Development of Technology to Utilize Recycled Aggregate for Drainage Pavement

Yoshihide Notsu
Chugoku Technical Office, Chugoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism

ABSTRACT: The use of drainage pavement has been increasing to improve safety and the roadside environment; however, drainage pavement utilizes new rather than recycled aggregate, leading to a decrease in the rate of recycled aggregate use. To maintain the current rate of recycled aggregate use, we developed technology to construct drainage pavement which partly consists of recycled aggregate.

The mixture was prepared using 13-0mm recycled aggregate, which is readily available in the Chugoku region. The results of the physical property test showed that the optimum asphalt content rate of the mixture with the recycled aggregate was 5.0 to 5.1%, which is slightly higher than that of mixtures with the new aggregate. The void rate, Marshal stability, and permeability coefficient for the mixture with the recycled aggregate met the criteria, while the index for the Cantabro loss amount did not.

The field experiment was conducted under three different conditions to test the functionality of the drainage pavement with recycled aggregate. As the drainage pavement with the recycled aggregate demonstrated the same functionality as that with new aggregate, we concluded that it has the appropriate functionality. We also confirmed that when 20% or less of the drainage pavement consists of recycled aggregate, the quality, mixing performance, as well as workability are the same as with new aggregate.

KEY WORDS: Recycling, drainage pavement, environment.

1 INTRODUCTION

Measures to prevent global warming, materialization of eco-friendly traffic, and formation of a cycling-oriented society have been studied in various fields. Eco-friendly technologies to use waste asphalt concrete (hereinafter referred to as “recycled aggregate”), heat insulation pavement, and drainage pavement have been studied and used widely for road construction.

Under these circumstances, drainage pavement, which is the theme of this current technological development, has functions to improve vehicle running safety and the roadside environment, and the number of examples of construction is also increasing year after year. Since 100% new aggregate is used in general for conventional drainage pavement, there is a concern that the utilization of recycled aggregate may decrease. To maintain the current recycling rate, an attempt was made in this study to develop technology to use recycled aggregate for drainage pavement.

2. EXAMINATION OF THE USE OF RECYCLED AGGREGATE FOR DRAINAGE PAVEMENT

2.1 Material property test

A test was conducted in a laboratory to examine the property of recycled aggregate. A questionnaire was sent to asphalt plants with recycled aggregate production facilities in the Chugoku region, and the type of recycled aggregate to be used for the mix proportion test was selected based on the result.

A physical test was conducted to confirm the material properties of the recycled aggregate and the new aggregate. The results were almost equivalent to the regional average (quantity of extracted asphalt, grading after extraction, and penetration of asphalt) shown in the answers to the questionnaire.

In addition, the recycled aggregate to be used for the mix proportion test was selected based on the results. The recycled aggregate was classified into 13-0 mm, 13-5 mm, and 5-0 mm according to the size. Since most recycled aggregate (93% of all recycled aggregate in the Chugoku region) was crushed to 13-0 mm size in the Chugoku region, two asphalt plants with mixing works that produce 13-0 mm aggregate were selected to prepare the aggregate for the mix proportion test.

2.2 Preliminary test

In the preliminary test, the mixing ratio of recycled aggregate in the drainage mixture (hereinafter referred to as “recycled drainage mixture”), when recycled aggregate was used as part of aggregate in the drainage mixture, was verified and the asphalt in use was examined.

2.2.1 Mixing ratio of recycled aggregate

After a test was conducted to examine the physical properties of the recycled aggregate to be used, trial calculations of combined gradations were carried out for four cases with different mixing ratios (10%, 20%, 30%, and 40%), and the result is shown in Table 1.

Table 1 ：Result of trial calculation for combined gradation (Recycled aggregate 13-0mm）

