Development of High-performance Binder and New Production Method of Recycled Aggregates for Recycling of Porous Asphalt Pavement

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ABSTRACT: In Japan, porous asphalt pavement is increasingly constructed every year as it is draining, improves driving safety and reduces road traffic noise. Early constructed sections have been in service for over 20 years and will soon require replacement. Thus, the establishment of technologies for recycling cut off porous asphalt pavement is pressing need. However, the porous asphalt mixture has a special particle size called super-open grade. Moreover, the high viscosity modified asphalt which contained polymer in large quantities is used for this mixture. From such a background, in order to perform good recycling in this mixture, the mixing rate of recycled aggregates is constrained to be 30% or less. So, in this research, while solving the above-mentioned problems, aiming at the higher mixing rate of recycled aggregates, it inquired from two steps shown below.

As the first step, higher mixing rate was enabled by applying superheated steam crushing technology instead of the conventional method at the time of recycled aggregates manufacture. Next, as the second step, even when recycled aggregate became a high mixing rate, the recycling binder renewable good was developed uniquely.

As a result, even when the mixing rate of recycled aggregates increased to 80%, comparable good quality was able to be secured as compared with virgin mix. Furthermore, when full-scale pavement was built and the durability by accelerated heavy vehicle simulator was evaluated, it was checked that the recycled porous asphalt mixture including 80% of recycled aggregates has comparable durability compared with virgin mixture.

KEY WORDS: Porous asphalt pavement, recycling, superheated steam disintegration, recycling binder, accelerated loading device

1 INTRODUCTION

In Japan, porous asphalt pavement is increasingly constructed every year as it is draining, improves driving safety and reduces road traffic noise. Early constructed sections have been in service for over 20 years and will soon require replacement.

Thus, technologies for recycling cut off porous asphalt pavement should be urgently established. From the viewpoint of effective reuse of resources, methods that can recycle a large amount of cut off materials at once are highly awaited. In order to mix recycled aggregates so as to constitute high percentages, the grain size of the recycled mixture should be stabilized, and a new binder (hereinafter “recycling binder”) needs be developed for restoring the properties of recycled porous asphalt pavement mixtures (Ayabe et al.2007, Konagai et al.2006, Ougi et al.2001).

The authors investigated the milling technologies that can recover aggregates of stable grain sizes and developed recycling binder that can produce good-quality pavement even when recycled aggregates are mixed so as to account a high percentage, according to the examination procedure of Figure 1 (Nishijima et al.2007).

Based on the results of laboratory tests, trial mixing and test construction were performed, and the durability of full-scale pavement was assessed by conducting accelerated loading test . The tests showed that even when the mixture contained recycled aggregates as much as 80%, the recycled mixture showed high performances and produced durable pavement.

This paper describes the investigations of the milling technology, development of the recycling binder, and durability test performed using an accelerated loading device.

