A Study on Recycling of Porous Asphalt Mixtures

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ABSTRUCT: In Japan, drainage pavements are highly regarded for the effectiveness of improving the running safety of vehicles and reducing road traffic noise. In recent years, therefore, these pavements have shown a drastic increase in number. Now that more than 17 years have passed since the start of full-scale construction of drainage pavements, it is presumed that the places of application thereof will reach the time of repair one after another, resulting in increased reclaimed asphalt pavement (RAP) generation from the porous asphalt concrete. However, because the existing techniques of recycling asphalt concrete do not cover the porous asphalt concrete with a high-viscosity modified asphalt, there is a pressing need to establish a recycling technique for this mixture. For recycling of rap generated from the porous asphalt concrete, there are wide-ranging problems including separate collection of generated rap and separate storage of recycled aggregates. In this study, we investigated three technical problems, i.e., [fine-graining of aggregate by milling], [mix design] and [adhesion of hot recycled aggregate to production equipment]. In the text, we report on 1) proposed mix design methods for recycling of rap from the porous asphalt mixture either into [dense-graded asphalt concrete] or into [porous asphalt concrete] and 2) investigation results on the method of heating recycled aggregate containing a high-viscosity asphalt.

KEYWORDS: Drainage pavement, porous asphalt mixture, recycle

1 INTRODUCTION

Being exposed to traffic loads and meteorological effects, asphalt pavements degrade in performance with the length of service and require maintenance and repair at regular intervals. In Japan, maintenance and repair works have increased with increasing pavement stock since 1980s. As a result, it has become difficult year by year to secure appropriate areas for disposal of reclaimed asphalt pavement (RAP) in and around large cities. Therefore, technical development intended for reusing RAP for road paving has been promoted. In 2000, the recycling rate of asphalt waste in the country reached 98%. Thus, the pavement recycling process has been disseminated as a common paving technology.

On the other hand, in the country, construction of drainage pavements effective in improving the running safety during rainy weather and reducing road traffic noise has increased drastically. In the case of the national highways under the direct control of the Government, it is reported that the area of drainage pavements constructed in 2005 reached 50 km^2 and that about 25% of the total area of the national highways has been replaced by drainage pavements [1)]. In addition, for the surface course of the expressway under the control of Expressway Co., Ltd. (former Japan Highway Public Corporation), drainage pavement has become a standard type since 1998. Therefore, construction of drainage pavements is expected to increase still more in the future. However, considering that the general renewal cycle of asphalt pavements is around 10 years, the existing pavements will reach the time to repair successively and will presumably have to be recycled.

Porous asphalt mixtures used for the surface course of the porous pavement have a special aggregate mix proportion of 80% or more in the total content of coarse aggregate in the mixture. Therefore, different from dense-graded asphalt mixtures in which the voids between aggregate particles are filled with asphalt mortar, porous asphalt mixtures have aggregate particles bonded point by point to each other and therefore use high-viscosity polymer-modified asphalt type H. However, the current recycling method is intended for dense-graded mixtures with straight asphalt, so it is necessary to make a study on how to recycle the porous asphalt mixtures.

In the light of such a situation, this paper elucidates technical problems in RAP of porous asphalt mixture with polymer-modified asphalt type H and presents the investigation results on possible solutions to these problems.

2 SPECIFICATIONS OF POROUS ASPHALT MIXTURE IN JAPAN

The specifications of porous asphalt mixtures generally used in the country are shown in Table 1. As shown in the table, these mixtures are characterized in that the void ratio is as great as 20% and polymer-modified asphalt type H is used. The grading envelope of porous asphalt mixtures specified in the Guidelines for Pavement Design and Construction is shown in Table 2 and the standard properties of polymer-modified asphalt type H in Table 3. As porous asphalt mixtures have an aggregate mix proportion of 80% or more in the total content of coarse aggregate in the mixture and. have aggregate particles bonded point by point to each other, they use high-viscosity polymer-modified asphalt type H in order to make the film thickness of binder as thick as possible.