	Asphalt plant	Plant C					Plant G					Range of gradition
	Mixing ratio of recycled aggregate (%)	10	20	30	40	Maximum amount of incorpor	10	20	30	40	Maximum amount of incorpor	
Aggregate mixing ratio	Crushd rock #6	79.8	74.7	66.9	57.8	73.1	80.0	75.1	67.5	58.6	73.4	
	Coarse sand	5.5	1.4	―	―	―	5.4	1.3	―	―	―	
	Recycled aggregate (13-0mm)	10.0	20.0	30.0	40.0	23.2	10.0	20.0	30.0	40.0	23.4	
	Filler	4.7	3.9	3.1	2.2	3.7	4.6	3.6	2.5	1.4	3.2	
Combined gradation pass% mass	19.2mm	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100
	13.2mm	98.5	98.6	98.7	98.9	98.5	98.4	98.5	98.5	98.7	98.5	90~100
	4.75mm	24.7	26.6	31.1	**36.7**	27.3	24.3	26.0	30.0	**35.4**	26.5	11~35
	2.36mm	15.0	15.0	17.7	**21.7**	15.0	15.0	15.0	17.7	**21.7**	15.0	10~20
	0.60mm	10.7	10.5	11.7	13.7	10.4	10.7	10.4	11.7	13.7	10.4	―
	0.30mm	7.9	7.9	8.6	9.5	7.9	8.0	7.8	8.4	9.0	7.8	―
	0.15mm	5.8	5.7	5.9	5.9	5.8	5.8	5.8	5.8	5.9	5.7	―
	0.075mm	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	3~7

* (shaded) Out standard

The result of the trial calculations show that the maximum mixing ratio of the recycled aggregate 13-0 within the range of gradation is approx. 30%, which will be approx. 20% when the medium value in the range of gradation is regarded as a target.

2.2.2 Examination of asphalt to be used

The properties of the asphalt were confirmed to determine the asphalt to be used for the recycled drainage mixture. It was decided that the mixing ratio of the asphalt prepared by mixing new asphalt and old asphalt, which was to be used for confirmation of the properties, should be determined based on the penetration after mixing.

The target penetration after mixing was set at more than 40 (1/10 mm), because the penetration of the asphalt prepared by mixing old and new asphalt, when the penetration of the new asphalt was more than 50 (1/10 mm), exceeded the standard penetration of the high-viscosity modified asphalt (40 (1/10 mm)) as a result of the test.

Furthermore, it has been confirmed that the new asphalt, which can be used to condition old asphalt, is conventional high-viscosity modified asphalt, high-viscosity modified asphalt for snowy and cold areas, and high-viscosity modified asphalt for recycled mixtures.

2.2.3 Marshall test

Based on the mixing ratios obtained by trial calculations, Marshall specimens were prepared and various tests were conducted. Table.2 shows the mixing ratios that cause the void rate to be 20%.

Table２：Mixing ratios that cause void rate to be 20%

	Asphalt plant	Plant C					Plant G					General drainage mixture	Range of gradation
	Grade nunber	№11	№12	№13	№14	№15	№16	№17	№18	№19	№20		
	Type of Asphalt	High-viscosity modified asphalt	High-viscosity modified asphalt	High-viscosity modified asphalt mixture for recycled mixtures	High-viscosity modified asphalt for snowy and cold areas	High-viscosity modified asphalt for snowy and cold areas	High-viscosity modified asphalt	High-viscosity modified asphalt	High-viscosity modified asphalt mixture for recycled mixtures	High-viscosity modified asphalt for snowy and cold areas	High-viscosity modified asphalt for snowy and cold areas		
Aggregate mixing ratio	Crushd rock #6	77.9	77.3	80.3	77.3	77.8	76.0	76.8	76.8	75.3	73.4	86.8	
	Coarse sand	–	–	–	–	–	–	–	–	–	–	8.2	
	Recycled aggregate (13-0mm	19.0	19.0	16.0	19.0	18.5	21.5	20.0	20.0	21.5	23.4	–	
	Filler	3.1	3.7	3.7	3.7	3.7	2.5	3.2	3.2	3.2	3.2	5.0	
Combined gradation pass (%) mass	19.2mm	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100
	13.2mm	98.5	98.5	98.5	98.5	98.5	98.4	98.3	98.3	98.4	98.4	98.4	90~100
	4.75mm	24.0	24.6	22.6	24.6	24.2	24.8	24.5	24.5	25.5	26.6	21.0	11~35
	2.36mm	12.2	12.8	11.4	12.8	12.6	13.4	13.3	13.3	14.1	15.0	13.0	10~20
	0.60mm	8.7	9.3	8.4	9.3	9.1	9.2	9.4	9.4	9.9	10.5	9.6	–
	0.30mm	6.6	7.2	6.6	7.2	7.0	6.9	7.3	7.3	7.6	8.0	7.8	–
	0.15mm	4.8	5.4	5.1	5.4	5.3	5.0	5.5	5.5	5.7	5.9	5.7	–
	0.075mm	4.0	4.5	4.2	4.5	4.4	4.1	4.6	4.6	4.7	4.9	5.0	3~7
Mixing ratio of new & old asphalt	New asphalt	12.7	12.7	10.8	12.7	12.5	20.7	19.2	19.2	20.7	22.4	0.0	
	Old asphalt	87.3	87.3	89.2	87.3	87.5	79.3	80.8	80.8	79.3	77.6	100.0	