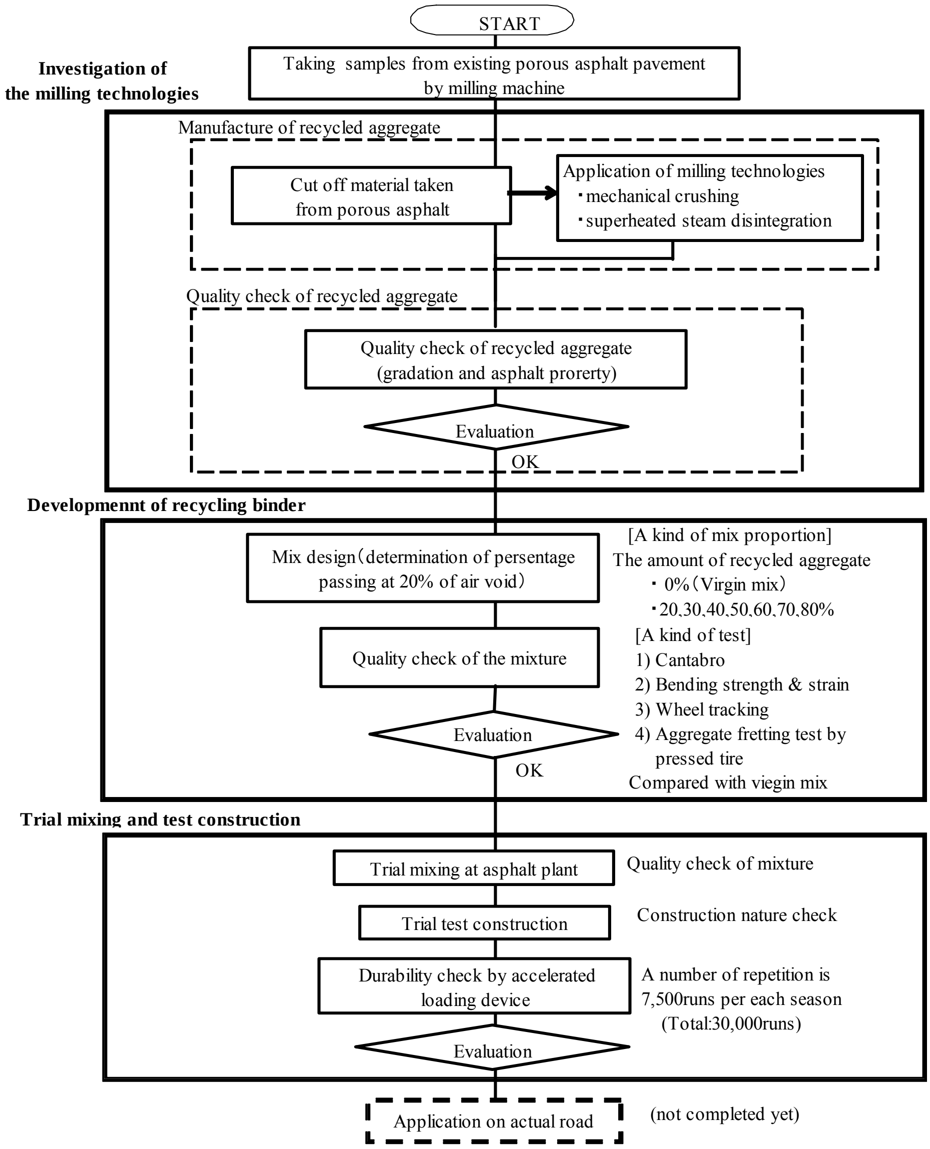


Figure 1: The examination procedure in this study.

2 INVESTIGATION OF TECHNOLOGY FOR MILLING POROUS ASPHALT PAVEMENT WASTES

2.1 Problems of the Conventional Method

The conventionally widely used method for producing recycled aggregates from pavement wastes involves mechanical crushing and has the following two big problems:
1) The grain size of aggregates is unstable after bitumen is removed by extraction test, and crushing causes further refining of aggregates. Thus, the upper limit of mixing recycled aggregates is only about 30% in general (Konagai et al.2006).
2) Mortar adheres inside drums of asphalt recycling plants when drier heated (Matsumoto et al.2004).

Aiming to stabilize the grain size of extracted recycled aggregates and increase the allowable mixing ratio of recycled aggregates, the feasibility of superheated steam disintegration was investigated as an alternative of traditional mechanical crushing.

Superheated steam disintegration involves sending vapor at 100℃ into a superheated steam generator, heating the vapor further to about 300℃, and disintegrating and classifying aggregates with the superheated steam. This method does not crush aggregates but loosens them by heat, and thus aggregates are not refined further. A flow of recycled aggregate production using superheated steam disintegration is shown in Figure 2.

