Proposal of recycling technology which uses compressed hot water to separately recover aggregate and asphalt from RAP

Y. Kanou and S. Akiba

Department of Civil Engineering, College of Industrial Technology, Nihon-Univ, Narashino, Chiba, Japan

ABSTRACT: Demands upon paving have recently been diversified by new key words: the environment and safety. The cause is the rapid spread of paving materials with diverse functions—drainage pavement, water retentive pavement etc.—since the late 1990s. These new pavement's functions have been achieved by porous asphalt mixtures and supported by modified asphalt. Recycling technologies have failed to respond to diversification of paving and its functions, because the qualities of materials included in reclaimed asphalt pavement (RAP) are unidentified. Therefore, it is difficult to secure demanded performance when they are reused. So that RAP recycling technologies can respond to the further diversification of pavement, it is essential to develop environmentally conscious technologies which encourage cyclic use of materials and simplify recycling systems.

The authors focused on the performance of high temperature highly compressed water which has attracted attention as an environmentally conscious solvent in the food and energy fields. This study used highly compressed hot water to separately recover aggregate and asphalt from RAP and to restore them as materials. As a result, compressed hot water at approximately 150ºC successfully separated and recovered coarse aggregate, fine aggregate, and asphalt (including modified asphalt) from diverse asphalt mixtures. The properties of the recovered aggregates and asphalt remained unchanged, confirming maintenance of the original qualities each possessed as a material. Thus, this technology is seen as a rational measure to deal with the diversification of pavement by restoring diverse materials produced from RAP to their initial condition, permitting their management and use in the same way as virgin materials.

KEY WORDS: Reclaimed asphalt pavement (RAP), recycled aggregate, compressed hot water, recycling technology, separately recover materials.

1 INTRODUCTION

As demonstrated by drainage pavement which has spread rapidly since the late 1990s, society's needs for pavements have widely diversified in recent years, with safety and the environment as the key words. While this has been accompanied by the development of new asphalts and the increasing use of recycled materials, existing material recycling technologies have not yet guaranteed the sustained use of materials.

The development of technologies to recycle reclaimed asphalt pavement (RAP), has accelerated since the 1970s under the impact of the effective use of resources and a shortage of disposal sites, achieving a materials recycling rate of 98% or higher in recent years[1].

However material recycling technologies executed by mechanical crushing results in scattering of quality during the production of recycled aggregate. This means that if a large quantity of recycled aggregate is used, the reclaimed mixture may lose its uniformity, revealing problems related to the depletion and diversification of paving material [2). We now face an urgent need to revise recycling systems to meet the society's needs in order that future paving technologies achieve sustainable development, with safety and the environment as the key words.

As measures to recycle diverse paving materials, in recent years, new recycling use additive agents have been developed and crushing technology using high temperature steam, or old asphalt adsorption technology based on adding fine powder have been proposed [3). In either case, to ensure the quality of recycled aggregate, it is necessary to comprehensively clarify the quantity and properties of the asphalt it contains and the grading of the aggregate. However as a result of the properties of the recycled aggregate with RAP as its base material, it is difficult to correctly manage this material. Another challenge to using recycled aggregate is fluctuation of the properties of the asphalt and the mix proportion of the aggregate required for old mixture and new mixture. Complex problems related to the management and use of recycled aggregate of this kind have, along with the diversification of paving materials, become more complex throughout overall recycling systems.

Based on the above, not only to make sustained use of material, but also to achieve high quality recycled mixtures and reduce the cost of recycling, when recycling material, it is essential to restore the materials to their original state, and to manage and use them in the same way as virgin materials. So the authors focused on the performance of high temperature highly compressed water which is used as a practical new environmentally conscious solvent in the food and energy fields. This research was undertaken as an attempt to use compressed hot water to separately recover aggregate and asphalt from RAP to recycle each of its constituent materials. This technology was developed in order to restore RAP, which is produced at a rate of about 30 million tons per year, into its original constituents, thereby sustainably recycling materials and rationalizing and simplifying recycling systems.

2 SEPARATE RECOVERY PERFORMANCE OF COMPRESSES HOT WATER

2.1 Outline of the experiment

Water is the solvent most closely related to our daily lives, and it provides superior safety and economic benefits. The benefits of using high temperature highly compressed water as the asphalt separation solvent are that controlling the temperature and pressure also regulates the density, electrical permittivity, and so on, and permits selective dissolving of nonpolar organic material such as asphalt [4).