The 2.36 mm percentage passing by mass of the recycled drainage mixture (recycled aggregate 13-0), which will cause the void rate to be 20%, show variations depending on the type of aggregate (No.6 crushed rock, sand, recycled aggregate, and filler). However, the percentage passing by mass is considered to be approx. 15% or less. The mixing ratio of the recycled aggregate at that time is estimated to be approx. 20%, although it is affected by the gradation of the recycled aggregate.

2.3 Laboratory test

Based on the results of the preliminary test, a mix proportion test was conducted to determine the optimum quantity of asphalt for the respective aggregate mix proportion ratios. Then a physical property test was conducted for the mixture using the optimum quantity of asphalt to confirm the physical properties of the mixture.

2.3.1 Confirmation of the properties of recycled drainage mixture

The result of the physical property test is shown in Table.3. The optimum quantity of asphalt for the general drainage mixture was 4.9%, while that for the recycled drainage mixture tended to be slightly larger (5.0-5.1%).

Table３：Result of confirmation of the properties of recycled drainage mixture

Asphalt plant		Plant C					Plant G					General drainage mixture
Grade nunber		NO.11	NO.12	NO.13	NO.14	NO.15	NO.16	NO.17	NO.18	NO.18	NO.20	
Type of asphalt		High-viscosity modified asphalt	High-viscosity modified asphalt	High-viscosity modified asphalt mixture for recycled	High-viscosity modified asphalt for snowy and cold areas	High-viscosity modified asphalt for snowy and cold areas	High-viscosity modified asphalt	High-viscosity modified asphalt	High-viscosity modified asphalt mixture for recycled	High-viscosity modified asphalt for snowy and cold areas	High-viscosity modified asphalt for snowy and cold areas	High-viscosity modified asphalt
Aggregate mixing ratio	Crushd rock #6	77.9	77.3	80.3	77.3	77.8	76.0	76.8	76.8	75.3	73.4	86.8
	Coarse sand	-	-	-	-	-	-	-	-	-	-	8.2
	Recycled aggregate (13-0mm	19.0	19.0	16.0	19.0	18.5	21.5	20.0	20.0	21.5	23.4	-
	Filler	3.1	3.7	3.7	3.7	3.7	2.5	3.2	3.2	3.2	3.2	5.0
Optimum quantity of asphalt(%)		5.1	5.1	5.1	5.1	5.1	5.0	5.0	5.0	5.0	5.0	4.9
Physical properties	Cantabro loss (%)	6.7	7.8	4.8	3.4	4.1	11.6	11.1	5.5	1.7	5.2	5.0
	Dynamic Stability	8750	10500	7438	11406	8021	6825	8712	7928	8167	10313	7350

The result of the Cantabro loss test is shown in Table3. Both the high-viscosity modified asphalt mixture for recycled mixtures and the high-viscosity modified asphalt for snowy and cold areas showed values that are almost identical to the values of the general drainage mixture. The Cantabro loss of the high-viscosity modified asphalt mixture shows a tendency to be larger than that of the general drainage mixtures. Japan Highway Public Corporation specifies that the standard Cantabro loss shall not exceed 20%.

2.3.2 Examination of the mixing method (heating or normal temperature) for recycled aggregate

The physical properties of the mixtures prepared using different recycled aggregate mixing methods (temperature), as well as the mixing method that would meet the criteria of quality of the recycled drainage mixture, were confirmed.

The mixing temperature was fixed at 170ºC during the test, and the recycled aggregate was mixed at 110ºC and at normal temperature. As a result, a difference in the physical properties of the mixtures, which would result from the difference in the heating method of the recycled aggregate, was not observed.

2.4 Test pavement on the premises

Test pavement was laid in one section (3.5 m x 20 m) on the premises of Chugoku Technical Office to examine the workability and physical properties.

