THICK-LIFT CONSTRUCTION OF AIRPORT PAVEMENT SURFACE COURSE USING ASPHALT CONCRETE WITH LARGE AGGREGATE PARTICLES

(Translation from Journal of JSCE, No.725/V-58 (Feb. 2003) and No.732/V-59 (May 2003).




Yoshitaka HACHIYA   Osamu TAKAHASHI   Hisaaki KATO   Kozo WADA

As airports handle increasing traffic and ever-larger aircraft, it is becoming necessary to increase the durability of airport asphalt pavements. There is also demand for increased efficiency in construction procedures so as to reduce construction cost. The thick-lift construction method for asphalt concrete containing large aggregate particles makes it possible to place thicker layers than conventional methods, and is considered one possible response to these needs. The applicability of this method to airport pavement surfaces and binder courses is examined through laboratory tests and experimental construction. Through a series of investigations, it is demonstrated that large-aggregate asphalt concrete has superior resistance to deformation, mechanical properties, pavement structure, and surface characteristics as compared with asphalt concrete containing conventional aggregates.

Keywords: *asphalt concrete, large aggregate, thick-lift construction, surface course, airport*

Yoshitaka Hachiya, a member of JSCE, is a Head of Airport Facilities Division, Airport Research Department, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure and Transport. He obtained the Degree of Dr. Engineering from Hokkaido University in 1991.

Osamu Takahashi, a member of JSCE, is an Associate Professor, Department of Civil and Environmental Engineering, Nagaoka University of Technology. He obtained the Degree of Dr. Engineering from Nagaoka University of Technology in 1998.

Hisaaki KATO, a member of JSCE, is a Head of Port and Airport Department, Kochi Prefecture. He is the former Director of Tokyo Airport Construction Office, Ministry of Land, Infrastructure and Transport.

Kozo WADA, a member of JSCE, is a Head of Construction Department, Central Japan International Airport Co., Ltd. He is the former Director of Nagoya Port and Airport Construction Office, Ministry of Land, Infrastructure and Transport.

1. INTRODUCTION

Asphalt pavements find application in both runways and taxiways at airports, but it is the taxiways that sometimes suffer excessive rutting as aircraft increase in size and operations become more frequent [1]. Asphalt concrete containing large aggregate particles seems to be an effective countermeasure against this rutting.

In the meantime, cracks and spalling occur in the summertime in areas where aircraft brakes are applied and turns are made. As a result, it is inevitable that an interface forms between the surface course and the binder course, since different asphalt concrete is generally used in each course. The danger of such distress increases with thinner surface courses [2].

With the prospect of existing pavements requiring more repair work, such as overlay construction, it is apparent that greater use will be made of asphalt concrete containing large aggregate particles, since it is considered excellent in deformation resistance. A thicker-than-conventional surface course will contribute to solving problems originating from insufficient bonding between the surface and binder courses if construction by the thick-lift method can be achieved.

Various properties need to be examined when applying large-aggregate asphalt concrete as a surface course: resistance against deformation, fatigue and scaling, property deviation with age, permeability, and the stability of grooving. Further, a number of problems arise in applying thick-lift construction to airport pavements:

1) it is difficult to achieve sufficient evenness,
2) density tends to vary through the thickness, and
3) the asphalt concrete takes a long time to cool.

In this study, laboratory tests and field experiments are used to investigate the applicability of thick-lift construction of large-aggregate asphalt concrete to airport pavement surface courses.

2. MATERIALS

Straight asphalt 60/80 was used, and both asphalt and aggregates satisfied the Japanese specifications for airport pavements [3]. The large aggregate had a maximum size of 30mm, and asphalt concretes containing 13mm and 20mm aggregate was also tested (these are the sizes currently used in the surface and binder courses of airport pavements). The aggregate gradation for the 30mm aggregate was determined in accordance with ASTM D3515, while for the 13mm and 30mm aggregates the above-mentioned quality specification were adopted. The resultant aggregate gradation for each asphalt concrete was as shown in **Table 1**.