The authors have worked to develop an asphalt extraction test using subcritical water, clarifying the superior asphalt separation performance of high temperature highly compressed water [5), 6). Past experiments successfully separated asphalt and aggregate through a subcritical water reaction (350°C·17MPa) of several tens of seconds without any impact by the type of asphalt. However in a case in which separation and material recycling technology are considered as the plant technology, from the technological and economic perspectives, it is difficult to apply high temperature highly compressed water as a separating solvent. So this study attempted to use compressed hot water at a temperature up to a highly feasible 200°C as the plant technology to separately recover the asphalt and aggregate from the asphalt mixture by a separation experiment.

2.2 Experiment method

The heatable sealed tank (internal capacity: 10L) in Figure 1 was used to perform an asphalt mixture separation experiment based on compressed hot water at a temperature up to 200°C. We used was a Marshall stability test use specimen (approx. 1,000g) made by applying a polymer modified asphalt type-H as a 5.5wt% membrane to dense-graded asphalt mixture (maximum diameter: 13mm). Type-H was selected as the specimen considering its superior aggregate holding capacity, which makes separation relatively difficult, and accounting for future increase in demand. Table 1 shows the properties of the polymer modified asphalt type-H.

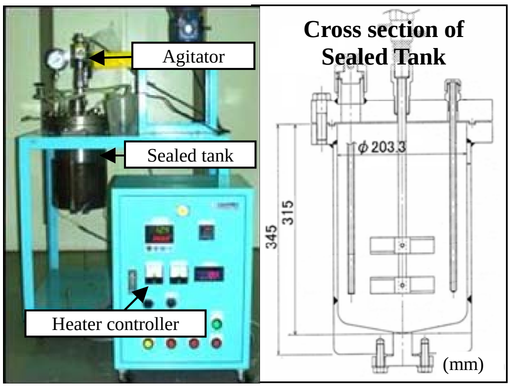

Figure 1: Separation Experiment System

Table 1: Properties of Polymer Modified Asphalt type-H

Test item		Test result	Standard properties
Penetration (25ºC)	(1/10mm)	54	Min. 40
Softening point	(ºC)	95.5	Min. 80.0
Extensibility (15ºC)	(cm)	100+	Min. 50
Ignition point	(ºC)	333	Min. 260
Membrane heating mass change rate	(%)	+0.03	Max. 0.6
Membrane heating penetration residual rate	(%)	83.6	Min. 65
Density	(g/cm^3)	1.024	ー

The separation experiment was executed in the following stages: crushing, separation and recovery.

1) Crushing process

Three specimens (approximately 3,000g) are submerged in hot water heated in advance to about 90°C in the sealed tank and crushed as they are agitated. The quantity of water used is 6 liters, which is the saturated water vapor pressure, according to the relationship between the volume of the sealed tank and the test temperature which has been set.

2) Separation process

The water and the specimens in the sealed tank are heated for set periods at the test temperatures (125°C·0.23MPa, 150°C·0.48MPa, 175°C·0.89MPa, and 200°C·1.55MPa). After the test temperature has been reached, it is agitated while kept hot with 0, 30 and 60 minutes as separation times.

3) Recovery process

The inside of the sealed tank is exhausted to recover the contents which are classified as coarse aggregate (aggregate size: 13.2 to 2.36mm) and fine aggregate (aggregate size: 2.36 to

0.15mm). The graded specimens are separately recovered as asphalt and aggregate by wet specific gravity separation. And in the part of the recovered material in which the asphalt and aggregate are insufficiently separated, the pieces of aggregate are fixed together by residual asphalt. Thus, the recovered material with diameter exceeding the maximum diameter of the blended aggregate is not handled as a separately recovered specimen.

2.3 Results and considerations

(1) Asphalt content

An asphalt extraction test (with Soxhlet extraction method) of the aggregate recovered by the separation experiment was performed, obtaining the asphalt content remaining in the aggregate [7]. Figures 2 to 5 show relationship of the asphalt content and separation time by test temperature. And the asphalt content of all aggregate is recorded as a polygonal line.