Pavement was laid in five cases, using conventional high-viscosity modified asphalt with 20% recycled aggregate (13-0 mm), the mixture prepared by mixing the high-viscosity modified asphalt for snowy and cold areas, and the mixture prepared by mixing the high-viscosity modified asphalt for recycled aggregate, as well as the mixture without recycled aggregate and conventional high-viscosity modified asphalt mixture with 10% recycled aggregate, which were prepared for comparison.It was confirmed that the physical properties of the respective drainage mixtures produced in advance on a trial basis at the asphalt plant conform to the standard specified in the Guidelines on Drainage Pavement Technology (Draft).

Concerning the workability, the rolling compaction condition and the flatness were judged as satisfactory as a result of visual confirmation.

Concerning the physical properties, the quantity of seepage water, dynamic coefficient of friction (DFT), texture measurement (MTM) results, core density measurement results (compaction degree and void rate), and asphalt content extraction test results were almost the same and judged to be satisfactory.

2.5 Test pavement on actual road

Based on the result of the respective tests, the workability, durability, and serviceability of the drainage pavement, in which recycled aggregate was used, were examined using the test pavement on an actual road.

In view of the climatic condition and the road utilization condition in the Chugoku region, three places within the jurisdiction were selected to lay test pavements. One material was laid for 100 m in one construction section, and the respective test materials were laid consecutively together with non-interference sections (5-20 m) on condition that a comparative pavement (new aggregate only) must be laid without fail.

i) Region A (snowy and cold areas)

Six areas shown in Fig.1 were provided for verification of the serviceability and durability of the recycled drainage mixture for which measures for snowy and cold areas had been taken, as well as for comparison with other test pavements.

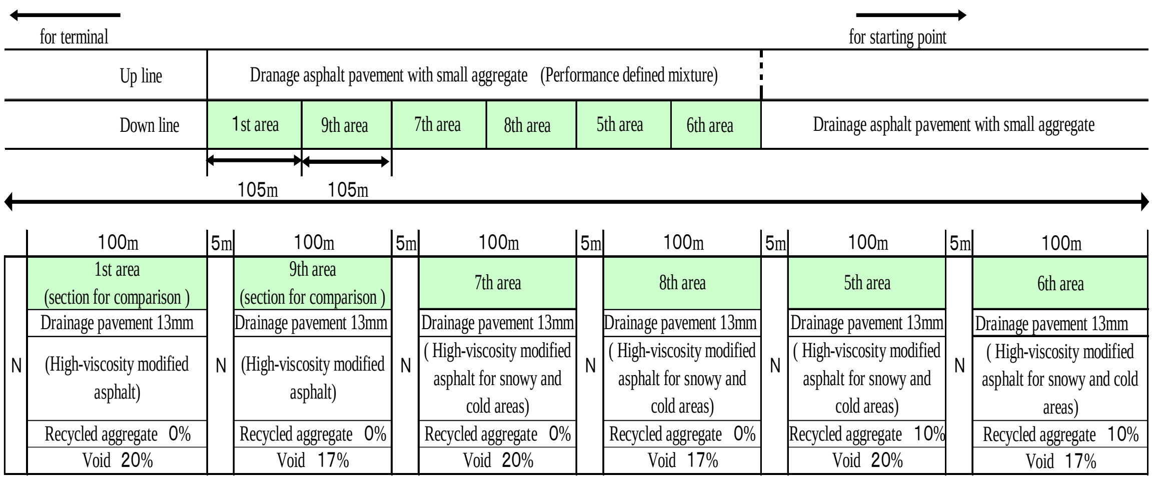

Fig. 1 : Outline of region A

ii) Region B (Paving program for the use of 3,000 or more of vehicles a day)

Four areas shown in Fig.2 were provided for verification of the serviceability and durability of the recycled drainage mixture when the mixing ratio of recycled aggregate was changed, as well as for comparison with other test pavements.

