FULL USAGE OF RECLAIMED ASPHALT CONCRETES AS BASES

Shisheng WU[1], Yoshitaka HACHIYA[2] and Koichi SUGIMOTO[3]

[1] Dr. Eng., STA Fellow, Airport Facility Laboratory, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure and Transport (1-1, Nagase 3, Yokosuka 239-0826, Japan)

[2] Member of JSCE, Dr. Eng., Chief, Airport Facility Laboratory, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure and Transport

[3] Technical Research Institute, Obayashi Road Corporation (2-12-36, Numakage, Urawa 336-0027, Japan)

Recycling of asphalt concrete is increasingly used as a major rehabilitation method in Japan because it can conserve natural resources, reduce costs and save energy. In this study, reclaimed asphalt concrete from Tokyo International Airport was evaluated for use in four types of base materials: recycled granular material, recycled cement stabilized material, recycled cement-emulsified asphalt stabilized material and recycled hot-asphalt stabilized material. The results of laboratory tests indicated: 1) These materials can satisfy base course and subbase requirements, and 2) they are sensitive to temperature and water.

Key Words: *Reclaimed asphalt pavement, base course, subbase, Tokyo International Airport*

1. BACKGROUND

Old asphalt concrete is generated during most pavement resurfacing and reconstruction projects in airports and highways. This material can be economically reused as a good quality paving material that conserves aggregate and asphalt, reduces transportation requirements, eliminates disposal problems, and lowers fuel consumption. Recycling of old asphalt concrete is not a new idea, but dates back to World War II. It is currently an important process in several countries that provides a useful source of aggregate for the construction industry from old asphalt concrete.

For example, in Canada asphalt concrete recycling has become a key component of the paving industry[1)]. Methods and equipment for a range of cold and hot asphalt concrete recycling processes are well developed and widely used across Canada, particularly in highway projects and urban areas.

In Japan, asphalt concrete has become increasingly recycled as a major rehabilitation method since the Law on Recycling of Waste Materials took effect. Besides reducing costs and saving energy, the conservation of natural resources is even more important because Japan is relatively poor in natural aggregate reserves. For pavement rehabilitation projects at airports, all of the reclaimed materials must be used within the same project. A series of laboratory tests were conducted as a fundamental study to develop this strategy.

In this study, four types of base materials from reclaimed asphalt pavement (RAP) were evaluated: recycled granular material (RGM), recycled cement stabilized material (RCSM), recycled cement-emulsified asphalt stabilized material

Table 1 Grain size analysis of aggregates

Sieve (mm)		37.5	26.5	19.0	13.2	4.75	2.36	0.60	0.30	0.15	0.075
		Passing percentage of weight (%)									
RAP	20-13mm	100.0	100.0	94.4	10.0	0.8					
	13-5mm			100.0	93.2	8.6	1.2	0.6	0.4	0.3	0.1
	5-0mm				100.0	95.2	51.4	10.4	3.9	1.1	0.4
Crusher-run (C-40)	40-0mm	100.0	90.8	75.8	60.1	19.9	15.8	9.4	7.6	6.1	5.0

Table 2 Summary of properties of aggregates

Type	RAP				Crusher-run (C-40)	
Grain size (mm)	20-13	13-5	5-2.36	2.36-0	40-2.36	2.36-0
Bulk specific gravity in saturated surface-dry	2.553	2.531	2.407	2.300	2.665	2.472
Bulk density (g/cm^3)	2.533	2.507	2.358	2.261	2.644	2.370
Apparent density (g/cm^3)	2.583	2.567	2.479	2.352	2.701	2.637
Absorption (%)	0.75	0.94	2.06	1.71	0.79	4.27
Liquid limit (%)	NP				20.4	
Plastic limit (%)	NP				17.3	
Plastic index	NP				3.1	
Loss percentage in washing test (%)		0.4				
Maximum specific gravity	2.590	2.585	2.472			
Maximum dry density (g/cm^3)					2.188	
Optimum water content (%)					5.7	
Modified CBR (%)					89	