The asphalt concrete was the optimum asphalt content (OAC) according to the Marshall stability test. In the Marshall stability tests, molds with an internal diameter of 152.4mm and 101.6mm were used for the 30mm aggregate concrete, and the 13mm and 20mm aggregate concretes, respectively [4], [5]. The Marshall stability tests for the asphalt concretes under the selected mixing conditions confirmed that the 30mm-aggregate asphalt concrete satisfied the recommendations of NAPA [6] and those with conventional aggregates satisfied the airport specifications, as shown in **Table 2**.

Table 1 Aggregate gradation

Sieve size (mm)	Maximum aggregate size (mm)		
	13	20	30
37.5	-	-	100
26.5	-	100	93.4
19.0	100	98.5	-
13.2	97.4	82.7	68.6
4.75	63.3	56.1	44.7
2.36	42.3	42.1	31.8
0.6	24.7	24.9	-
0.3	15.9	16.1	13.3
0.15	8.6	8.7	-
0.075	5.5	5.5	4.2

(unit : %)

Table 2 Properties of asphalt concretes

Maximum aggregate size (mm)	Optimum asphalt content (%)	Density (g/cm^3)	Air voids (%)	Saturation (%)	Stability (kN)	Flow (1/100cm)	Retained stability (%)
13	5.7	2.375	3.1	80.9	12.3	31	95.3
20	5.5	2.379	3.3	79.2	15.0	28	89.4
30	4.6		4.1	72.1	36.0	42	85.0
Standard	-	-	2-5	75-85	8.8<	20-40	75<

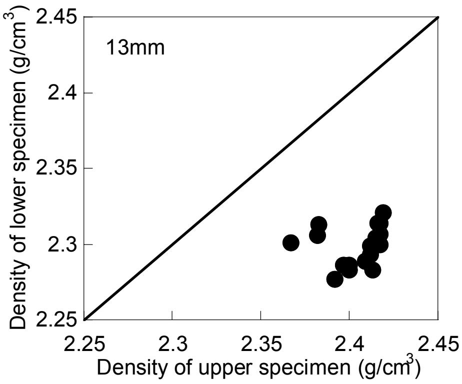
3. EXAMINATION OF THICK-LIFT CONSTRUCTION METHOD

3.1 Laboratory test

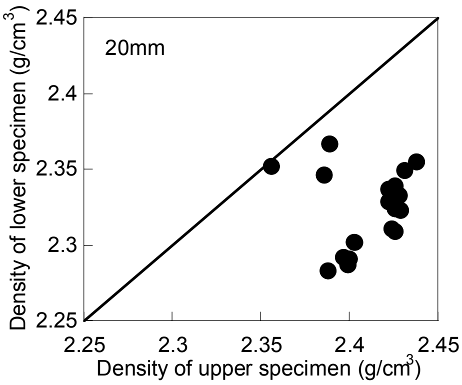
Dense graded asphalt concrete layers with conventional-sized aggregates were constructed by the thick-lift method, and their properties were examined in laboratory tests [7]. The test samples, measuring 300mm square by 150mm in thickness, were prepared using a roller compactor. Once their temperature had dropped sufficiently, specimens measuring 300mm in length, 50mm in width, and 75mm in thickness were removed from the upper and lower faces using a diamond cutter. The density of the upper specimen was found to be higher than that of the lower one irrespective of aggregate size, as shown in **Figure 1**.

Using the same specimens, variations in mechanical properties corresponding to the density nonuniformity were examined. Flexural testing was carried out by single-point loading over a 200mm span, using loading rates of 1mm/min. and 100mm/min. and at temperatures of 0°C, 20°C, and 40°C. Other conditions corresponded to the procedure described in references [4] and [5].