Table1: Specifications of Porous Asphalt Mixture

Item	Specification
Placing thickness	4～5cm
Binder	Polymer-modified asphalt type H
Max. particle size of coarse aggregate	20mm or 13mm
Target void ratio	About 20%

Table2: Grading Envelope of Porous Asphalt Mixture

<table>
<tr><th colspan="2">Item</th><th>Max. particle size 20mm</th><th>Max. particle size 13mm</th></tr>
<tr><td rowspan="6">Percent passing by mass (%)</td><td>26.5mm</td><td>100</td><td>－</td></tr>
<tr><td>19.0mm</td><td>95～100</td><td>100</td></tr>
<tr><td>13.2mm</td><td>64～84</td><td>90～100</td></tr>
<tr><td>4.75mm</td><td>10～31</td><td>11～35</td></tr>
<tr><td>2.36mm</td><td colspan="2">10～20</td></tr>
<tr><td>75μm</td><td colspan="2">3～7</td></tr>
</table>

Table3: Standard Properties of Polymer-modified Asphalt Type H

Item		Standard value
Penetration	(1/10mm)	40 or more
Softening point	(℃)	80.0 or more
Ductility (15℃)	(cm)	50 or more
Toughness (15℃)	(N・m)	20 or more
Mass change by thin-film oven test	(%)	0.6 or less
Residual penetration after thin-film oven test	(%)	65 or more
Flash point	(℃)	260 or more

3 TECHNICAL PROBLEMS WITH RECYCLING OF POROUS ASPHALT MIXTURE

Problems relating to the RAP of porous asphalt mixture are wide-ranging, beginning with separate collection of waste and separate storage of recycled aggregate. This section deals with the technical problems with "mix design method" and "heating of recycled aggregate in the manufacturing process."

3.1 Problems with the Mix Design

Problems with the mix design show below:

- According to the Public Works Research Institute's findings (Nitta et al. 2004), etc., polymer-modified asphalt type H is difficult to recover by abson extraction (ASTM D 1856-95a) and the degree of degradation (of asphalt and modifier) is difficult to grasp.
- For these reasons, the "content of recycling additive for recycling of base asphalt" and "content of modifier for making up for decrease in modifying effect" are difficult to determine with the binder properties only.
- When recycling into straight asphalt mixture, possible effects of the modifier in the recycled aggregate are concerned about.

3.2 Problem with Hearing Recycled Aggregates in Manufacturing Process

Problem with hearing recycled aggregates in manufacturing process show below:

- In order to enable meting and unifying of old asphalt and recycling additive in a short time, it is necessary to heat the recycled aggregate to as high a temperature as possible to such an extent that no load is applied to the manufacturing equipment and that asphalt does not degrade.
- When heating the recycled aggregate by a special dryer for recycled aggregates, possible adhesion of asphalt mortar, etc. to the dryer blades (flights) and trommel is concerned about.

4 INVESTIGATION ON MIX DESIGN METHOD

For this investigation, we took up two cases, i.e., recycling waste of porous asphalt mixture into porous asphalt mixture and recycling it into dense-graded asphalt mixture. The concept and outline of the mix design are described below.

4.1 Recycling into Porous Asphalt Mixture

4.1.1 Outline of the mix design

Though polymer-modified asphalt type H is 40 (1/10 mm) or more in penetration (unit not shown hereinafter) as well as polymer-modified asphalt type II, it is higher by 10°C or more in softening point, shows a tenacity higher by 3 times or more and has a 60°C viscosity of 20,000 Pa・s or more. Therefore, when the modifier content is determined using the tenacity, 60°C viscosity, etc. as parameters after the recycling-additive content has been set with the penetration as parameter, variation in penetration may result.

With consideration to this, we investigated the following mix design method for recycling into porous asphalt mixture. The flow of the mix design is shown in Figure 1.

- Determine the recycling-additive content using the mixture properties as parameters.
- Though the mixture property used as the main parameter is the cantabro loss, adopt such parameters as the dynamic stability determined by the wheel tracking test shown in Photo1 if need be. Note that the dynamic stability (DS) is the number of wheel passes per unit deformation in 15 minutes from 45 to 60 minutes after the start of testing. The greater value of this stability indicates higher rutting resistance.
- Determine the recycling-additive content and modifier content, taking into account the minimum addition amounts necessary for uniform mixing and the economical efficiency, in addition to the mixture properties.
- Determine the design asphalt content after setting the optimal asphalt content (OAC) by dripping test.