Table 3 Properties of asphalt emulsion

Testing items		Result
Engler viscosity (25℃)		7
Residue-on-sieving (1.18mm) (%)		0
Cement mixing (%)		0.2
Charge of particle		Nonionic
Residue by evaporation		60
Residue by evaporation	Penetration (25℃)	195
	Solubility in toluene (%)	99.87
Storage stability (24h) (%)		0
Freezing stability (-5℃)		-

Table 4 Properties of recycling agent

Testing items		Result
Kinematic viscosity (60℃) (mm^2/s)		244.9
Flash point (COC) (℃)		224
Viscosity ratio after thin film oven (60℃)		1.33
Loss on thin film oven test (%)		-1.84
Specific gravity		1.0329
Component analyses (mass %)	Asphaltene	0.0
	Saturates	41.3
	Aromatics	47.5
	Resin	6.6
	Recovery ratio	95.4

(RCESM) and recycled hot-asphalt stabilized material (RHSM). The primary objectives of this study were as follows.

1) Evaluate the performance of recycled base materials from Tokyo International Airport;
2) Determine the procedure for preparing these base materials to meet the specification.

2. PERFORMANCES OF MATERIALS

The following materials were used in this study: reclaimed asphalt pavement (RAP) from Tokyo International Airport, crusher-run C-40, Portland cement, asphalt emulsion, virgin asphalt (Straight asphalt 60/80) and recycling agent. **Table 1** and **Table 2** give the grain size analysis and the key

Table 5 Result of asphalt extraction test

Sieve (mm)		37.5	26.5	19.0	13.2	4.75	2.36	0.60	0.30	0.15	0.075	Asphalt content (%)
		Passing percentage of weight (%)										
RAP	20-13mm	100.0	100.0	98.9	55.4	27.1	20.7	13.5	10.3	8.3	4.9	2.3
	13-5mm			100.0	94.9	31.4	19.5	13.3	10.2	7.9	4.8	2.6
	5-0mm				100.0	98.1	65.0	35.4	26.1	18.0	11.9	6.2
	20-0mm	100.0	100.0	98.6	82.6	52.4	37.7	21.9	16.2	12.2	7.7	4.4

Table 7 Combined gradations of RGM

Sieve (mm)		37.5	26.5	19.0	13.2	4.75	2.36	0.60	0.30	0.15	0.075
		Passing percentage of weight (%)									
Ratio of RAP (%)	100	100.0	100.0	98.8	77.7	40.2	20.4	4.2	1.7	0.5	0.2
	75	100.0	97.7	93.1	73.3	35.2	19.3	5.6	3.2	1.9	1.5
	50	100.0	95.4	87.3	69.0	30.1	18.1	6.8	4.7	3.4	2.6
	25	100.0	93.1	81.6	64.5	25.0	17.0	8.2	6.1	4.7	3.9
	0	100.0	90.8	75.8	60.1	19.9	15.8	9.4	7.6	6.1	5.0

Table 8 Results of compaction test and modified CBR test for RGM

Items	Ratio of RAP (%)				
	0	25	50	75	100
Maximum dry density (g/cm^3)	2.188	2.121	2.090	2.010	1.943
Optimum water content (%)	5.7	5.7	6.2	7.0	5.2
Modified CBR (%)	89.0	33.0	13.0	6.6	4.2

Table 6 Gradation ratio of RAP

Grain size (mm)	20-13	13-5	5-0
Weight ratio (%)	21.8	39.5	38.7

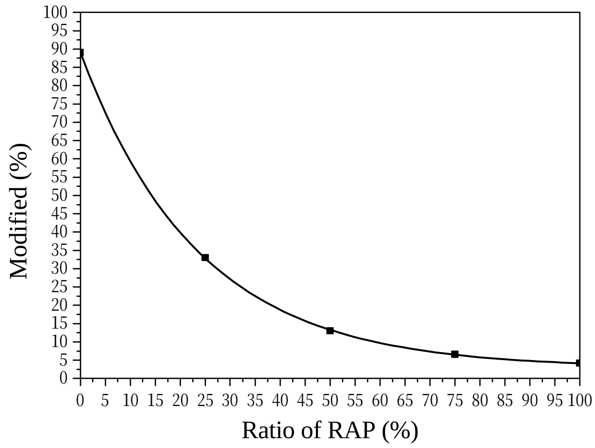


Fig.1 Modified CBR test for RGM

performance characteristics of the aggregates, respectively. **Table 3** and **Table 4** also show the properties of asphalt emulsion and recycling agent, respectively.