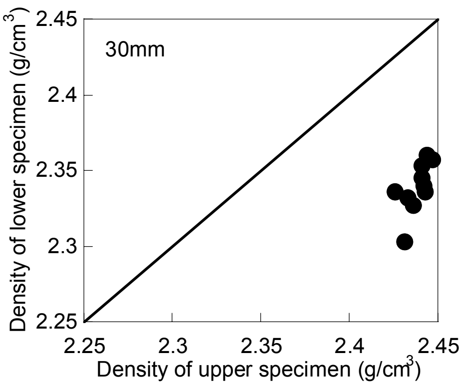
The flexural test results were analyzed from the viewpoints of both strength and strain at failure. **Figure 2** shows flexural strength. The strength of the upper specimens is higher, to greater or lesser degree, than that of the lower specimens for all loading rates and irrespective of asphalt concrete type. This is a consequence of the variation in density with thickness. A similar trend is seen in the results of strain at failure, though not as clearly as in the flexural strength case, as shown in **Figure 3**.



a) Maximum size of 13mm

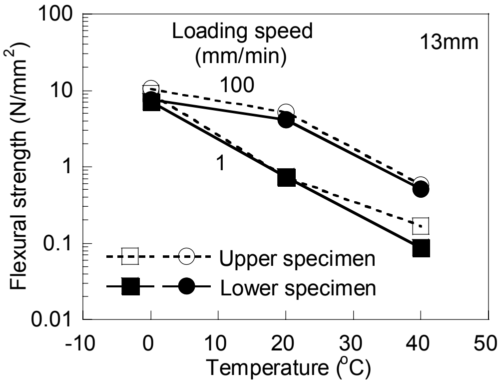


b) Maximum size of 20mm

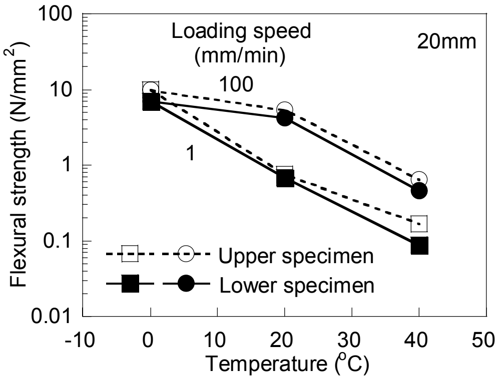


c) Maximum size of 30mm

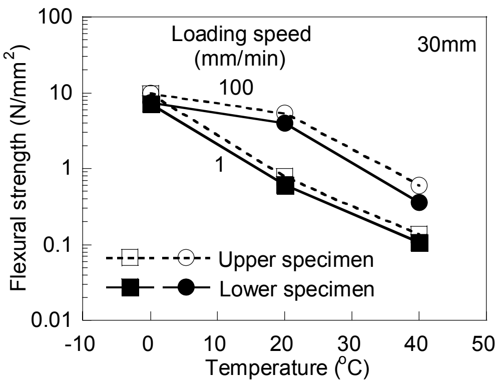
Figure 1 Density difference



a) Maximum size of 13mm

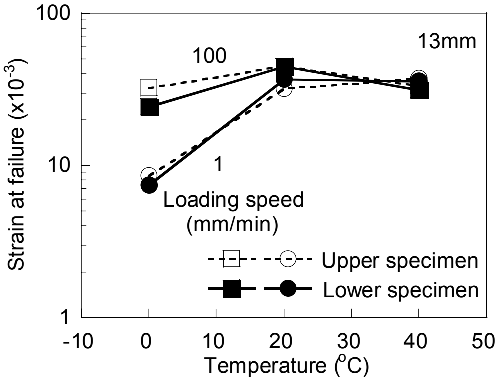


b) Maximum size of 20mm

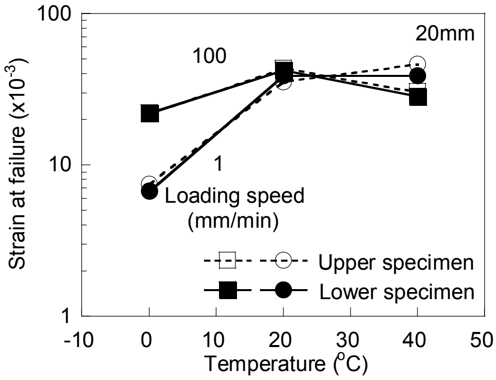


c) Maximum size of 30mm

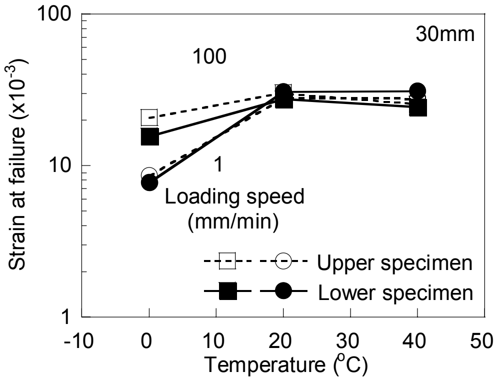
Figure 2 Flexural strength difference



a) Maximum size of 13mm



b) Maximum size of 20mm



c) Maximum size of 30mm

Figure 3 Strain difference at failure

These results demonstrate that when asphalt concrete measuring 150mm in thickness is prepared in one lift, the density and resultant flexural strength at the top of the sample are higher, to a greater or lesser degree, than at the bottom.

3.2 Field trial of thick-lift construction method

An experimental pavement was constructed using the thick-lift method, and its behavior under aircraft loading was analyzed. In this experiment, asphalt concretes with three types of aggregate were examined: aggregate with a maximum particle size of 13mm, 20mm, and 30mm. These asphalt concretes were placed in one lift to a thickness of 10cm [7].

a) Test outline

The experimental pavement consisted of a 5cm binder course laid over an existing concrete pavement followed by the 10cm surface course constructed by the thick-lift method. Test sections were designated in accordance with the maximum aggregate size in the surface course; that is, T10-13 for the 13mm aggregate, T10-20 for the 20mm, and T10-30 for the 30mm. Each test section measured 3.5m in width and 30m in length. The binder course laid under all test sections consisted of coarse graded asphalt concrete with a maximum aggregate particle size of 20mm to satisfy the current specifications as mentioned above.