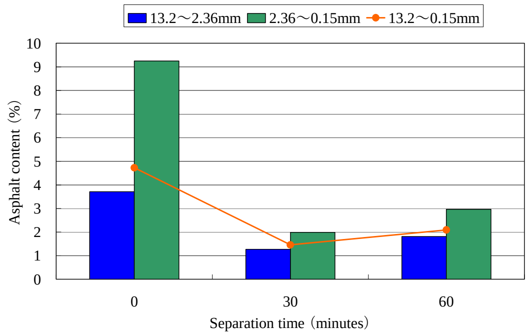

Figure 2: Asphalt Content and Separation Time (125°C)

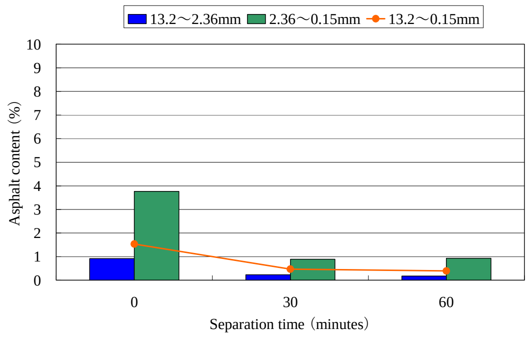

Figure 3: Asphalt Content and Separation Time (150°C)

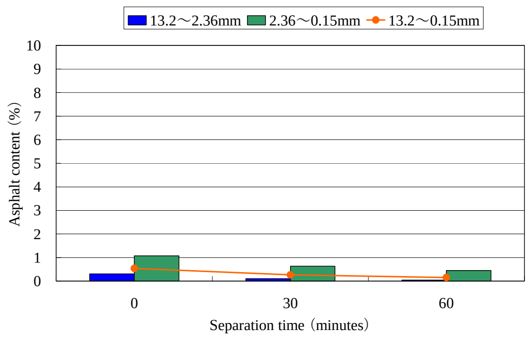

Figure 4: Asphalt Content and Separation Time (175°C)

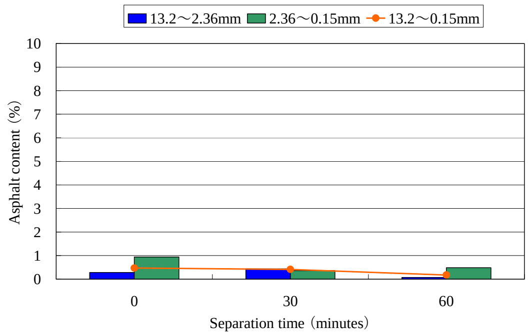

Figure 5: Asphalt Content and Separation Time (200°C)

In the 125°C experiment, the asphalt content when the temperature was reached (separation time: 0 minutes) was about 4.7wt% of the entire specimen, and only a little asphalt had separated. In the 150°C experiment, the asphalt content when the temperature was reached fell to 1.5wt%, and a little less than 4wt% of the fine aggregate remained, but overall, over 70% or more of the asphalt separated. And at 175°C and 200°C, the asphalt content when the temperature was reached was below 0.5wt%, and as the temperature rose to 175°C or higher, the asphalt separation performance did not improve. And at all test temperatures, until separation time of 30 minutes, the asphalt content fell greatly, but the asphalt separation did not advance for about 60 minutes. The asphalt content of all aggregate at and after separation time of 30 minutes was from 1.5 to 2.0wt% at 125°C, from 0.4 to 0.5wt% at 150°C, and from 0.2 to 0.4wt% at 175°C and 200°C.

(2) Aggregate recovery rate

The asphalt was extracted from the specimen recovered by the separation experiment, and the aggregate recovery rate was obtained by solving the following formula (1) to calculate the percentage of the aggregate blended in the specimen which was recovered aggregate remaining after extraction.

$$R_{Ag} = \frac{M_2}{M_1} \times 100 \tag{1}$$

Where: R_{Ag}: aggregate recovery rate (%)
M_1: dry mass of blended aggregate (g)
M_2: dry mass of recovered aggregate (g)

Figures 6 to 9 show the aggregate recovery rate and separation time relationship by test temperature. The aggregate recovery rate from all the blended aggregate is recorded by the polygonal line.

