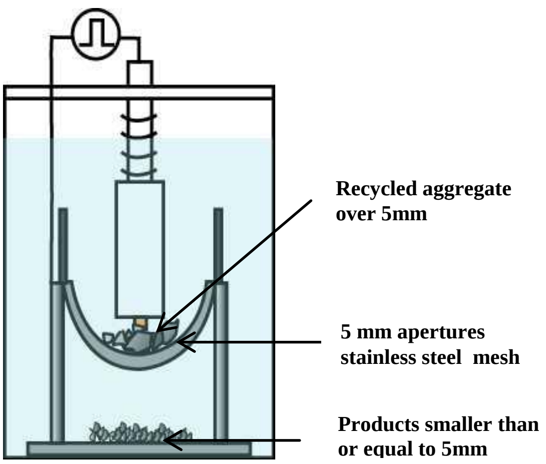
Charging voltage (kV)	Number of discharges on 5mm mesh	Number of discharges on 2.5 mm mesh	Total discharged energy (kJ)
30	25	25	180
30	50	50	360

Table 6 Conditions for modified type-H asphalt specimens

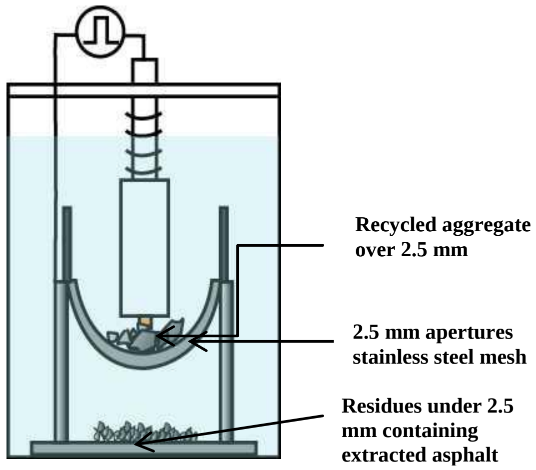
Charging voltage (kV)	Number of discharges on 5mm mesh	Number of discharges on 2.5 mm mesh	Total discharged energy (kJ)
30	50	50	360
30	75	50	450
30	100	50	540



a) Pulsed power discharge into specimens on 5 mm apertures stainless steel mesh



b) Production of recycled aggregate over 5 mm



c) Production of recycled aggregate over 2.5 mm and residues under 2.5 mm

Fig.3 Pulse power discharge apparatus [10]

Not only is asphalt concrete composed of asphalt binder and aggregate but also it is composed of air voids. The discharge of pulsed power inside asphalt concrete causes the dielectric breakdown of the gas inside air voids. As a result, the generated plasma induces shock waves followed by tensile stress that remove the asphalt binder from aggregate surface.

2.3 Pulsed Power Discharge Procedure

Pulsed power was discharged inside asphalt concrete specimens on stainless steel meshes with apertures of 5 mm and 2.5 mm to separate them into both recycled aggregate over 5 mm; and over 2.5 mm and the residues under 2.5 mm containing the extracted asphalt binder. The process is as follows: at the start, after discharging the required pulsed power energy on the asphalt concrete specimens on the 5 mm mesh, the remaining recycled aggregate over 5 mm was collected. Then, on the 2.5 mm mesh, the same process was applied on the other part of the asphalt concrete specimens which size was smaller or equal to 5mm to produce the over 2.5 mm recycled aggregate. At the end, the products which size was smaller or equal to 2.5 mm were categorized as the residues under 2.5 mm (Fig. 3 and Table 7).

Table 7 Size of pulsed power discharge products

Products	Recycled aggregate over 5mm	Recycled aggregate over 2.5mm	Residues under 2.5 mm
Size S (mm)	S>5	2.5<S≤5	S≤2.5

2.4 Residual Asphalt Recovery

Residual asphalt was recovered automatically from over 5 mm and 2.5 mm recycled aggregate utilizing an asphalt extraction testing machine with propane as solvent at the Kumamoto Prefectural Center of Constructional Technology, Kumamoto, Japan. Next, asphalt was recovered utilizing the Abson method according to ASTM D1856-09 [11].