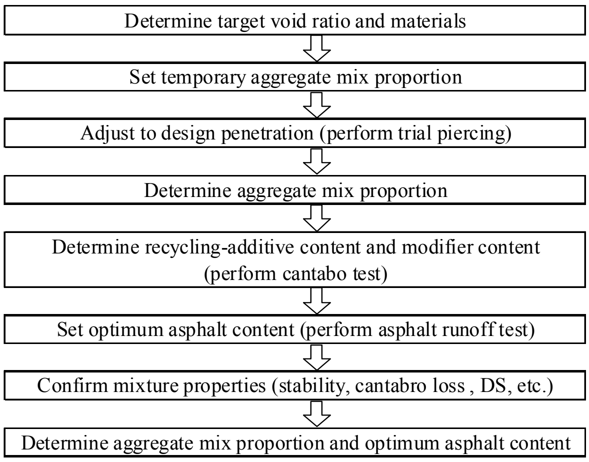

Figure1: Outline of Mix Design (recycling into porous asphalt mixture)

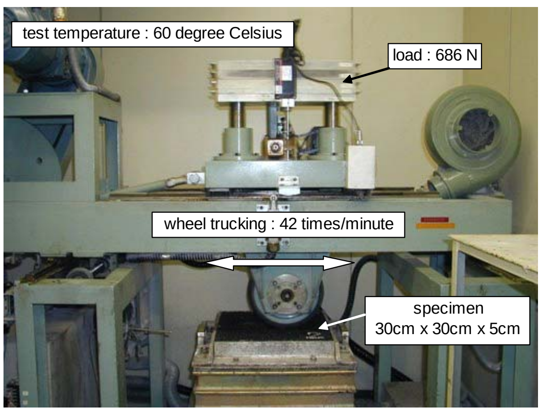

Photo1: State of Wheel Tracking Test

(1) Method of determining the recycling-additive content and modifier content

Set the recycling-additive content at three levels, 10%, 20% and 30%, and make it vary according to need. Determine the minimum modifier content, asking the manufacturer for confirmation about the minimum modifier content for uniform mixing. In most cases, the minimum content seems to be about 2% in solid phase for emulsion type modifiers and about 3% for powder type modifiers. In the present case, we set the modifier content at three levels, 0%, 3% and 6%, and decided to make the addition amount vary according to need. Note that these addition amounts are for recycled asphalt.

(2) Method of determining the design asphalt content

Make the asphalt content vary with the recycling-additive content and modifier content determined in Paragraph (1) above, perform the asphalt runoff test, set the OAC and confirm necessary mixture properties to determine the design asphalt content.

4.1.2 Example of the mix design

An attempt was made to establish the mix design by using the recycled aggregate (13-5 mm) made of waste of porous pavement from a road being in service for 8 years and setting its mixing ratio at 50%. The target mixture properties were about 20% in void ratio, 10% or less in cantabro loss , 5,000 passes/mm or more in DS and 75% or more in residual stability. These investigations were made, assuming the OAC of 50% for the new mixture to be the temporary OAC.

(1) Determination of recycling-additive content and modifier content

The relation of the recycling-additive content and modifier content to the cantabro loss is shown in Figure 2. With consideration to these results and the miscibility and economical efficiency of the modifier, the recycling-additive content was determined as 30% and the modifier content as 6%.

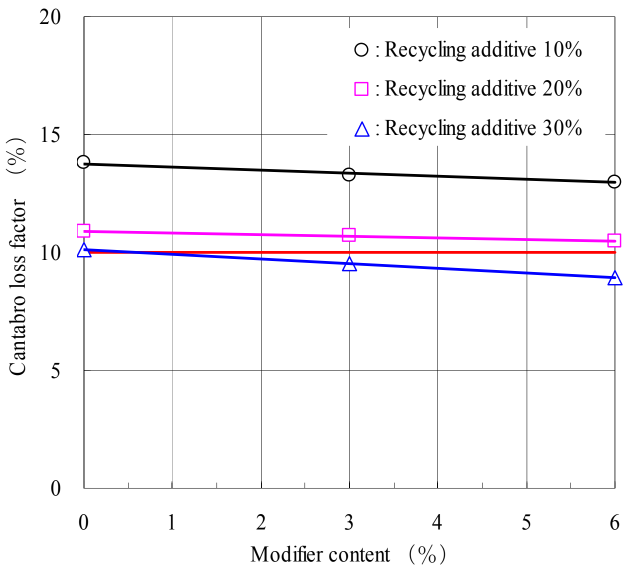

Figure2: Recycling Additive Content and Modifier Content Vs. Cantabro Loss

(2) Determination of design asphalt content

Using the asphalt content made to vary with the above-mentioned recycling-additive content and modifier content, the dripping test was performed to set the OAC, after which the DS and other property values were calculated to determine the design asphalt content. With the OAC, all of the target mixture properties were satisfied as shown in Table 4, so the value of 5.0% was determined as the design asphalt content.