b) Construction

The construction procedure was the same for all test sections. Namely, the same equipment (including the same asphalt finisher, vibration roller, and tire roller) was used and compaction details, as determined on the basis of a preliminary compaction test, were also identical. Primary compaction was carried out with the vibration roller, and consisted of rolling twice without vibration and four times with vibration. This was followed by ten passes of the tire roller for secondary compaction. The work was carried out during the daytime in July.

Figure 4 shows the temperature change with time at various depths in the T10-13 surface course. Since it takes a long time for the temperature to drop below 80^{o}C, certain measures to accelerate temperature reduction should be taken in such construction conditions.

Cores were taken from each test section for measurements of density variations; the surface course and binder course were separated out from the cores, and the surface course was again divided into upper and lower parts.

Table 3 shows the density measurements for the surface asphalt concrete layers. There is no difference in density between the upper and lower samples for all sections, and the samples are almost 100% compacted. This contrast with the laboratory test, in which the samples were 15cm thick, might result from the 10cm layer thickness and from the fact that a vibrating roller was used.

c) Loading tests

The B-747 landing gear assembly used in the loading tests was run repeatedly over the experimental pavement up to 1,000 times, and the surface characteristics were observed. These tests were carried out in November and the temperature at the pavement surface was between 20.9 and 36.4^{o}C. Longitudinal roughness was measured using a 3m profilometer before and after each loading test along three lines. Surface irregularities in the transverse direction were also measured by the use of a transverse profilometer along two lines so that rut depth could be obtained.

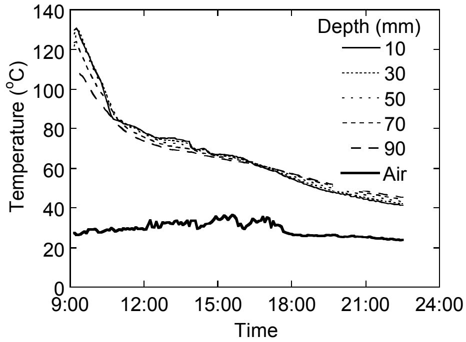


Figure 4 Temperature changes in surface course

Table 3 Density difference

Maximum aggregate size (mm)	Upper		Lower	
	Density (g/cm^3)	Degree of compaction (%)	Density (g/cm^3)	Degree of compaction (%)
13	2.375	99.9	2.413	101.5
20	2.385	99.9	2.346	98.3
30	2.390	99.9	2.398	100.2