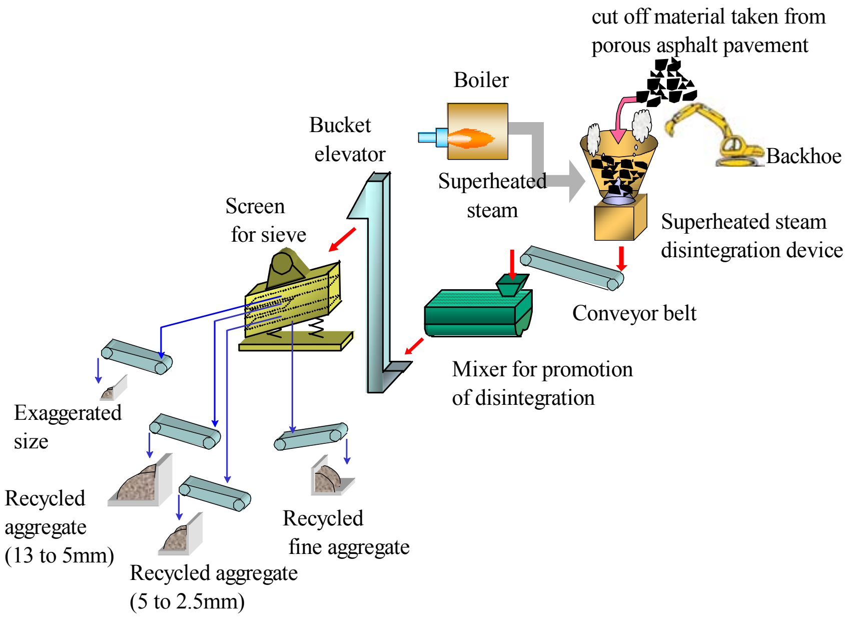


Figure 2: The manufacture flow of recycled aggregate by superheated steam disintegration.

2.2 Comparative Investigation of Mechanical Crushing and Superheated Steam Disintegration

(1) Comparison of the grain sizes of recovered aggregates

The grain size distributions of specimens prepared by removing bitumen using the two methods are shown in Figure 3. In the specimens of apparent grain size class of 13-5 mm, the fraction that passed the sieve of 4.75mm after extraction test was about 15% less in superheated steam disintegration than in mechanical crushing, showing that the former causes less refining of grains than the latter. Subsequently, mix proportions were calculated so as to maximize the percentage of recycled aggregates while satisfying an almost central value of the standard grain sizes for porous asphalt mixtures stated in the Guideline for Design and Construction of Pavement of Japan Road Association. As a result, judging from the grain sizes, the maximum amount of recycled aggregates that could be mixed was about 50% when the aggregates were recovered by mechanical crushing, while the percentage could be increased to about 90% by recovering aggregates by superheated steam disintegration.

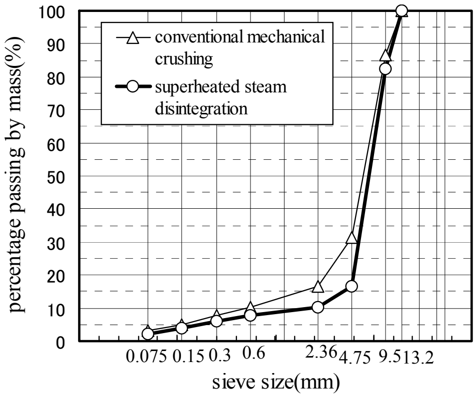


Figure 3: Gradation of apparent grain size class of 13-5mm after extraction test.

(2) Comparison of the properties of recovered bitumen

The properties of bitumen recovered from recycled aggregates are shown in Table 1. The results show that superheated steam did not cause deterioration of the bitumen.

Table 1: Test result of asphalt property after superheated steam disintegration.

Material	Penetration (1/10mm)	Softening point (℃)	Ductility (cm)
Mechanical crushing	23	65.0	10
Surperheated steam	23	66.0	10
cut off porous pavement (original)	24	67.0	10

3. DEVELOPMENT OF RECYCLING BINDER

3.1 Basic Concepts

Aiming to prepare recycled porous asphalt mixture that has performances equivalent to new porous asphalt mixtures of high viscosity modified asphalt prepared using 100% new materials (hereinafter referred to as the “virgin mixture”), the bitumen of recycled porous asphalt mixture (“recycled asphalt”) was decided to consist of old bitumen and recycling binder to be newly added.

The conceptual relationships between the percentage of recycled aggregates and the amounts of asphaltene and polymer required for recycling binder are shown in Figure 4.The figure shows that the larger the amount of recycled aggregates to be mixed, the smaller the asphaltene content and the larger the polymer content the recycling binder should have. It is ideal to decide and supply recycling binder that is optimum to the mixing ratio of recycled aggregates and the deterioration states of old bitumen at each site, but in this study, two kinds of recycling binder (A and B) were decided to be developed to cover mix ratios of 20 to 80% recycled aggregates.