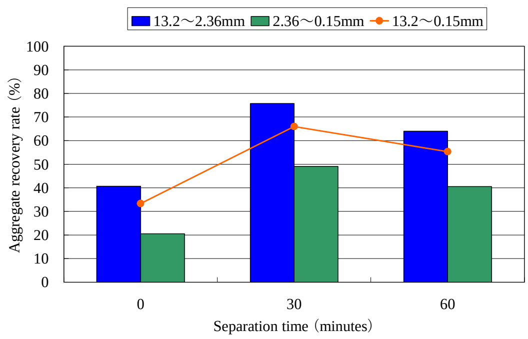

Figure 6: Aggregate Recovery Rate and Separation Time (125°C)

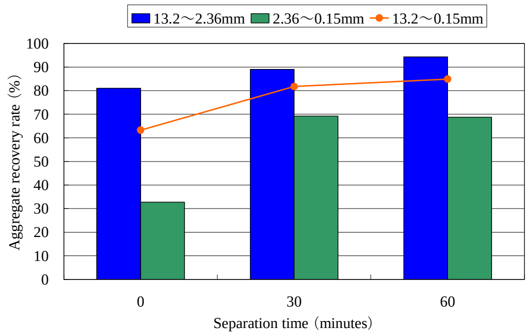

Figure 7: Aggregate Recovery Rate and Separation Time (150°C)

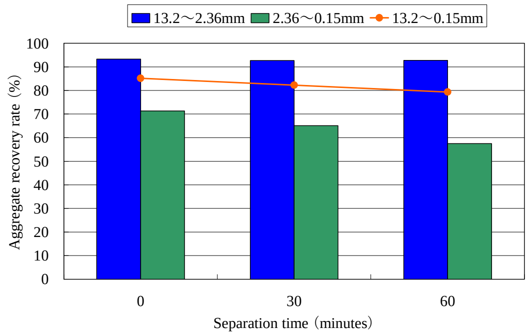

Figure 8: Aggregate Recovery Rate and Separation Time (175°C)

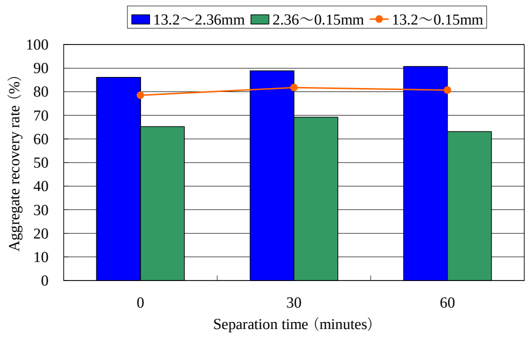

Figure 9: Aggregate Recovery Rate and Separation Time (200°C)

At 125°C and 150°C, the aggregate recovery rate tended to rise for 30 minutes after the temperature was reached. And at 150°C, after 30 minutes, the aggregate recovery rate of coarse aggregate rose along with the separation time to more than 90%. At 175°C and 200°C on the other hand, at the same time that the temperature was reached, about 90% of the coarse aggregate was recovered, and at separation times longer than this, the recovery rate including that of the fine aggregate did not increase. And at all temperatures, the recovered aggregate was overall uniform, while the aggregate not recovered was partially aggregated by the re-adhesion of the residual asphalt or the separated asphalt.

The above confirmed that the separate recovery performance of compressed hot water is dependent on the temperature and on the time. And as a result of the separation experiment, the 30 minute separation process by compressed hot water at 150°C or higher recovered between 80% and 90% of the aggregate with more than 90% of the asphalt separated. Incidentally, we considered getting steam pressure and the specimen spreading, and the weight ratios of the specimen to water are 1 to 2 in this study. Depending on the state of the specimen and the shape of the tank, we may increase the ratios of the specimen.

3 QUALITY OF THE MATERIALS SEPARATELY RECOVERED

3.1 Outline of the experiment

It is said that the asphalt in the RAP is generally hardened and loses its ductility as an effect of aging when it is provided for use. However the degree this occurs varies according to the period of use and type of asphalt, so it is difficult to perform standardized management and use of present recycled aggregate. On the other hand, aggregate is not substantially altered according to the time the mixture is manufactured or by long-term use, so it is possible to restore it to its original state by separating the asphalt. In this chapter, the properties of asphalt and aggregate which have been separately recovered under conditions of 150°C or higher, which has been confirmed to be effective by the separation experiment, have been highly evaluated. In addition, we should have also analyzed it for recycling about the water, although the dirt and the cloudiness were not detected in the water after this experiment in this study.