Table4: Mixture Properties

Item		Test result
Recycled-asphalt content	(%)	5.0
Density	(g/cm^3)	2.011
Void ratio	(%)	20.3
Stability	(kN)	7.14
Flow value	(1/100cm)	35
Residual stability	(%)	92.2
Dynamic stability (DS)	(passes/mm)	6,500 or more
Cantabro loss (20℃)	(%)	9.1

4.2 Recycling into Dense-graded Asphalt Mixture

4.2.1 Outline of the mix design
(1) Recycling into straight asphalt mixture
Considering that the mix design should desirably be simplified as far as possible and understanding that the penetration of the recovered asphalt was not the true value, we investigated the mix design method shown below. The flow of the mix design is shown in Figure 3.

- Determine the recycling-additive content using the penetration of the recycled asphalt as parameter as in the case of ordinary recycled asphalt mixtures.
- Perform marshall stability test to determine the OAC.

(2) Recycling into modified asphalt mixture
Considering that the mix design should desirably be simplified as far as possible as in the case of recycling into straight asphalt mixture, we investigated the mix design method shown below. The flow of the mix design is shown in Figure 3.

- Determine the recycling-additive content using the penetration of the recycled asphalt as parameter
- Determine the modifier content and OAC using the marshall characteristic value and DS as parameters.

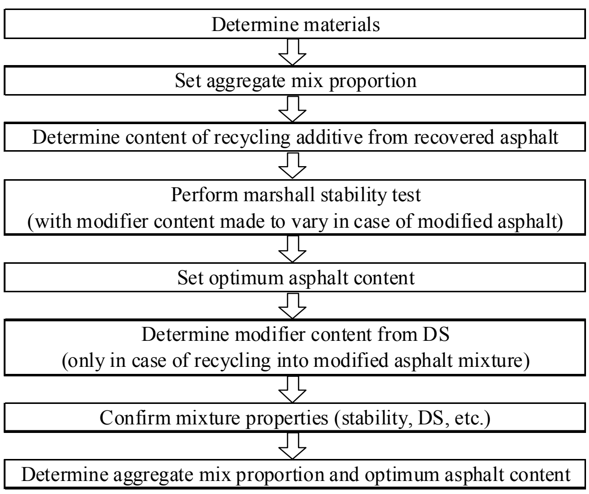

Figure3: Outline of Mix Design (recycling into dense-graded asphalt mixture)

4.2.2 Example of the mix design

This section presents an example of the mix design for recycling the recycled aggregate (13-0 mm), made of rap of porous asphalt mixture from a road being in service for 6 years, into dense-graded asphalt mixture (13) (mixing ratio of recycled aggregate: 50%).

(1) Recycling into straight asphalt mixture

1) Determination of recycling-additive content

By setting the target penetration at three levels, 40, 50 and 60 and using the asphalt recovered by the abson method, we established the “relation of the recycling-additive content and modifier content to the cantabro loss factor” to determine the recycling-additive content leading to the target penetration. The determined addition amount was 5% for the target penetration of 40, 9% for 50 and 12% for 60.

2) Marshall characteristic value

The results of the marshall stability test are given in Table 2. According to the test results, the standard property values of the dense-graded asphalt mixture (13) except the flow value for the target penetration of 60 were satisfied with the OAC at each target penetration. An equivalent void ratio was obtained at the same compaction temperature as that for the new mixture with straight asphalt, so we considered that the decrease in workability by the modifier in the recycled aggregate would be small.

3) DS

The DS values at each target penetration are included in Table 5. The great DS value of 3,000 (passes/min) seems o be attributable to the effect of the modifier in the recycled aggregate. The DS is greater, the higher the penetration is. The reason for this is considered to be that the modifier in the recycled aggregate becomes apt to be melted and dissolved with increasing recycling-additive content, resulting in higher effect of modification. Therefore, higher rutting resistance is also considered promising.