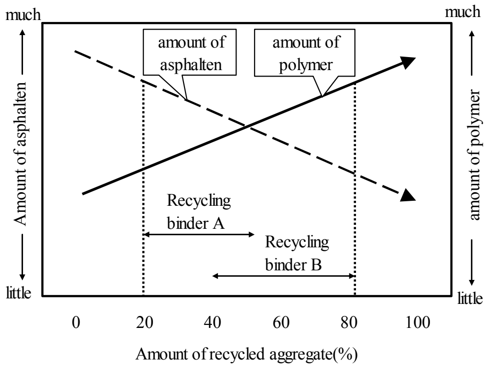


Figure4:Relationship between amount of asphalten and polymer required for recycling binder.

3.2 Evaluation of the Performances of Recycled Porous Asphalt Mixture

(1) Items of evaluation

The four items shown in Table 2 were decided to be used as the performances for evaluating the characteristics of recycled porous asphalt mixture, and each was tested.

Table2:Test item and evaluation criteria.

Evaluation item	Test item	Test condition	Evaluation criteria
Scattering resistance of mixture in a low-temperature domain	Cantabro test at low temperature	Test temperature: zero℃	Virgin mixture and more than equivalent
Scattering resistance of mixture in a high-temperature domain	Aggregate fretting test by pressed tire	Test temperature: 60℃ Revolving speed:10.5 rotations/min.	Virgin mixture and more than equivalent
Rutting resistance of mixture in a high-temperature domain	Wheel tracking test	Test temperature: 60℃ Running speed:42passes/min.	more than 3,000passes/mm
Cracking resistance of mixture in a low-temperature domain	flexure test (check bending fracture strain)	Test temperature: -10℃ Loading speed:50mm/min.	Virgin mixture and more than equivalent

(2) Investigation of Mix Proportions

The mix proportions investigated were decided to be as shown in Table 3 by taking the properties of the two binders into account.

Table 3:Investigation of mix proportion.

A kind of recycling binder	Mixing rate of recycled aggregate(%)							
	0	20	30	40	50	60	70	80
A		○	○	○	○			
B				○	○	○	○	○
high viscosity generally used(for comparison)	○							

○: Carried-out combination

(3) Results of Evaluation

The test results of evaluation are shown in Figure 5a) to d).

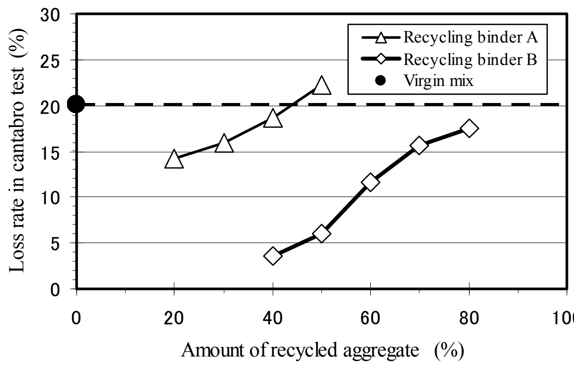
1) A ggregate scattering resistance at low temperatures
The results of a low temperature Cantabro test at 0℃ are shown in Figure 5a). Mixtures that contained 40% and 80% recycled aggregate and recycling binders A and B, respectively, were

found to have performances equivalent to or better than those of the virgin mixture.

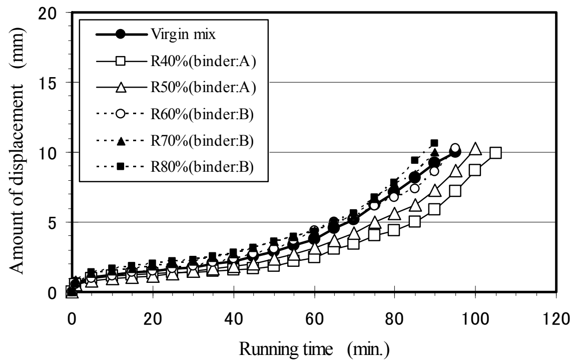
2) Aggregate scattering resistance at high temperatures
The displacement measurements in an aggregate scattering test at 60℃ are shown in Figure 5b). When the running time until the displacement reached 10 mm was compared with that of the virgin mixture, the performances were equivalent or better up to 50% recycled aggregates in recycling binder A and were almost equivalent, although slightly lower, with 80% recycled aggregates in recycling binder B.