The asphalt extraction test (Soxhlet method)[2)] was used to evaluate the performance of the reclaimed asphalt pavement. **Table 5** shows the results. The penetration of the recycled asphalt is 23 (1/100cm).

3. COMPOSITION DESIGNS AND PROPERTIES OF BASE MATERIALS

In this study, the properties of the four types of materials were investigated.

(1) Recycled granular material (RGM)

a) Composition

The simplest use of old asphalt concrete is uniform blending, at a plant or in-place, of suitably processed, reclaimed asphalt pavement (RAP) with conventional granular material for base course or subbase applications. The recycled granular material in this study was composed of RAP or/and crusher-run C-40. The RAP is classified into three different grain sizes with gradation ratios given in **Table 6**. For recycled granular material (RGM), five combinations of RAP and C-40 were tested at 40℃[3)], with RAP ratios of 100%, 75%, 50%, 25% and 0%. **Table 7** gives their combined gradations. To obtain adequate RGM compaction, care must be taken to avoid segregation.

Table 9 Modified CBR targets

Type	Modified CBR (%)	Ratio of RAP
Base course	80	3
	45	18
Subbase	30	28
	20	37

Table 10 Compaction test for RCSM

Type	Ratio of RAP (%)							
	25		50		75		100	
Cement content (%)	4	8	4	8	4	8	4	8
Maximum dry density (g/cm^3)	2.055	2.135	1.966	2.072	1.872	1.968	1.772	1.871
Optimum water content (%)	5.9	7.9	6.0	7.7	6.7	7.7	5.5	6.1

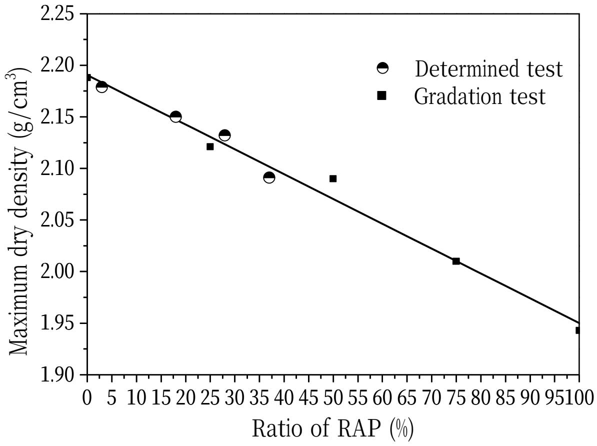


Fig.2 Maximum dry density for RGM

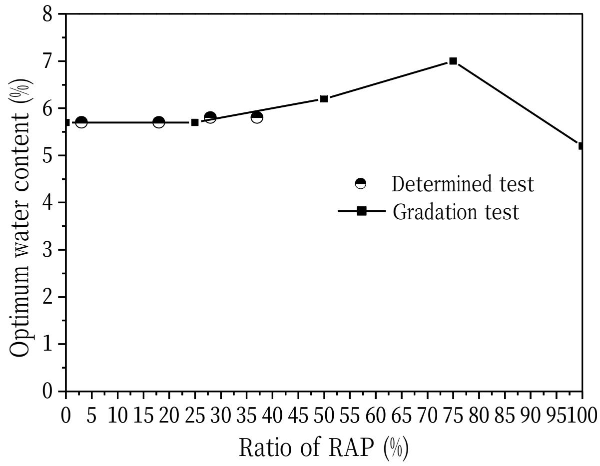


Fig.3 Optimum water content for RGM

The compaction and modified CBR tests[2)] were employed for these gradations to determine the optimum ratio of RAP in RGM. **Table 8** summarizes the results.

Fig.1 shows the relationship between the modified CBR and the ratio of RAP. The CBR of RGM decreases significantly for RAP ratios greater than about 20%. Based on the current specification[4)], the modified CBR should be over 80% for the base course and over 30% for the subbase of asphalt pavements, and over 45% and 20% for the base course and subbase, respectively, for concrete pavements. Consequently, when a target modified CBR is specified, the corresponding ratio of RAP can be determined from the figure (seen in **Table 9**).