2.5 Investigation of the Surface of Pulsed Power Discharge Products

To investigate the performance of pulsed power technology at extracting asphalt binder from asphalt concrete, surfaces of representative parts of recycled aggregate over 5mm and 2.5mm, and residues under 2.5 mm were examined through the digital microscope KH-7700 HIROX with magnification x35.

2.6 Oven-Dry Density and Water Absorption Tests

Oven-dry density and water absorption tests were performed on all types of recycled aggregate larger than 2.5 mm and residues under 2.5 mm according to Japanese Industrial Standards (JIS A 1109 and JIS A 1100).

Furthermore, oven-dry density and water absorption tests were conducted on virgin aggregate used to make the asphalt concrete specimens

3. RESULTS AND DISCUSSION

3.1 Pulsed Power Discharge Products

Figs.4 and 5 display collected recycled aggregate and residues under 2.5 mm after discharging pulsed power into asphalt concrete specimens underwater.

Fig.4 Recycled aggregate larger than 2.5 mm

Fig.5 Residues under 2.5 mm containing

3.2 Images of Recycled Aggregate and Residues under 2.5 mm

Images of pieces of recycled aggregate and part of residues under 2.5 mm were magnified 35 times using the digital microscope KH-7700 HIROX. The above-mentioned images can be seen in Figs.6,7,8, and 9.

Fig.6 Almost-clean piece of aggregate

Fig.7 Partially-coated piece of aggregate

Fig.8 Totally-coated piece of aggregate

Fig.9 Residues under 2.5 mm containing extracted asphalt binder

According to the results of the investigation of the performance of pulsed power technology at extracting asphalt binder from asphalt concrete, recycled aggregate larger than 2.5 mm is mainly composed of almost-clean(Fig.6) and partially-coated aggregate(Fig.7) while residues under 2.5 mm consist mainly of fragments of coarse aggregate, totally-coated fine aggregate(Fig.8), and extracted asphalt binder(Fig.9).

3.3 Recycling Rates

As evident in Figs 10 and 11, with increasing pulsed power energy the recycling rate (Eq.(2)) of aggregate over 5 mm decreased markedly, contrary to that of over 2.5 mm recycled aggregate, which significantly increases from 128% to 141.3% for straight asphalt and from 123% to 163% for modified type H asphalt as a result of aggregate breaking.

$$R = \frac{PR}{PI} \times 100 \quad (2)$$

Here, *R* is aggregate recycling rate in percentage, PR is proportion of recycled aggregate in percentage, and PI is initial proportion of corresponding virgin aggregate in asphalt concrete specimens.

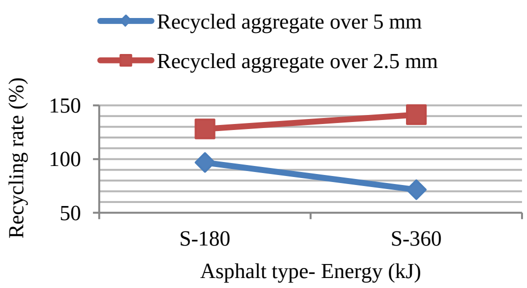


Fig.10 Recycling rates of straight asphalt concrete aggregate

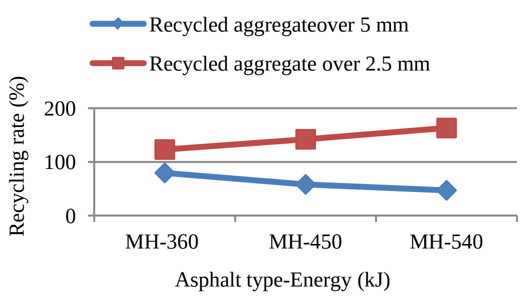


Fig.11 Recycling rates of modified type- H asphalt concrete aggregate

3.4 Asphalt Content of Recycled Aggregate

Straight and modified type H asphalt concrete specimens required 360 kJ and 540 kJ respectively (Figs.12 and 13) to achieve approximately 1% asphalt content of recycled aggregate over 5 mm.