3) Rutting resistance at high temperatures
The results of a wheel tracking test at 60℃ are shown in Figure 5c). The test was performed using loads of 686±10N and specimens of 100% compaction. Although the test conditions were different from those for determining the number of wheel passes that causes plastic deformation, the results were judged to have satisfied the required wheel passes of 3,000 passes/mm for Class N7 (heaviest traffic volume in Japan) based on the results in the past.

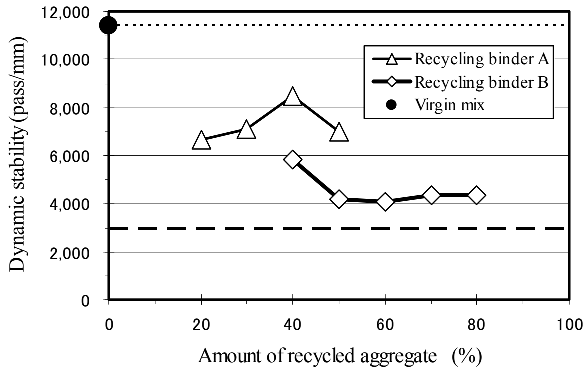
4) Crack resistance at low temperatures
The bending fracture strains at -10℃ are shown in Figure 5d). As the amount of recycled aggregates increased, the bending fracture strain dropped. The strains were similar with those of the virgin mixture up to about 40% recycled aggregates in recycling binder A and up to 80% recycled aggregates in recycling binder B.



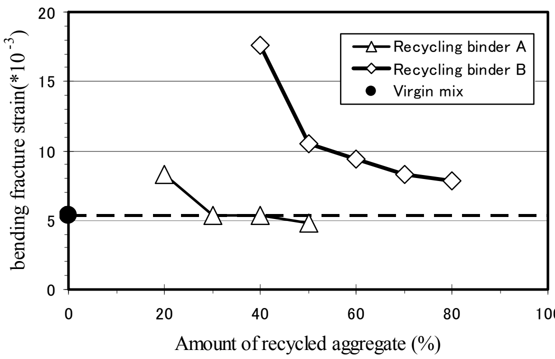
a) Cantabro test in low temperature



b) Aggregate fretting test by pressed tire



c) Wheel tracking test



d) Bending fracture strain

Figure 5:Results of evaluation in the laboratory.

4. Trial mixing and test construction
Based on the results of the laboratory tests, trial mixing was performed in an existing asphalt

recycling plant in the procedure shown in Figure 6. Test pavement was constructed on an accelerated loading yard, and the durability was assessed by accelerated loading.

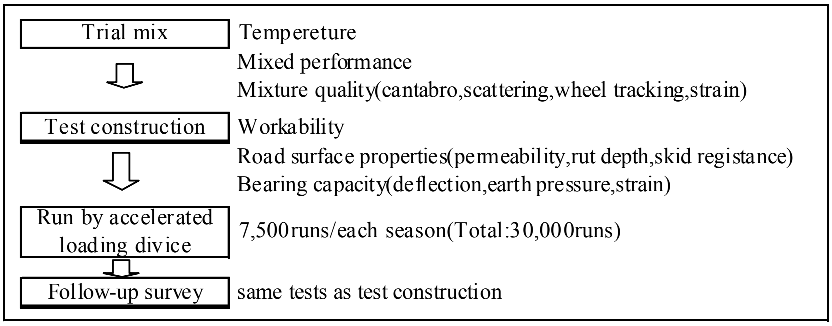
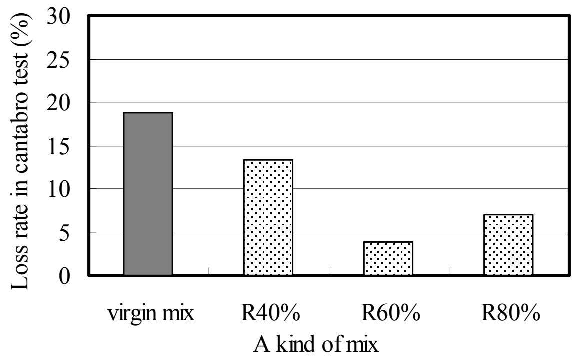


Figure 6: The flow of the outline and the test items of trial mix and construction.