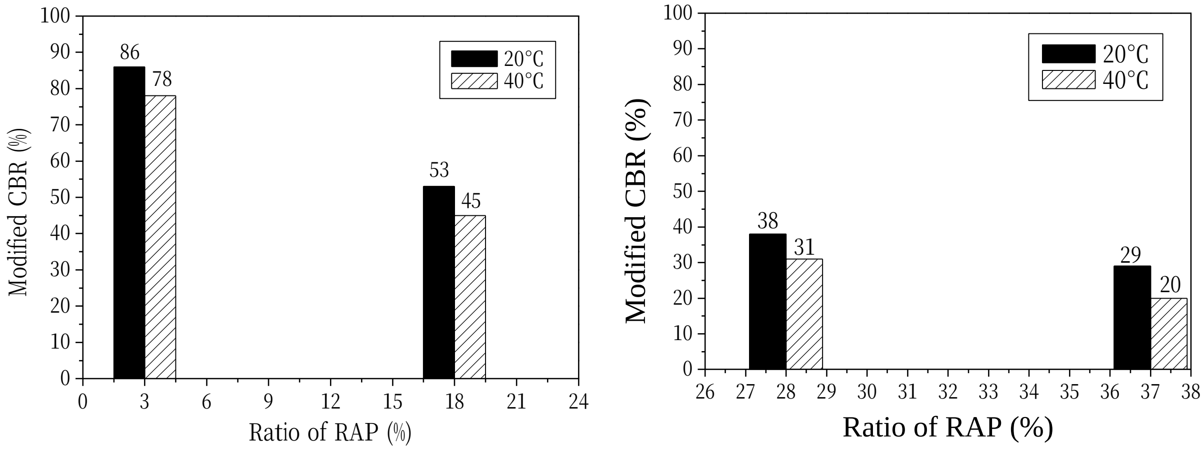
The compaction test was also used to verify the compositions (**Table 10**). **Figs. 2** and **3** show the relationship of the ratio of RAP to the maximum dry density and optimum water content, respectively. These figures confirm the ratios of RAP listed in **Table 9**. Unfortunately, the use of RAP in RGM does not have a major advantage for reclaimed asphalt concrete.

b) Properties

Based on the ratios of RAP in **Table 9**, the modified CBR test and the CBR test were conducted to evaluate the performance of RGM under different temperatures and curing methods. **Fig.4** shows the effect of temperature on the modified CBR. Obviously, the modified CBR is higher at lower temperatures. Moreover, the modified CBR increases with decreasing ratio of RAP. This phenomenon shows that RGM is sensitive to the temperature. Therefore, if the material is used in hot locations, the ratio of RAP should be strictly controlled.

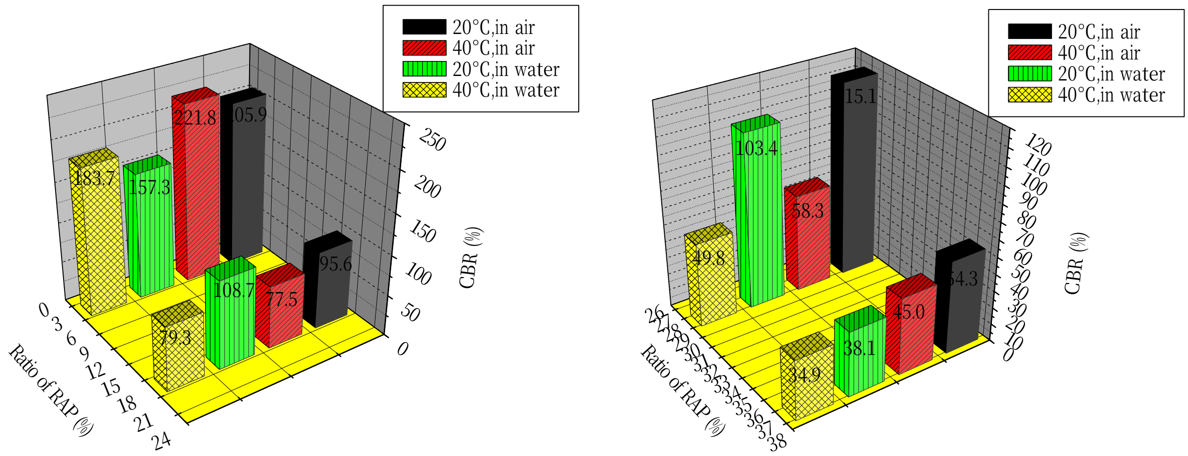
Fig.5 gives the effects of the temperature and curing method on CBR. The following findings were obtained.