3.2 Results and considerations

(1) Quality of the recovered asphalt
Asphalt separated from asphalt mixture by compressed hot water is mostly in granular form, and absorbs little water. Figure 10 is a photo of the recovered asphalt after drying (separation process: 150°C for 30 minutes).

Figure 10: Recovered Asphalt (150°C·30 minutes)

The results of the asphalt extraction test of the recovered asphalt confirmed that about 45 to 50wt% of micro granules is mixed in the recovered asphalt. Therefore, the properties of the recovered asphalt were evaluated by performing an asphalt penetration test (JIS K 2207) and asphalt softening point test (JIS K 2207) using the specimen after the asphalt recovery test (JPI-5S-31). Figure 11 shows the penetration and softening point. In addition, deteriorated asphalt with the same heating history applied to prepare the specimens was evaluated. This examination was carried out to reuse of the recovered asphalt and evaluated a change in quality with the separation. And then, we evaluated the deteriorated asphalt through the same process. Therefore, we think the differences of each other are the influence with the classification. In addition, the asphalt was recovered with the experiment in the above chapter, and showed the Properties of virgin asphalt (Polymer Modified Asphalt type-H) in table 1.

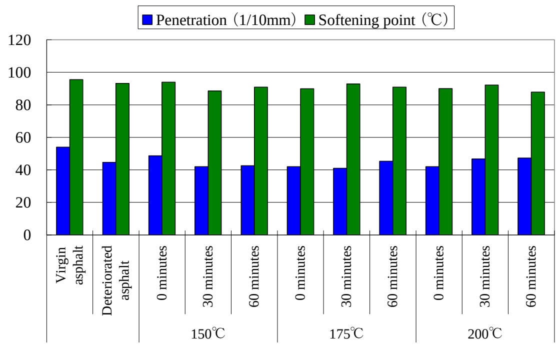

Figure 11: Properties of Recovered Asphalt (150°C·30 minutes)

The penetration and softening point of the recovered asphalt do not differ very much according to test temperature and separation time, maintaining penetration of 40 or more and softening point of 80.0°C or higher, which are indicated to be standard properties. However, it is necessary to study using it in mixed state or removing the micro granules using subcritical water, because micro granules of almost identical mass are mixed in the recovered asphalt.

(2) Quality of the recovered aggregate

Figure 12 shows two photos of the recovered aggregate after drying (separation process: 150°C for 30 minutes), and Figure 13 shows grading curves of the recovered aggregate (separation process: 150°C for 30 minutes) and the blended aggregate (aggregate size: 13.2 to 0.15mm).

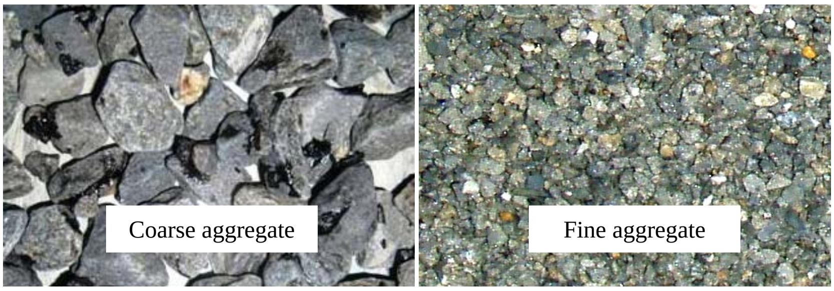

Figure 12: Recovered Aggregate (150°C·30 minutes)

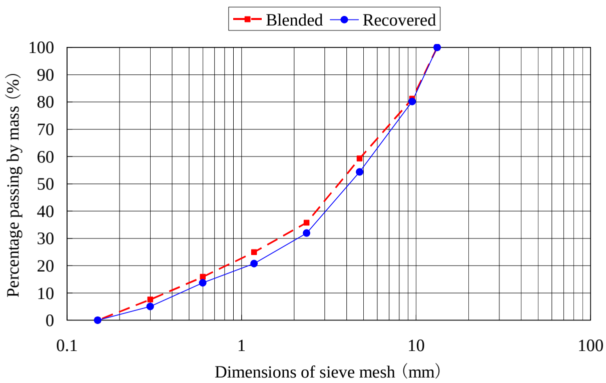

Figure 13: Grading of Blended Aggregate and Recovered Aggregate (150°C·30 minutes)

Only a little asphalt remains in the recovered aggregate, but it is uniformly distributed in the specimen. And the grading of the entire recovered aggregate (aggregate size: 13.2 to

0.15mm) is almost the same as the grading of the aggregate originally blended to prepare the specimens.