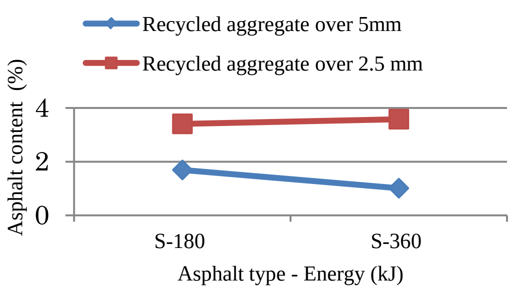


Fig.12 Asphalt content of recycled aggregate from straight asphalt concrete specimens

As detailed in Fig.12, for straight asphalt concrete specimens, asphalt content of recycled aggregate over 2.5 mm decreases to 3.41% and

3.58% from 5% (whole content in a specimen) at 180 kJ and 360 kJ as pulsed power discharged energy respectively. Asphalt content of recycled aggregate over 2.5 mm decreases as well reaching 1.69% and 1.01% at 180 kJ and 360 kJ respectively.

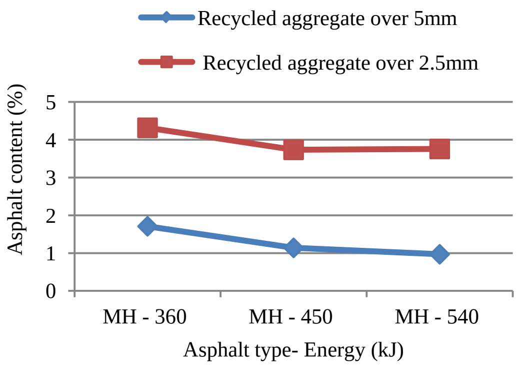


Fig.13 Asphalt content of recycled aggregate from modified asphalt concrete specimens

As indicated in Fig.13, for type–H modified asphalt concrete, asphalt content of recycled aggregate over 5mm decreases to 0.97% at 540 kJ as pulsed power discharged energy. Asphalt content of recycled aggregate over 2.5 mm decreases to 3.76% at 540 kJ.

These results show that the extraction of modified asphalt binder is not as easy as that of straight asphalt and requires more pulsed power discharge energy to produce the same asphalt content due to the presence of polymer modifier which increases its elasticity.

Furthermore, for both straight and type-H modified asphalt concrete, asphalt content tests revealed that finer recycled aggregate contained higher asphalt content. Although asphalt content of recycled aggregate over 2.5 mm is higher than that of recycled aggregate over 5 mm, asphalt content of both recycled aggregate over 5 mm and 2.5 mm decreases when pulsed power discharged energy increases.

It could be inferred therefore that significant amount of asphalt binder was extracted from asphalt concrete specimens as part of the residues under 2.5 mm using pulsed power discharge.

3.5 Oven-dry Density

Inspection of Fig.14 indicates that oven-dry density of recycled aggregate over 5 mm from straight asphalt concrete specimens increases from 2.88 g/cm^3 to 2.94 g/cm^3 when pulsed power discharged energy increases from 180 kJ to 360 kJ. For type-H modified asphalt concrete, oven-dry density of recycled aggregate over 5 mm increases as well from 2.87 g/cm^3 to 2.94 g/cm^3 when pulsed power discharged energy increases up to 540 kJ. It is evident from the results of oven-dry-density tests that type-H modified asphalt concrete required more energy to achieve the same 2.94 g/cm3 oven dry–density recycled aggregate over 5 mm compared to straight asphalt.