(a) For a constant temperature, the CBR of RGM cured in air is generally greater than that cured in



(a) Base course (b) Subbase

Fig.4 Effect of temperature on modified CBR for RGM



(a) Base course (b) Subbase

Fig.5 Effect of temperature and curing method on CBR for RGM

water. Therefore, if RGM is used for a base course, a good drainage system is necessary.

(b) For the same curing method, the CBR of RGM for a subbase at 20℃ is greater than that at 40℃; whereas for a base course with a RAP ratio of 3%, the conclusion is opposite. The case again shows that RGM with a large ratio of RAP is very sensitive to temperature.

(2) Recycled cement stabilized material (RCSM)

a) Composition

The aggregates used were the same as those of the RGM. However, the portion with a grain size of 26.5 and larger was removed. Four ratios of RAP (100%, 75%, 50% and 25%) were evaluated with compaction tests and unconfined compression tests[2]. The cement content in the samples for the compaction test was 4% and 8%, while contents of 2%, 4%, 6%, 8% and 10% were used for the unconfined compression test. **Table 10** and **Table 11** give the results for the compaction and unconfined compression tests, respectively. Regardless of the RAP ratio, the cement content significantly effects the maximum dry density and optimum water content of RCSM. **Fig.6** indicates the relationship between the unconfined compression strength and the cement content. According to the relevant specifications for airports[4], the unconfined compression strength of RCSM should be not less than 3 N/mm^2 for the base course, nor less than 2 N/mm^2 for the subbase. Cement contents that satisfy the requirements for various RAP ratios can be obtained from **Fig.6**.

Unconfined compression tests were conducted to

Table 11 Unconfined compression test result for RCSM

		Ratio of RAP (%)			
Cement content (%)	Type	25	50	75	100
2	Strength (N/mm^2)	1.32	0.57	0.31	0.25
	Dry density (g/cm^3)	2.03	1.891	1.819	1.738
4	Strength (N/mm^2)	3.23	1.97	0.94	0.64
	Dry density (g/cm^3)	2.059	1.969	1.855	1.774
6	Strength (N/mm^2)	5.16	3.1	1.77	1.39
	Dry density (g/cm^3)	2.106	2.01	1.938	1.826
8	Strength (N/mm^2)	6.31	4.24	2.67	1.84
	Dry density (g/cm^3)	2.142	2.073	1.965	1.870
10	Strength (N/mm^2)	8.97	6.36	3.62	2.34
	Dry density (g/cm^3)	2.178	2.139	1.985	1.892

Table 12 Determining cement content

Ratio of RAP (%)	Cement content (%)	
	Target strength: 3N/mm^2 (base course)	Target strength: 2N/mm^2 (subbase)
25	3.9	2.8
50	5.7	4.2
75	8.8	6.4
100	12.4	8.7

Table 13 Verification test result of RCSM

Target strength (N/mm^2)	3 (base course)				2 (subbase)			
Ratio of reclaimed asphalt pavement (%)	100	75	50	25	100	75	50	25
Cement content (%)	12.4	8.8	5.7	3.9	8.7	6.4	4.2	2.8
Actual strength (N/mm^2)	3.03	3.19	2.97	2.76	1.74	2.02	2.10	2.01
Dry density (g/cm^3)	1.888	2.015	2.048	2.062	1.873	1.955	2.012	2.046