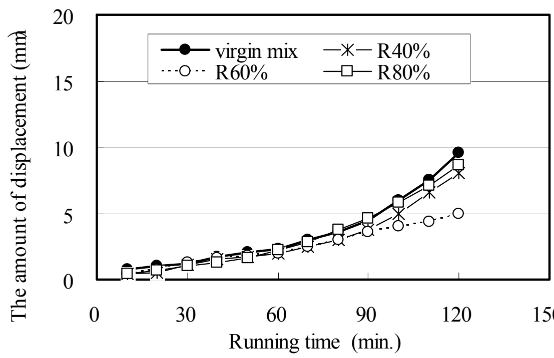
4.1 Results of trial mixing

The mix proportions tested were 40%, 60% and 80% recycled aggregates (“R40%”, “R60%” and “R80%”, respectively). Recycling binder A was used for R40%, and recycling binder B was used for R60% and R80%. All mix proportions satisfied the target mixing temperature of 170±10℃. Visual inspection showed that the mixtures were fully mixed.

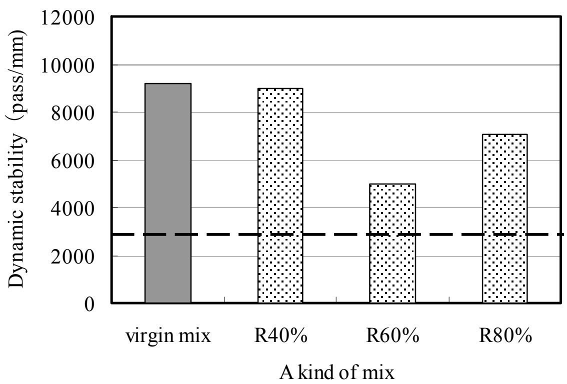
The properties of the mixtures are shown in Figures 7a) to d). All recycled porous asphalt mixtures were shown to have performances similar to or better than those of the virgin mixture.



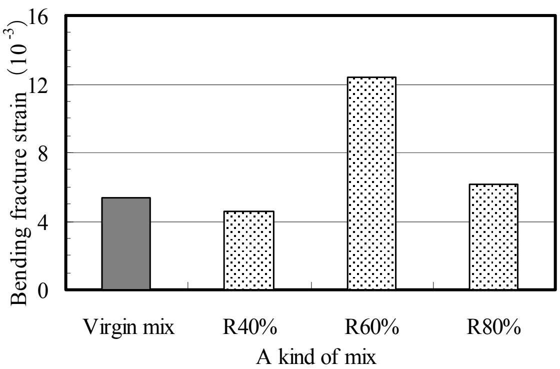
a) Cantabro test result at low temperature



b) Aggregate scattering test by pressed tire



c) Wheel tracking test



d) Strain in Bending fracture test

Figure 7: Results of trial mixing.

4.2 Results of Test Construction

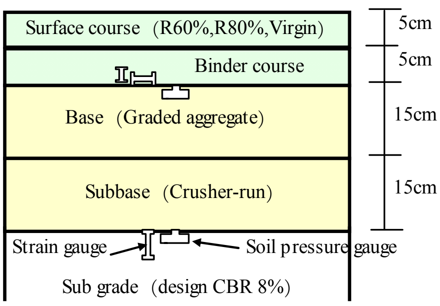
(1) Evaluation of the Performance for Construction

Cross section and position of test points in test construction yard are shown in Figure 8.Three test pavement sections of R60%, R80% and the virgin mixture were decided to be constructed based on restrictions on the traveling distance of the accelerated loading device and from a viewpoint of selecting high mixing ratios of recycled aggregates.

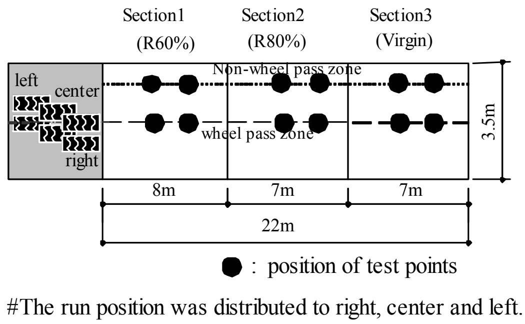
The workability and the performances for construction of the recycled porous asphalt mixtures (R60% and R80%) were as good as those of the virgin mixture. Soil pressure gauges and strain gauges were embedded in the sections to monitor the behaviors inside the pavement.