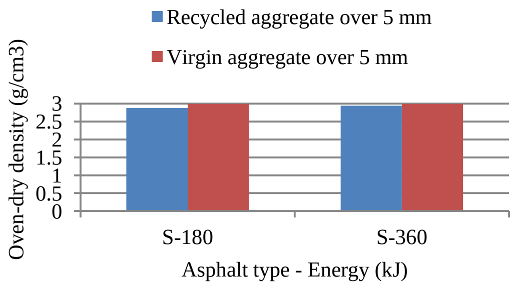


Fig.14 Oven-dry density of recycled aggregate over 5 mm from straight asphalt specimens

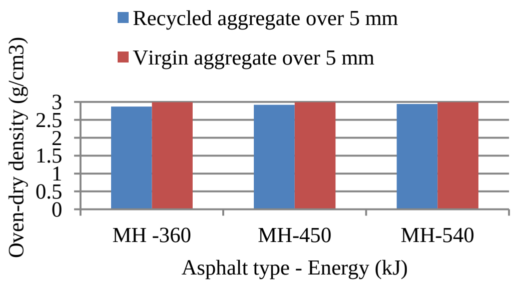


Fig.15 Oven-dry density of recycled aggregate over 5 mm from modified asphalt specimens

For both straight and modified type-H asphalt concrete specimens recycled aggregate over 5 mm, the oven-dry density increases when pulsed power discharged energy increases and is almost equal to that of the virgin aggregate utilized to make the corresponding specimens (Figs. 14 and 15).
Furthermore, an increase in pulsed power discharged energy appears to improve the oven-dry density of asphalt concrete recycled aggregate**.**

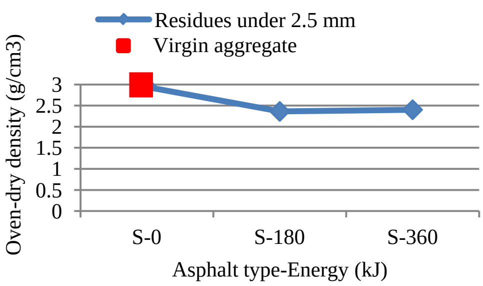


Fig.16 Oven-dry density of residues from straight asphalt specimens and virgin aggregate

From Figs.16 and 17 it can be seen that oven-dry density of residues under 2.5 mm decreases due to the improvement in quality of the corresponding recycled aggregate over 5 mm and 2.5 mm when discharged energy increases up to 540 kJ. These results provide evidence that the decrease in oven-dry density is caused by the aggregate separation into smaller pieces and effective asphalt binder extraction from recycled aggregate larger than 2.5 mm.

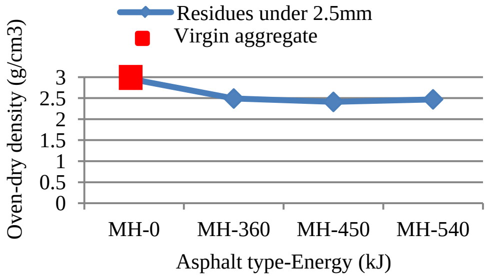


Fig.17 Oven-dry density of residues from modified type-H asphalt specimens and virgin aggregate under 2.5 mm

3.6 Water Absorption

The results of water absorption tests are shown in Figs. 18 and 19. For straight asphalt, the lowest water absorption ratio 0.73% was observed at 360 kJ for recycled aggregate over 5 mm. For type-H modified asphalt, the lowest 0.82% water absorption ratio was achieved by discharging 450 kJ as pulsed power energy. In other words, type-H modified asphalt concrete requires more pulsed power discharged energy to achieve approximately 0.80% water absorption recycled aggregate over 5 mm. According to these results it appears that the effect of pulsed power discharge on recycled aggregate over 5 mm water absorption is similar to that on its asphalt content and oven-dry density in terms of quality improvement.