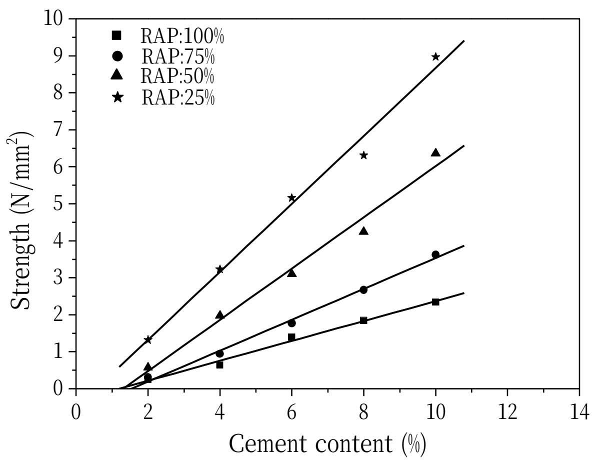


Fig.6 Strength and cement content for RCSM

verify the specified compositions. The results shown in **Table 13** indicate that the cement contents in **Table 12** can satisfy the strength requirement for a base course in an airport. The gradation of RCSM was thus determined.

b) Properties

This study incorporated the unconfined compression test, the freeze-thaw test and the dry-wet repeated test.

Table 14 gives the test conditions for the unconfined compression test. **Table 15** shows the test results. The temperature, period and method of curing have a great effect on the properties of RCSM. When other conditions are same, the strength at 20℃ is higher than that at 40℃, showing that RCSM is also sensitive to temperature. The strength of RCSM increases with the curing period, which is similar to its effect on cement concrete. Although the strength when cured in water is less than that in air, the properties of RCSM can satisfy the specified requirement with a suitable cement content.

The freeze-thaw test and the dry-wet repeated test were conducted to evaluate the durability of RCSM. The results, shown in **Table 16** and **Table 17,** indicate that RCSM has good durability, so it can be used in areas with severe climate conditions.

(3) Recycled cement-emulsified asphalt stabilized material (RCESM)

a) Composition

The aggregates and other components were the same as those used in the recycled cement stabilized

Table 14 Test conditions for RCSM

Curing period (days)	7		28		91			
Curing method	In air		In air		In air		28d in air, 63d in water	
Curing temp. (℃)	20	40	20	40	20	40	20	40

Table 15 Test results for RCSM

a) Base course

Curing period and method	Test temp. (℃)	20				40			
	Ratio of RAP (%)	25	50	75	100	25	50	75	100
	Cement content (%)	3.9	5.7	8.8	12.4	3.9	5.7	8.8	12.4
7d, in air	Strength (N/mm^2)	2.91	3.46	3.04	3.67	2.57	2.68	2.67	2.64
	Dry density (g/cm^3)	2.057	2.037	2.026	1.970	2.052	2.045	2.025	1.976
28d, in air	Strength (N/mm^2)	3.35	3.51	3.85	4.38	4.04	3.14	3.33	3.29
	Dry density (g/cm^3)	2.071	2.027	2.010	1.986	2.077	2.021	2.009	1.997
91d, in air	Strength (N/mm^2)	4.78	4.92	5.66	5.43	4.09	3.98	3.58	4.33
	Dry density (g/cm^3)	2.082	2.033	2.022	1.997	2.080	2.034	2.019	2.000
91d, in water	Strength (N/mm^2)	3.54	3.81	4.08	5.31	2.79	2.99	3.04	3.06
	Dry density (g/cm^3)	2.088	2.030	2.009	1.960	2.078	2.033	2.011	1.958

b) Subbase

Curing period and method	Test temp. (℃)	20				40			
	Ratio of RAP (%)	25	50	75	100	25	50	75	100
	Cement content (%)	2.8	4.2	6.4	8.7	2.8	4.2	6.4	8.7
7d, in air	Strength (N/mm^2)	2.26	2.04	1.87	2.22	1.90	1.90	1.58	1.45
	Dry density (g/cm^3)	2.040	1.998	1.924	1.900	2.030	2.002	1.927	1.912
28d, in air	Strength (N/mm^2)	2.73	2.34	2.23	2.09	2.99	2.05	1.81	1.61
	Dry density (g/cm^3)	2.046	1.974	1.946	1.886	2.044	1.983	1.946	1.877
91d, in air	Strength (N/mm^2)	3.39	2.79	3.11	3.12	2.93	2.43	2.12	1.97
	Dry density (g/cm^3)	2.053	1.986	1.939	1.905	2.050	1.989	1.942	1.916
91d, in water	Strength (N/mm^2)	2.44	2.48	2.59	2.50	2.31	2.02	1.86	1.69
	Dry density (g/cm^3)	2.058	1.990	1.949	1.890	2.066	1.999	1.941	1.894