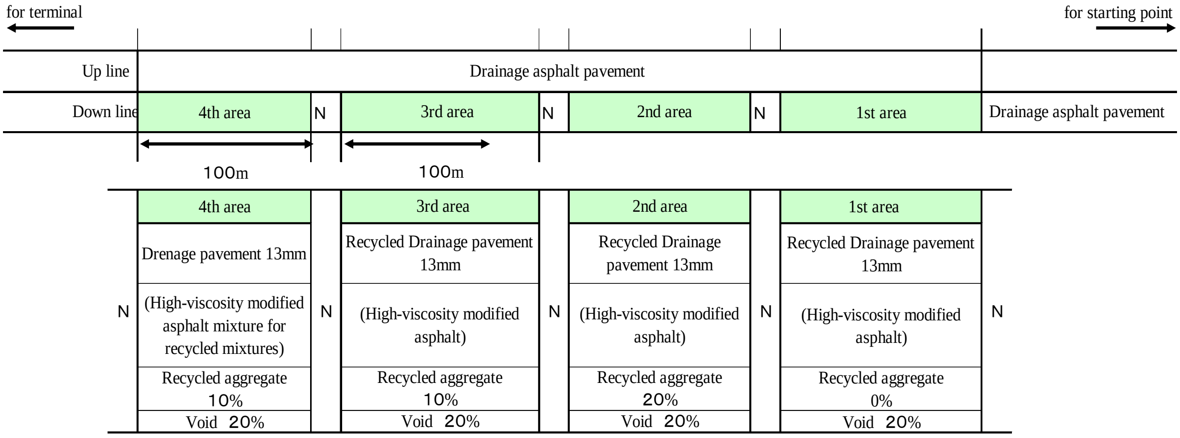

Fig. ２ : Outline of region B

iii) Region C (Paving program for the use of 1,000 to 3,000 vehicles a day)

Four areas shown in Fig.3 were provided for verification of the serviceability and durability of the recycled drainage mixture when the mixing ratio of recycled aggregate was changed, as well as for comparison with other test pavements.

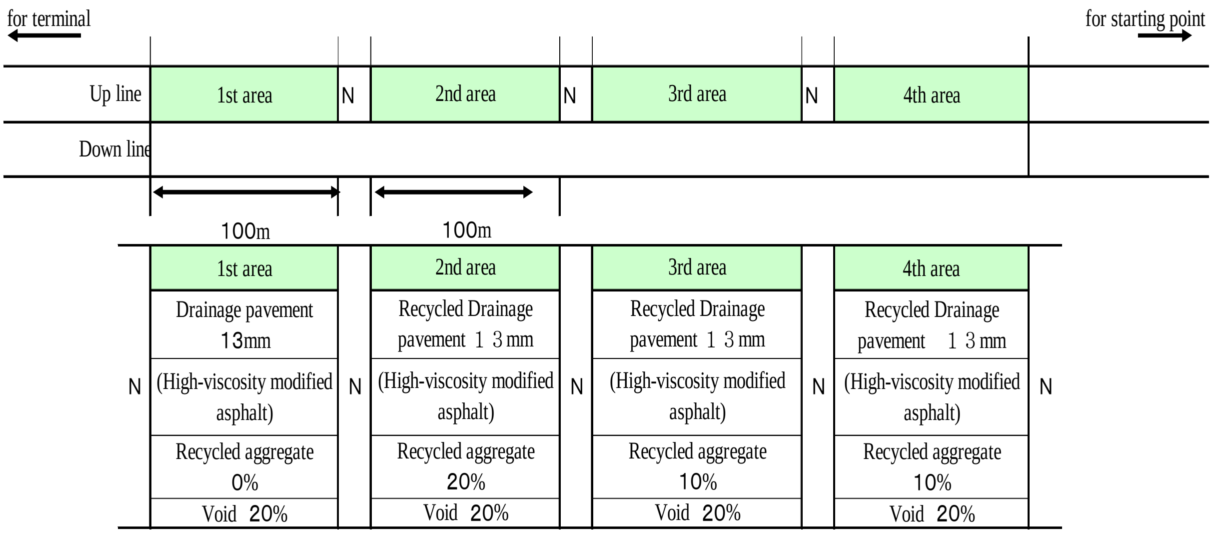

Fig. ３ : Outline of region C

As shown in Tables 4,5and6, after pavement work, a follow-up study was conducted to examine the quantity of rut depth, cracking rate, flatness, quantity of seepage water, skid resistance, and road surface texture depth. Three year later, the behavior of the respective recycled drainage pavement is almost the same, and both the functions and performance of the respective pavements are considered to be satisfactory.