Table5: Results of Marshall Stability and Wheel Tracking Tests

Target penetration (1/10mm)	OAC (%)	Void ratio (%)	Void fills with asphalt (%)	Stability (kN)	Flow value (1/100cm)	DS (passes/mm)
40	5.6	4.0	75.8	13.50	36	3,000
50	5.6	3.9	74.7	12.80	38	4,500
60	5.6	3.9	74.4	11.43	41	4,800

4) Determination of target penetration

In the present mix design, the same level of DS is shown at the target penetrations of 50 and 60, so the modifier is considered to have been melted and dissolved in either case and the flow value at the target penetration of 60 is out of the standard value. Taking these into consideration, we judged the target penetration of 50 (recycling-additive content of 9%) to be appropriate.

(2) Recycling into modified asphalt mixture

1) Recycling-additive content

In the light of the results of (1) above, the recycling-additive content was determined as 9% at the target penetration of 50.

2) Marshall characteristic value

The marshall stability test results obtained by making the modifier content vary are given in Table 6. As shown in this table, the standard and target values are satisfied with the OAC at each modifier content.

Table6: Results of Marshall Stability Test and Wheel Tracking Test

Modifier content (%)	OAC (%)	Void ratio (%)	Saturation (%)	Stability (kN)	Flow value (1/100cm)	DS (passes/mm)
2	5.6	3.9	74.5	13.65	35	5,100
3	5.6	4.2	76.2	16.21	38	6,500 or more
4	5.6	4.1	75.9	16.80	38	6,500 or more

3) Determination of modifier content

The DS values at varying modifier contents are included in Table 6. As shown in the table, the DS even at the minimum modifier content (solid) of 2% for uniform mixing is as great as 5,100 passes/mm. Based on this result, we judged the modifier content (solid) of 2% to be appropriate.

4.3 Investigation on Heating of Recycled Aggregate

4.3.1 Heating temperature of recycled aggregate

A heating experiment was made on the recycled aggregate (13-0 mm) shown in 4.2.2 in an actual asphalt plant. As a result, it was confirmed that the recycled aggregate can be heated up to about 160°**C** with the exhaust gas temperature kept at 200°**C** or less, provided that its moisture content is 2% or less.

It was also confirmed that when the recycled aggregate is heated up to about 160°**C**, the adhesion of its fine particles to the trommel in the recycling dryer is limited as shown in Photo 2, but when it is heated up to about 140°**C**, the adhesion to the trommel increases as shown in Photo 3.

Photo2: State of Trommel after Heating Experiment (160°C)

Photo3: State of Trommel after Heating Experiment (140°C)

4.3.2 Investigation on improvement of heat efficiency

The reason why the exhaust gas temperature increases though the recycled aggregate is not heated sufficiently is presumably due to the short staying time resulting from the large amount of coarse particles and also to the phenomenon that sufficient heat exchange (heating of recycled aggregate) is not done because the recycled aggregate "does not drop like a curtain" as shown in Figure 4. As this phenomenon also occurs at a moisture content of 2% or less, it is necessary to improve the heat exchange efficiency, as a matter of course.

Considered as a solution to this problem was to make it possible to improve the staying time and dropping pattern of the recycled aggregate by pouring it together with a new aggregate and thereby to improve the heat exchange efficiency in the recycling dryer. Moreover, this solution would result in decreasing the asphalt content (ratio) in all aggregates (recycled aggregate + new aggregate) flowing through the recycling dryer, so the adhesion of asphalt mortar to the dryer blades and trommel could be prevented.