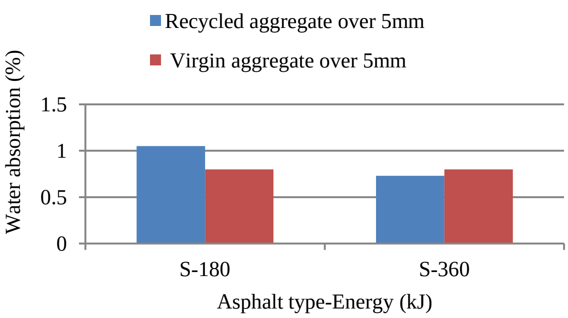


Fig.18 Water absorption of recycled aggregate over 5mm from straight asphalt specimens and virgin aggregate

Furthermore, from Figs 18 and 19 it can be seen that the effect of pulsed power discharge on water absorption of recycled aggregate over 5 mm from straight asphalt concrete specimens is in good agreement with that on recycled aggregate from modified type-H asphalt concrete specimens.

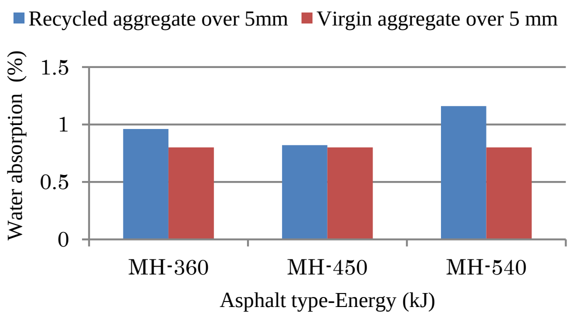


Fig.19 Water absorption of recycled aggregate over 5 mm from modified type-H asphalt specimens and virgin aggregate

Despite the relatively higher water absorption ratio of over 5 mm recycled aggregate from modified asphalt concrete specimens at 540 kJ, water absorption decreases and becomes closer to water absorption of corresponding virgin aggregate when pulsed power discharged energy increases.

On the whole, water absorption of residues under 2.5 mm from straight and modified type-H asphalt concrete specimens (Figs.20 and 21) decreases with increasing pulsed power discharged energy. The results found in Fig.20 confirm that for the less resistant straight asphalt, the increase in water absorption when pulsed power discharged energy increases up to 180 kJ is a consequence of an effective asphalt binder extraction from recycled aggregate over 5mm and 2.5 mm. However, when pulsed power energy increases from 180 kJ to 360kJ, the increase in the amount of fragments of coarse aggregate resulted in the slight decrease in water absorption.

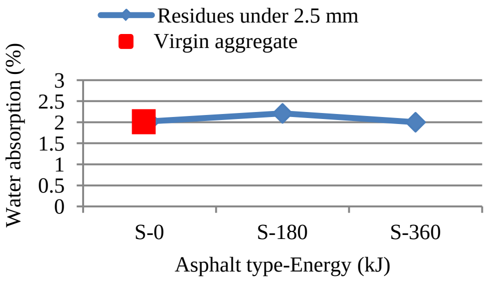


Fig.20 Water absorption of residues from straight asphalt specimens and virgin aggregate under 2.5 mm

With respect to the more resistant modified type-H asphalt, the results highlighted in Fig.21 imply that simultaneous separation of aggregate into finer pieces and asphalt binder extraction from recycled aggregate over 5mm and 2.5 mm are responsible for the increase in quality namely the decrease in water absorption when discharged energy increases from 360 kJ to 540 kJ.

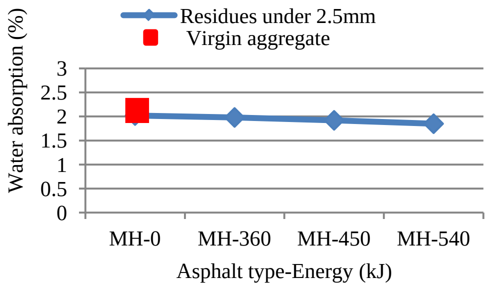


Fig.21 Water absorption of residues from modified type-H asphalt specimens and virgin aggregate under 2.5 mm

The results of oven-dry density and water absorption tests conducted on residues under 2.5 mm demonstrate straight and modified type-H asphalt binder extraction mechanisms. In other words, when pulsed power discharge energy increases, the amount of pieces of broken aggregate increases while that of extracted asphalt binder decreases.