Table 16 Freeze-thaw test results for RCSM

Type	Base course				Subbase				Specified value
Ratio of RAP (%)	25	50	75	100	25	50	75	100	
Cement content (%)	3.9	5.7	8.8	12.4	2.8	4.2	6.4	8.7	
Lost weight (g)	44.0	16.8	13.2	11.5	54.0	21.6	16.8	16.9	
Lost ratio (%)	1.21	-0.15	0.80	-0.11	0.84	0.63	1.22	0.37	Below 14
Maximum volume variation (%)	0.40	0.35	0.35	0.28	0.36	0.48	0.28	0.59	Below 2

Table 17 Dry-wet repeated test results for RCSM

Type	Base course				Subbase				Specified value
Ratio of RAP (%)	25	50	75	100	25	50	75	100	
Cement content (%)	3.9	5.7	8.8	12.4	2.8	4.2	6.4	8.7	
Lost weight (g)	28.7	9.4	6.0	7.1	49.7	19.1	8.7	8.7	
Lost ratio (%)	1.19	0.50	1.47	0.24	1.80	0.59	0.28	0.36	Below 14
Maximum volume variation (%)	0.60	0.28	0.48	0.31	0.56	0.48	0.40	0.35	Below 2

material. Two RAP contents were evaluated: 100% and 75%. The emulsion content was determined based on the Technical Guidelines for Recycled Base Course Method[3]. **Table 18** and **Table 19** give the results of the compaction and unconfined compression tests, respectively. The cement content has a clear effect on RCESM. **Fig.7** easily provides the cement content for a given unconfined compression strength under different ratios of RAP. Consequently, **Table 20** shows the determined gradation of RCESM that satisfies the base requirement.

b) Properties

The unconfined compression test was conducted to investigate the effect of temperature and curing method on the properties of RCESM. **Table 21**

Table 18 Compaction test for RCESM

Type	Cement content (%)	Ratio of RAP (%)	
		75	100
Maximum dry density (g/cm^3)	4	1.910	1.835
	8	2.000	1.892
Optimum water content (%)	4	3.8	3.5
	8	5.3	4.3

Table 19 Unconfined compression test for RCESM

		Cement content (%)				
Ratio of RAP (%)	Type	2	4	6	8	10
75	Strength (N/mm^2)	0.31	0.94	1.77	2.67	3.62
	Dry density (g/cm^3)	1.819	1.855	1.938	1.965	1.985
100	Strength (N/mm^2)	0.25	0.64	1.39	1.84	2.34
	Dry density (g/cm^3)	1.738	1.774	1.826	1.870	1.892

Table 20 Determined gradation for RCESM

Target strength (N/mm^2)	3 (base course)		2 (subbase)	
Ratio of RAP (%)	75	100	75	100
Cement content (%)	8.1	11.1	6.4	8.6
Measured strength (N/mm^2)	2.89	2.98	1.88	1.73
Dry density (g/cm^3)	1.991	1.946	1.926	1.867

Table 21 Properties of RCESM

Curing	Target strength	3N/mm^2 (base course)				2N/mm^2 (subbase)			
	Test temperature	20℃		40℃		20℃		40℃	
	Ratio of RAP	75%	100%	75%	100%	75%	100%	75%	100%
	Cement content (%)	8.1	11.1	8.1	11.1	6.4	8.6	6.4	8.6
91d in air	Measured strength (N/mm^2)	4.85	4.42	3.29	2.43	2.91	2.57	2.08	1.52
	Dry density (g/cm^3)	2.014	1.947	2.026	1.946	1.960	1.897	1.974	1.910
23d in air, 63d in water	Measured strength (N/mm^2)	4.18	3.14	2.85	1.89	2.45	1.65	1.66	1.11
	Dry density (g/cm^3)	2.026	1.952	2.028	1.941	1.974	1.908	1.977	1.903