Table. 4 : Comparison of follow-up investigations in region A

Route	Investigation starting year	Type of pavement	Rut depth(mm)			Craking rate(%)			Flatness(mm)		
			Initial value	2008	Variation from initial value	Initial value	2008	Variation from initial value	Initial value	2008	Variation from initial value
Route 9	2006	6th area	5.5	6.8	1.3	0.0	0.0	0.0	1.26	1.30	0.04
		5th area	5.8	7.3	1.5	0.0	0.0	0.0	1.32	1.58	0.26
		8th area	6.3	8.4	2.1	0.0	0.0	0.0	0.95	1.02	0.07
		7th area	5.4	6.4	1.0	0.0	0.0	0.0	1.20	1.16	-0.04
		9th area	5.8	8.1	2.3	0.0	0.0	0.0	0.73	0.82	0.09
		1st area	5.6	7.7	2.1	0.0	0.0	0.0	1.00	1.33	0.33
		Type of pavement	Quantity of seepage water(ml/15sec)			Skid resistance(μ60)			Road surface texture depth(MTM)(mm)		
			Initial value	2008	Variation from initial value	Initial value	2008	Variation from initial value	Initial value	2008	Variation from initial value
		6th area	1266	374	-70.5	0.46	0.42	-0.04	0.68	0.73	0.05
		5th area	1304	419	-67.9	0.53	0.49	-0.04	0.70	0.74	0.04
		8th area	1293	288	-77.7	0.53	0.48	-0.05	0.72	0.78	0.06
		7th area	1304	323	-75.2	0.51	0.46	-0.05	0.69	0.70	0.01
		9th area	1274	476	-62.6	0.51	0.45	-0.06	0.71	0.70	-0.01
		1st area	1345	566	-57.9	0.54	0.48	-0.06	0.88	0.93	0.05

Table. 5 : Comparison of follow-up investigations in region B

Route	Investigation starting year	Type of pavement	Rut depth(mm)			Craking rate(%)			Flatness(mm)		
			Initial value	2008	Variation from initial value	Initial value	2008	Variation from initial value	Initial value	2008	Variation from initial value
Route 2	2006	1st area	4.8	7.7	2.9	0.0	0.0	0.0	0.80	0.88	0.08
		2nd area	5.5	8	2.5	0.0	0.0	0.0	0.63	0.76	0.13
		3rd area	6.1	7.8	1.7	0.0	0.0	0.0	0.60	0.70	0.10
		4th area	4.3	6.8	2.5	0.0	0.0	0.0	0.91	0.84	-0.07
		Type of pavement	Quantity of seepage water(ml/15sec)			Skid resistance(μ60)			Road surface texture depth(MTM)(mm)		
			Initial value	2008	Variation from initial value	Initial value	2008	Variation from initial value	Initial value	2008	Variation from initial value
		1st area	1325	928	-30.0	0.58	0.52	-0.06	0.68	0.66	-0.02
		2nd area	1351	874	-35.3	0.54	0.52	-0.02	0.63	0.68	0.05
		3rd area	1372	874	-36.6	0.59	0.53	-0.06	0.65	0.69	0.04
		4th area	1327	414	-68.8	0.54	0.49	-0.05	0.56	0.65	0.09

Table. 6 : Comparison of follow-up investigations in region C

Route	Investigation starting year	Type of pavement	Rut depth(mm)			Craking rate(%)			Flatness(mm)		
			Initial valu	2008	Variation from initial value	Initial valu	2008	Variation from initial value	Initial valu	2008	Variation from initial value
Route 188	2006	1st area	2.8	2.8	0.0	0.0	0.0	0.0	0.88	0.95	0.07
		2nd area	2.5	3.0	0.5	0.0	0.0	0.0	0.65	0.70	0.05
		3rd area	3.1	3.6	0.5	0.0	0.0	0.0	0.71	0.65	-0.06
		4th area	2.1	3.1	1.0	0.0	0.0	0.0	0.69	0.74	0.05
		Type of pavement	Quantity of seepage water(ml/15sec)			Skid resistance(μ60)			Road surface texture depth(MTM)(mm)		
			Initial valu	2008	Variation from initial value	Initial valu	2008	Variation from initial value	Initial valu	2008	Variation from initial value
		1st area	1367	927	-32.2	0.55	0.51	-0.04	0.62	0.63	0.01
		2nd area	1290	754	-41.6	0.57	0.55	-0.02	0.60	0.66	0.06
		3rd area	1310	679	-48.2	0.55	0.49	-0.06	0.54	0.60	0.06
		4th area	1348	461	-65.8	0.44	0.37	-0.07	0.60	0.67	0.07

As shown in Fig. 4 , however, the secular change in the quantity of seepage water was different in Region C when new and recycled aggregate were mixed.