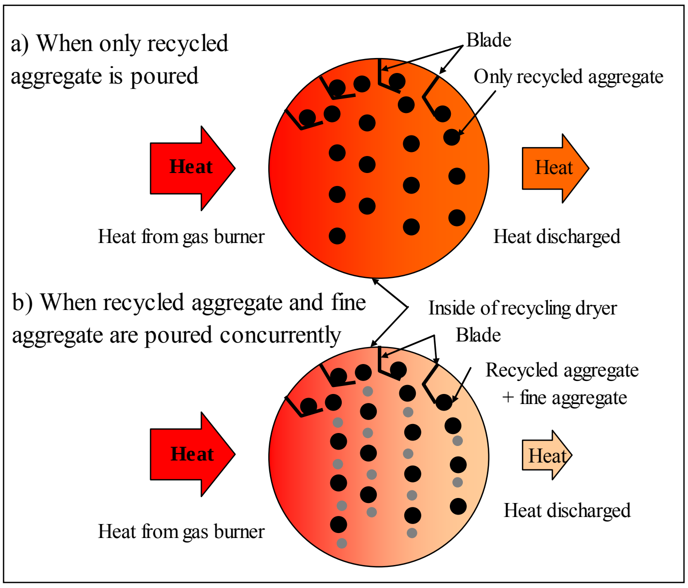

Figure4: Schematic View of Aggregate Heated

4.3.3 Experimental results

The recycled aggregate with a moisture content of about 5% was poured together with crushed stone No. 6 and sand, and the effect of this concurrent pouring was confirmed.

As a result, it was confirmed that with crushed stone No.6 as well as sand, the recycled gas can be heated to the specified temperature with the exhaust gas temperature kept below 200°C and that the adhesion of asphalt mortar can be prevented.

4.3.4 Method of heating recycled aggregate

Based on the above results, we consider it effective to pour sand concurrently when a large amount of fine aggregate is used as in the case of manufacturing dense-graded asphalt mixtures and to pour coarse aggregate such as crushed stone No. 6 concurrently when a small amount of fine aggregate is used as in the case of manufacturing porous mixtures.

5 CONCLUSIONS

1) In the case of recycling into porous asphalt mixture, we propose a method of determining the recycling-additive content and modifier content by using the mixture properties such as

cantabro loss as parameters and considering the minimum contents necessary for uniform mixing and the economical efficiency.

2) In the case of recycling into dense-graded straight asphalt mixture, we propose a method of beginning by determining the recycling-additive content at which the penetration of the recycled asphalt is about 50 and determining the OAC by making the recycled asphalt content vary with the obtained recycling-additive content and performing the marshall stability test.

3) In the case of recycling into dense-graded straight asphalt mixture, we consider that the rutting resistance can be expected to improve because the decrease in workability by the effect of the modifier in the recycled aggregate is small.

4) In the case of recycling into dense-graded modified asphalt mixture, we propose a method of determining the modifier content satisfying the target value by making the modifier content vary, performing of Item 3) above and determining the DS, etc. at each OAC.

5) In order to “secure the heating temperature” and “prevent the adhesion of asphalt mortar to the parts of the dryer” when heating the recycled aggregate, we consider it effective to pour sand concurrently when a large amount of fine aggregate is used and to pour coarse aggregate concurrently when a small amount of fine aggregate is used as in the case of manufacturing porous mixtures.

6 CLOSING REMARKS

As to the recycling of waste of porous pavement into porous asphalt mixture, test construction was carried out in an actual road by applying the mix design methods proposed herein. According to the ongoing follow-up survey, good performance has been observed even in those sections being in service for three or more years after construction. In addition, the “mix design method for recycling into dense-graded asphalt mixture” and “method of heating recycled aggregate” are slated for application to test construction in an actual road. We intend to present the results of these applications when the occasion permits.

A “method of using the penetration of recovered asphalt as parameter” has been proposed for recycling waste into dense-graded asphalt mixture. However, there may be cases where the degradation of asphalt in recycled aggregate is great (less than 20 in penetration), so we consider that the future problem is how to develop such a method as to make it possible to judge the degree of degradation in mixture properties and determine the recycling-additive content.

REFERENCE

Japan Road Association, 2004. *A Pavement Recycling Manual.* Japan

Kamiya, K, 2004. *Status of Recycling of Porous Asphalt Mix*. Japan Highway Public Corporation, Research Institute. Japan

Kanou, T., 2008. *The current state of the recycling and problem in the pavement field.* Public Works Management Journal, Economic Research Association. Japan

Konagai, A, 2006. *Recycling of Porous Asphalt Concrete.* Civil Engineering Journal, Public Works Research Center. Japan

Nitta, H., Ito, M., 2004. *Study on Recycling Method of Modified Asphalt.* Civil Engineering Journal, Public Works Research Center. Japan