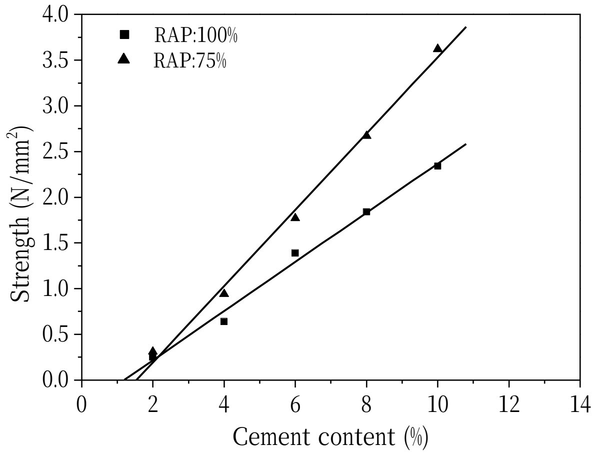


Fig.7 Strength and cement content (for RCESM)

shows the results, which suggest the following conclusions: (a) Strength decreases with increasing temperature, which indicates that RCESM is also sensitive to the temperature. (b) The curing method has a significant influence on the properties. Curing in air is better than in water. (c) The required strength may not be achieved if the temperature is high and the ratio of RAP is large.

(4) Recycled hot-asphalt stabilized material (RHASM)

Hot-mix recycling of asphalt concrete is used increasingly as a primary rehabilitation method by pavement agencies throughout Japan. However, it is a complex process that will be researched in another special study. Therefore, in this study, only the RHASM composition with a 100% RAP ratio was analyzed.

Table 22 gives the combined gradation of RHASM, which is within the standard range of grain size. As discussed previously, penetration of the recycled asphalt is 23 (1/100cm), which does not satisfy the target design penetration of 70 (1/100cm).

Table 22 Combined gradation of RHASM

Sieve (mm)	19.0	13.2	4.75	2.36	0.60	0.30	0.15	0.075	Asphalt content (%)
Passing percentage of weight (%)	99.8	89.1	56.3	37.1	21.7	16.2	11.7	7.5	4.29
Gradation range (%)	50-100			20-60				0-10	

Table 23 Marshall test result for RHASM

Asphalt content (%)	Compaction time	Stability (kN)	Flow value (0.01cm)	Air void (%)	Saturation (%)
4.57	50	11.4	31	4.5	70.2
	75	14.6	30	3.9	73.3
5.0	50	11.9	35	3.2	78.5
	75	13.6	30	3.0	79.6
5.5	50	11.3	39	2.0	86.6
	75	14.2	33	2.0	86.6
6.0	50	11.0	38	1.7	89.2
	75	11.8	38	1.5	90.3
6.5	50	9.6	42	1.5	91.0
	75	11.6	44	1.2	92.6
Specified value		>7.35	20-40	3-6	70-85

Consequently, a recycling agent is required with a content determined by the weight of the recycled asphalt. In this test, the content was 11.7%.

The Marshall test[2)] was conducted to evaluate the gradation. **Table 23** summarizes the results for compaction times of 50 and 75. This table suggests that RHASM can satisfy the gradation requirement as a base even if the ratio of RAP is 100%.

4. CONCLUSIONS

The followings are the main conclusions of this study to conduct to use reclaimed asphalt concretes fully.

1) All types of recycled materials that contain reclaimed asphalt concrete can satisfy the requirements for a base course and a subbase.

2) Recycled materials are sensitive to temperature and water. Thus, it is very important to decide the ratio of RAP for the recycled materials based on the local environmental conditions.

3) RCSM, RCESM and RHASM are more suitable than RGM for using large amounts of recycled asphalt concrete.

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アスファルトコンクリート発生材の路盤としての全量再生化

伍　石生・八谷好高・杉本浩一

アスファルトコンクリートの再生は，天然資源利用節約，コスト縮減，省エネルギが可能となることから，わが国においてはますます主要な補修方法となってきている．本研究では，東京国際空港での廃アスファルトコンクリートを 4 種類の路盤，すなわち粒状材，セメント安定処理材，セメントアスファルト乳剤安定処理材，加熱混合アスファルト安定処理材，として使用する場合の可能性について評価した．室内試験の結果から 1)用いた廃アスファルトコンクリートは上層路盤ならびに下層路盤として使用可能であること，2)再生路盤材料は温度ならびに水分の影響を受けることが明らかになった．