Table 4 Longitudinal evenness

Maximum aggregate size (mm)	Line	Before	After	Difference
13	1	2.15	2.36	+0.21
	2	2.28	2.17	-0.11
	3	1.99	2.19	+0.20
	Average	2.14	2.24	+0.10
20	1	1.67	1.86	+0.19
	2	2.06	1.89	-0.17
	3	2.20	1.47	-0.73
	Average	1.97	1.74	-0.24
30	4	0.99	1.10	+0.11
	5	1.74	1.66	-0.88
	6	2.20	2.25	+0.05
	Average	1.64	1.67	+0.03

(unit : mm)

The measured longitudinal roughness before and after loading tests is summarized in **Table 4**. The roughness falls within the requirements of the Japanese specifications [3]. Further, since the roughness scarcely changed after the loading tests, it is concluded that repeated loading up to 1,000 times does not result in deterioration.

Table 5 Rut depth

Maximum aggregate size (mm)	Line 1	Line 2	Average
13	2.0	2.0	2.0
20	3.5	4.5	4.0
30	1.5	1.5	1.5

(unit:mm)

Table 5 shows the rut depth calculated from measured transverse profiles before and after loading tests. Asphalt concrete with the large aggregate of 30mm maximum size has better resistance to rutting than the other asphalt concretes. The measured maximum rut depth meets the specifications, which require a maximum of 10mm and 17mm on runways and taxiways, respectively.

From these results of field trials of thick-lift construction for a pavement surface layer 10cm in thickness, it is determined that the pavement satisfied the specifications for density, longitudinal roughness, and rut depth. The pavement was scarcely influenced by repeated loading at all. It is concluded that 10cm-thick asphalt concrete layers can be satisfactorily constructed using the thick-lift method.

4. EVALUATION OF MATERIALS FOR AIRPORT PAVEMENT SURFACE COURSE

To examine the applicability of asphalt concrete containing large aggregate particles to airport pavement surface courses, various properties were investigated.

4.1 Required performance as surface course material

The primary performance requirements for the surface course material of airport pavements are resistance to deformation and fatigue resistance, as represented by anti-rutting and anti-cracking properties. Resistance to deformation is required from the viewpoint of aircraft operations, whereas fatigue resistance reduces pavement failure. Also required is resistance to stripping of the asphalt from aggregate; aggregate particles can be become segregated and scattered as a result of horizontal forces acting on the pavement during aircraft braking and turning at high speed. Further, aging under normal environmental conditions, permeability, and the durability of grooves marked on the runway surface under repeated aircraft loading must satisfy certain requirements.

Asphalt concrete containing large aggregate particles must have properties that are superior, or at minimum equivalent, to those of conventional asphalt concretes.

4.2 Deformation and fatigue resistance

a) Deformation resistance

Deformation resistance was evaluated through wheel tracking tests using specimens of 100mm and 150mm in thickness [4]. By compacting the specimens with the roller compactor, densities of 98% or more of the standard density were obtained for all asphalt concretes (with maximum aggregate sizes of 13mm, 20mm, and 30mm).

The measured dynamic stability of each asphalt concrete is shown in **Figure 5**. The stability of the large-aggregate asphalt concrete is three times that of the conventional asphalt concretes, so it is evaluated as excellent in deformation resistance. **Figure 6**, which shows the permanent deformation after wheel tracking tests, gives similar results. These results demonstrate that asphalt concrete containing large aggregate particles is suitable for application to taxiways, where large aircraft run at low speeds.