4. CONCLUSION

Since pulsed power discharge inside ordinary concrete produced high quality recycled aggregate, the authors proposed its application to extract asphalt binder from asphalt concrete specimens.

In the course of this study, pulsed power was discharged into 5% asphalt content straight and modified type-H asphalt concrete. The results show that pulsed power discharge affected aggregate gradation by increasing the recycling rate of aggregate over 2.5 mm up to 163% and decreasing that of over 5mm aggregate up to 47% due to aggregate breaking. Due to the high elasticity of modified type-H asphalt binder, its extraction is more difficult than that of straight asphalt and requires more pulsed power discharged energy. Quality of recycled aggregate improved with an increase in discharged energy characterized by the decrease in water absorption and the increase in oven -dry density.

Further study should investigate the recovery of modified asphalt from the above-discussed residues under 2.5 mm and the separation of various types of polymer modified asphalt into decomposed polymer modifier and straight asphalt for separate recycling.

5. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of Associate Professor Takao Namihira, Dr. Yuichi Tomoda, Mr. Yasuo Miyazaki and the other members of Prof. Shigeishi's Group. The authors would like to express their sincere gratitude to Showa Rekisei Industries Co., Ltd. Kumamoto Mixture Factory, Kumamoto, Japan for forming the asphalt concrete specimens utilized in this study.

6. REFERENCES

[1] Kubo, K.: Pavement Team, Public Works Research Institute, Japan: Recycling in Japan, 2009.

[2] Japan Modified Asphalt Association, Polymer Modified Asphalt Pocket Guide. Japan Modified Asphalt Association (JMAA), 2010, pp. 3-5.

[3] Tam V, “Comparing the implementation of concrete recycling in the Australian and Japanese constructions industries,” Journal of Cleaner Production, Vol. 17, 2009, pp. 688-702.

[4] Su K., Hachiya Y., Maekawa R., “Laboratory investigation of possibility of re-recycling asphalt concretes”, Proc. 6th ICPT, 2008, pp. 435-442.

[5] Inoue S., Iizasa S., Wang D., Namihira T., Shigeishi M.., “Concrete recycling by pulsed power discharge inside concrete,” Int. J. Plasma Environmental Science and Technology, 2012, pp. 183-188.

[6] Akiyama H., High-Voltage Pulsed Power Engineering. Tokyo, Ohm-sha, 2003, pp. 1-2. (in Japanese)

[7] Japanese Standards Association: JIS A 5021, “Recycled aggregate for concrete-class H,” 2005.

[8] Japan Modified Asphalt Association Standard, Quality and Test Methods of Polymer Modified Asphalt for Road Pavement. Japan Modified Asphalt Association (JMAA), 2007, p. 3.

[9] Bluhm H., Pulsed Power Systems: Principles and Applications. Berlin: Springer, 2006.

[10] Namihira T., Shigeishi M., Nakashima K., Murakami A., Kuroki K., Kiyan T., Tomoda Y., Sakugawa T., Katsuki S., Hidenori A., Ohtsu M., “Recycled coarse aggregate produced by pulsed discharge in water,” IEEJ Trans. Fundamentals and Materials, Vol. 6, Issue 3, 2006, pp. 197-198.

[11] ASTM Standards: D1856-09, “Standard Test Method for Recovery of Asphalt From Solution by Abson Method,” 2009, West Conshohocken, PA, DOI: 10.1520/D1856-09, www.astm.org .

Int. J. of GEOMATE, Sept., 2015, Vol. 9, No. 1 (Sl. No. 17), pp. 1403-1410.
MS No. 4325 received on May 01, 2014 and reviewed under GEOMATE publication policies.

Pertinent discussion including authors' closure, if any, will be published in Sept. 2016 if the discussion is received by March 2016.
Corresponding Author: R. Ivan Amoussou