As shown in Table 7, the percentage of the gradations 2.36 mm and 75μm in the recycled drainage mixtures is about 1-2% larger, and the quantity of asphalt is also about 0.1-0.3% larger. As a result, the film covering recycled aggregate became thicker than the film covering new aggregate, possibly reducing the quantity of seepage water because voids were crushed more or less.

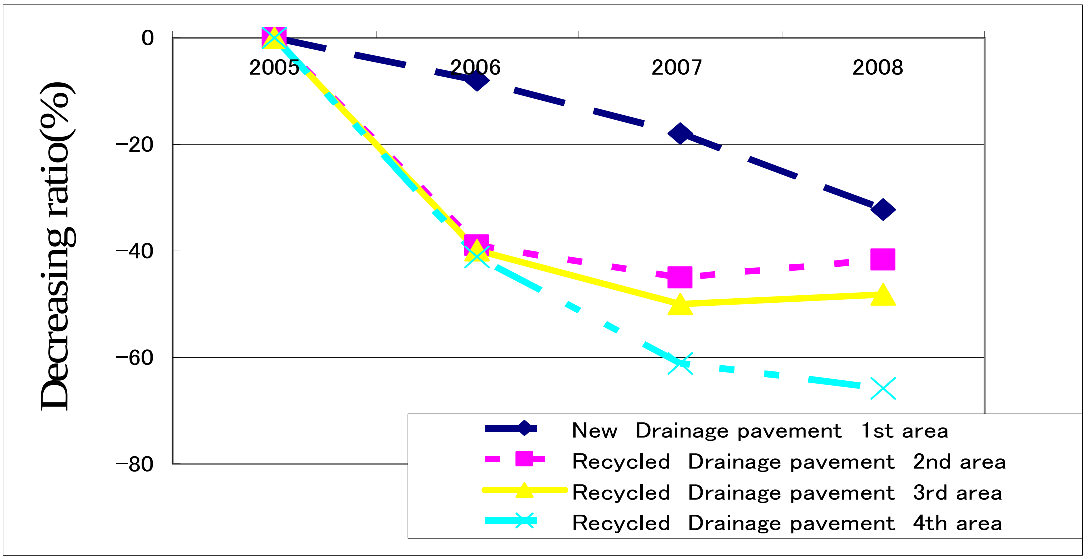

Fig.4 : Change in quantity of seepage water in region C

Table.7 : List of materials and physical property test items in region C

Type of drainege asphalt mixture	Mixing ratio of recycled aggregate (%)	Type of Asphalt	Asphalt content(%)	2.36mm pass wight (% mass)	75μm pass wight (% mass)	Voids(%)	Dynamic Stability	Coefficient of permeability×10^-2 (cm/sec)	Cantabro loss (%)
General drainage mixture	0	High-viscosity modified asphalt	4.88	13.6	3.9	20.6	7,000	0.16	6.0
Recycled drainage mixture	20	High-viscosity modified asphalt	5.22	14.6	5.5	19.0	6,300	0.14	6.0
Recycled drainage mixture	10	High-viscosity modified asphalt	5.13	15.0	5.2	19.6	6,300	0.15	6.0
Recycled drainage mixture	10	High-viscosity modified asphalt mixture for recycled	4.95	15.6	4.9	19.8	7,000	0.15	5.0

3 CONCLUSION

The intent of this study was to develop technology to lay recycled drainage asphalt pavement using recycled aggregate. Based on the results of the tests on the pavement on the premises and the pavement on actual roads, it has been confirmed that the quality, mixing performance, workability, etc. of the recycled drainage pavement (with a maximum mixing ratio of approximately 20%) with recycled aggregate are almost the same as those of drainage pavement with new aggregate.

However, it was found that attention should be paid to the difference in the pavement properties resulting from the type of asphalt adhering to the recycled aggregate to be used and the quantity of new asphalt to be added.

The recycling rate of the aggregate used in asphalt pavement is high at present, but the increase in the reconstruction and repair work using drainage pavement with a large quantity of new aggregate can reduce the recycling rate. This technology is useful for maintaining the present aggregate recycling rate, and its use is expected to increase in future.