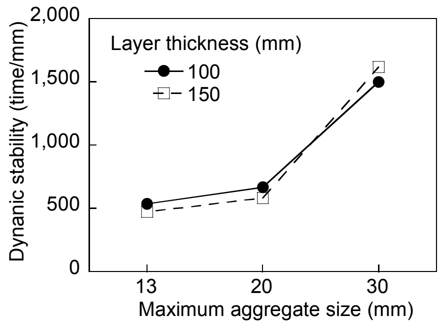


Figure 5 Dynamic stability

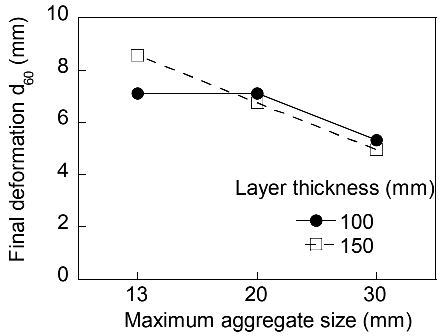


Figure 6 Final deformation after wheel tracking test

b) Fatigue resistance

To evaluate the fatigue resistance of asphalt concrete containing large aggregate particles, repeated flexural tests were carried out on specimens cut from the above field trial [8]. The specimens were prepared from the upper surface of the pavement in areas not directly loaded with the B-747 loading assembly. The specimens were 50mm wide, 75mm high, and 300mm long. The tests were conducted with two-point support under displacement control using sinusoidal displacement. The span was 250mm and one-point loading was applied. Four or five strain amplitudes were selected between 1,000 and $2{,}500\times10^{-6}$, and tests were carried out at temperatures of -10, 0, 5, and 10°C. Loading frequency was set at 5Hz based on past studies [9], [10].

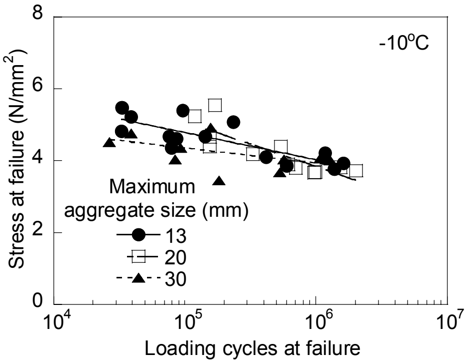
Test results were summarized in accordance with reference [10]. **Figure 7** shows the relationship between stresses and strains at failure. Each point in the figure represents one test result, and the straight line is the regression curve. Since there is no significant difference in fatigue characteristics among the asphalt concretes with different aggregate sizes at any temperature, the fatigue resistance of large-aggregate asphalt concrete is shown to be almost equivalent to that of conventional asphalt concretes.

4.3 Surface characteristics

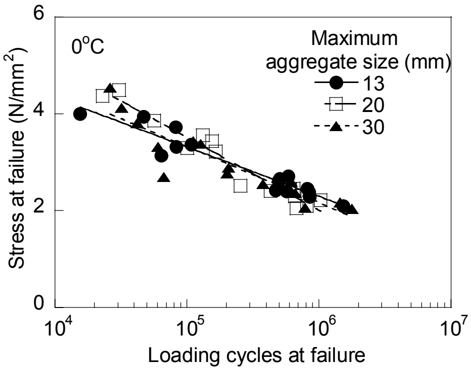
The stripping resistance and permeability of asphalt concrete containing large aggregate particles were examined, because the apparently rough surface texture might make it susceptible to such problems. The influence of aging on their properties was also studied. Both examinations were carried out by laboratory tests on samples taken from the field trial after about three and a half years of running tests.

a) Aggregate stripping resistance

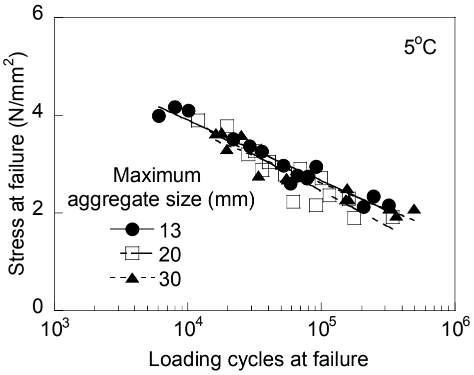
Aggregate stripping and abrasion resistance was evaluated using the raveling test and Cantabro test, respectively [5].