(2) Durability Evaluation by Accelerated Loading Device

The items investigated have been listed in Figure 6. Results of test construction are shown in Figure 9a) to f).The accelerated loading device had double tires that passed on the pavement back and forth with a load of 49 kN. A view of construction and the run situation by the accelerated loading device are shown in Photo 1a) and b).



a)Cross section



b)Position of test points

Figure 8: Cross section and position of test points in test construction yard.

a) construction situation

b) run situation by accelerated loading device

Photo1: A construction situation and a run situation in the test section.

1) Properties of the road surface

The results of on-site permeability test are shown in Figure 9a). Repetitive wheel passes caused slight drops in permeability, but the drops were likely to not constitute practical inconvenience. No clear differences were found between mixtures of different amounts of recycled aggregates.

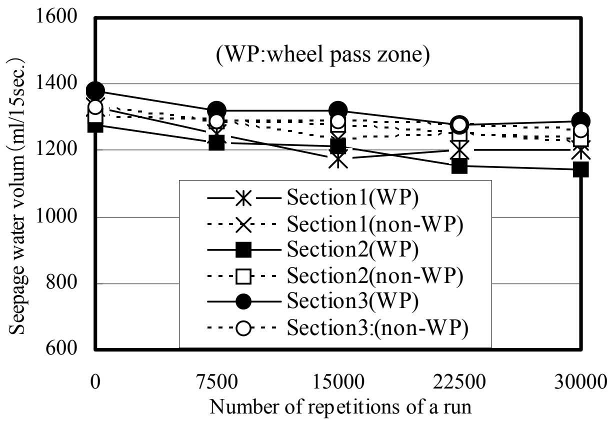
The rut depths after wheel passes are shown in Figure 9b). Ruts were formed on all sections at the initial stage of wheel passing but did not develop much thereafter.

The rut depths were similar on Sections 2 (R80%) and 3 (virgin mixture) but were deep on Section 1 (R60%). The deep ruts were likely attributable to the dynamic stability (refer to Figure 7c)) of the mixture, but were only about 15 mm even after 30,000 wheel passes and would not impede practical services.

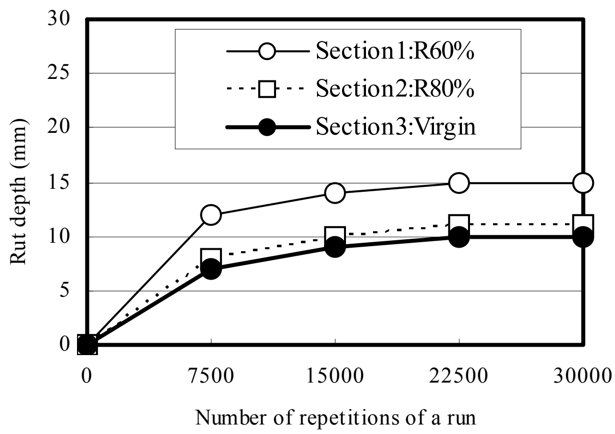
Skid resistance values (μ 60 values) that were measured with a dynamic friction tester are shown in Figure 9c). The μ 60 values gradually increased along with repetitive wheel passing and passage of time, showing increases in skid resistance. No differences were observed between driving and non-driving zones.

2) Bearing capacity of pavement

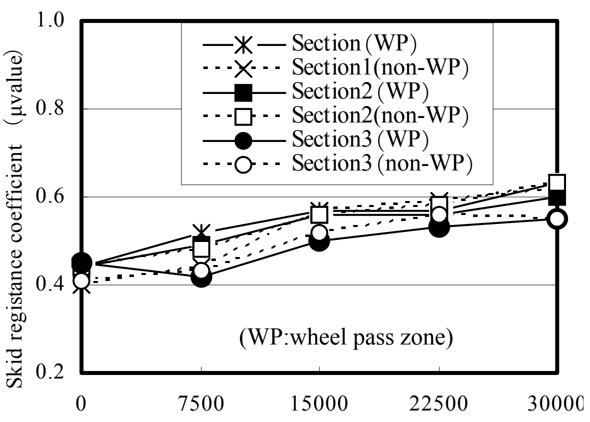
Deflections which are D0 values before temperature correction at the driving zones measured with a falling weight deflectometer are shown in Figure 9d) for each section. No differences were observed between the sections, showing that all sections had similar bearing capacities. Some of soil pressure and strain values that were measured while passing the loading tire are shown in Figure 9e) and f). No large differences in soil pressure and strain were observed between the sections, backing the conclusion of the sections having similar bearing capacities. Detailed investigation, such dynamic analysis, will be conducted using the collected data.