In aggregate separately recovered by compressed hot water at 150°C or more, there is a slight difference in its asphalt content, but there is no significant difference in the impact on aggregate of compressed hot water at 200°C or less. Therefore, results showing superior separate recovery performance are obtained from the separation experiment, and under the most practical conditions (separation process at 150°C for 30 minutes), the quality of the recovered coarse aggregate was confirmed by performing the coarse aggregate density and water absorption test (JIS A 1110). Figure 14 shows the density and the absorption of the virgin coarse aggregate and the recovered coarse aggregate.

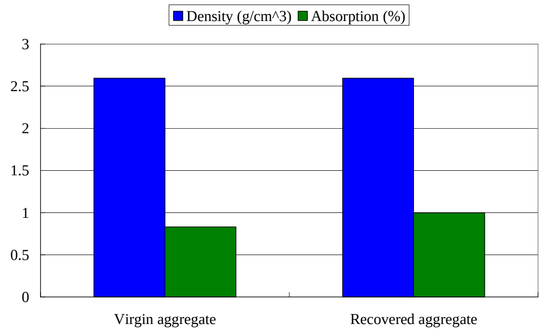

Figure 14: Properties of Recovered Aggregate (150°C·30 minutes)

The quality of the recovered coarse aggregate is as good as the virgin aggregate, its density is 2.5g/cm^3 or higher and its absorption is 3% or less, which satisfy quality standards. For this reason, aggregate separately recovered from asphalt mixture by compressed hot water is generally restored to its original quality, and it is presumed that it can be handled the same way as virgin aggregate.

4 SUMMARY

The following is a summary of the knowledge obtained from this research.

1) Separate recovery performance by compressed hot water is dependent on temperature and time. As a result of the experiments, a 30 minute separation process by compressed hot water at 150°C or more separated 90% or more of asphalt and recovered 80% to 90% of aggregate.

2) Asphalt separately recovered by compressed hot water was not greatly transformed from its state before separation. However because micro granules of almost identical mass are mixed in the recovered asphalt, it is necessary to study using it in mixed state or adding an additional separation process.

3) Aggregate separately recovered by compressed hot water is restored to its approximately original state regarding its grading, density, and water absorption properties. Therefore, it is possible to manage and use recovered aggregate in the same way as virgin aggregate.

We did not examine about the economy and the energy consumption at this stage, because this study is a part of the fundamental experiment. Therefore, we intend to calculate this technical total cost in consideration of driving time and the throughput. Furthermore, it will be necessary for us to examine the value of the recovered aggregates based on this technical total cost in the future.

REFERENCES

1) Msaru Yamada (1984): *Study of Quality and Serviceability of Recycled Asphalt Mixture,* Collected Reports of the Japan Society of Civil Engineers, No. 348, Japan.

2) Kunizo Akiba and Takemi Inoue (1997): *Study of Recycling of Modified Asphalt Mixture,* Collected Reports of the Japan Society of Civil Engineers, No. 564, Japan.

3) Yoshio Hisari et al. (1999): *Research on the Resource Recycling of Reclaimed Asphalt Paving Using Fine Powder Materials*, Collected Reports of the Japan Society of Civil Engineers, No. 627, Japan.

4) Yousuke Kanou et al. (2006): *Separation and Recovery of Aggregate from Asphalt Pavement Wastes Using High-temperature and High-pressure Water*, Journal of the Japan Petroleum Institute, Vol. 49, Japan.

5) Shoichi Akiba et al. (2007): *Quality and Performance of Aggregate Separated from Reclaimed Asphalt Pavement by Using High-Temperature and Highly-Pressure Water*, Journal of Pavement Engineering, JSCE, Vol. 12, Japan.

6) Yousuke Kanou et al. (2005): *A Study on Test of Extraction of Asphalt from Asphalt Mixture Using Supercritical Water,* Journal of Pavement Engineering, JSCE, Vol. 10, Japan.

7) Japan Road Association (2007): *Pavement Survey*/T*esting Method Manual*, Vol. 3, Japan.