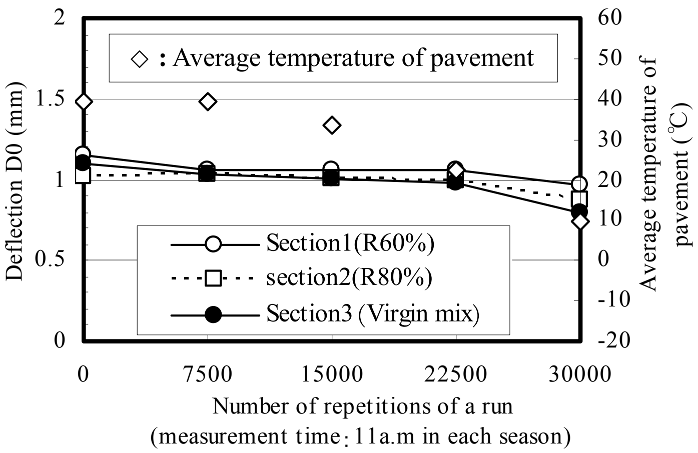
a) Permeability test



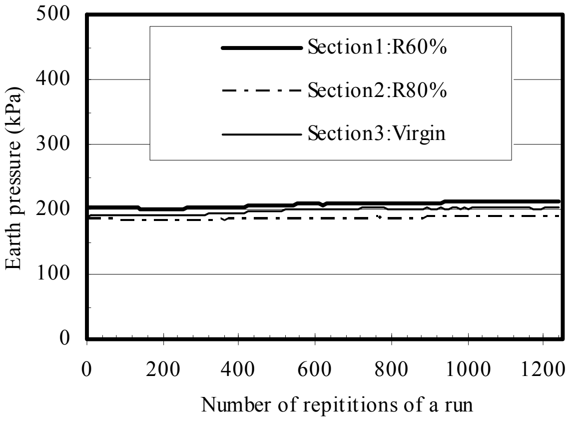
b) Rut depth



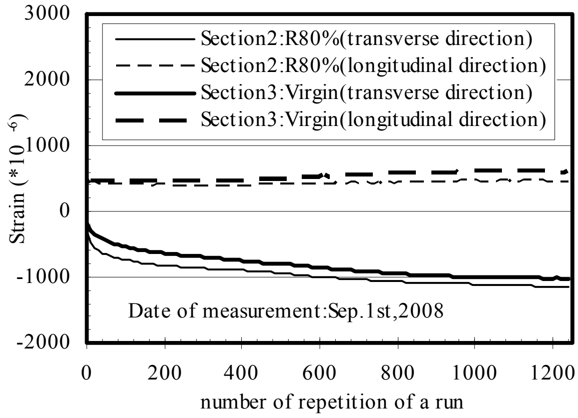
c) Skid resistance value



d) Deflection by FWD



e) Vertical pressure at the top of sub grade



f) Transverse strain at the bottom of binder course

Figure9: Results of test construction.

5. CONCLUSIONS

The following conclusions were obtained from this study:

1) Recycled aggregates that were recovered using the conventional mechanical crushing method could be added so as to account for 50% or less of all aggregates, while those recovered using superheated steam disintegration are possible to be added up to about 90% of all aggregates.
2) Superheated steam disintegration did not cause deterioration of bitumen contained in recycled aggregates.
3) Of developed recycling binders, Binder A could restore the performance of mixtures to the level of the virgin mixture up to recycled aggregate content of about 40%, and Binder B could restore the performance of mixtures up to recycled aggregate contents of about 80%.
4) Mixtures containing 40%, 60% and 80% recycled aggregates mixed in an existing asphalt plant showed satisfactory mixture properties.
5) The performance for construction was satisfactory in both 60% and 80% recycled aggregate contents. Accelerated loading test showed that the mixtures were as durable as virgin mixtures.

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