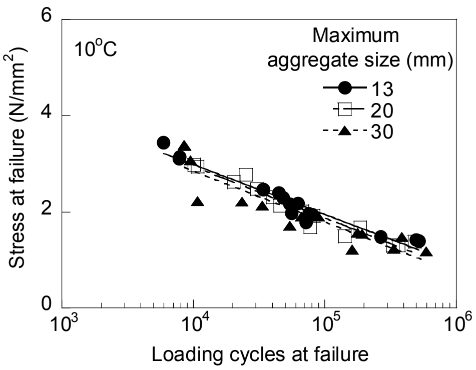
a) -10^{o}C



b) 0^{o}C



c) 5^{o}C



d) 10^{o}C

Figure 7 Fatigue resistance

The raveling test was carried out on a specimen of length 400mm, width 150mm, and thickness 50mm using a back-and-forth raveling system at a temperature of 20^{o}C. The Cantabro test was with a specimen of diameter 100mm and height 65mm at 20^{o}C.

The results of both tests are given in **Table 6**. This shows that the stripping resistance of asphalt concrete with 30mm aggregate differs little from that of conventional asphalt concretes. This means that the material is suitable for application to runways and high-speed exit taxiways, where the surface is subject to horizontal loading.

b) Permeability

To evaluate permeability, two kinds of test were conducted, one in accordance with JIS A 1218 and the other with ASTM D 3637. The tests were carried out on specimens of diameter 10cm and 15cm for asphalt concretes with a maximum aggregate size of 13mm and 20mm, and 30mm, respectively. **Table 7** shows the results. Both permeability and air volume decrease with air voids in asphalt concrete. Regarding the influence of different maximum aggregate sizes, both permeability and air volume decrease by a greater or lesser degree as the maximum aggregate size increases. Thus, the permeability of asphalt concrete containing large aggregate particles does not greatly differ from that of conventional asphalt concretes.

c) Aging resistance

The resistance of the asphalts to aging was evaluated in terms of penetration, softening point, ductility, and ingredient analysis in accordance with JIS K 2207 and reference [4]. Asphalt was extracted from the top layer of the experimental pavement's surface course using the Abson method [4].

Table 6 Anti-stripping properties

Maximum aggregate size (mm)	Abrasion (cm^2)	Loss (%)
13	0.41	8.3
20	0.52	5.4
30	0.55	9.1

Table 7 Permeability

Maximum aggregate size (mm)	No.1			No.2			No.3		
	Air void	Permeability	Air volume	Air void	Permeability	Air volume	Air void	Permeability	Air volume
13	2.2	13.83	0.32	2.5	168	8.25	2.1	6.31	0.71
20	1.6	9.66	0.79	1.3	0.04	0.03	1.6	-	-
30	2.5	62.5	0.76	2.3	-	-	2.2	-	-

(unit : % - Air void, 1×10^{-6}cm/s – Permeability, $1\times10^{-9}cm^2$ - Air volume)

Table 8 Properties of recovered asphalt

Maximum aggregate size (mm)	Penetration (1/10mm)	Softening point (°C)	Viscosity (Pa·s)	Ductility (cm)	Ingredients (%)			
					Asphaltene	Saturate	Aromatic	Resin
13	33	52.5	370	29	18.2	15.2	40.5	23.7
20	41	50.5	320	100 (+)	15.9	15	42.4	23
30	43	50.5	300	100 (+)	16.2	15.4	43.4	23.3

Table 8 shows the test results. The asphalt from concrete containing large aggregate particles does not, on the whole, age as much as that from conventional asphalt concretes, as the latter shows a tendency to stiffen more. In the ingredient analysis, the highest concentration of asphaltene was found in the case of the 13mm aggregate, while aromatics were barely lower in the case of the 30mm aggregate. It is concluded that asphalt extracted from concrete containing large aggregate particles is less influenced by aging than that from conventional asphalt concretes.

4.4 Groove durability

Groove durability was evaluated by two methods: a wheel-tracking test to examine the deformation of grooves and a raveling test for spalling. Specimens for these tests were prepared in the laboratory.

a) Test method

In the wheel-tracking test, specimens measuring 300mm square by 50mm high were used, while those for the raveling test were 150mm wide, 400mm long, and 50mm high. (Except that in the case of maximum aggregate size of 30mm, the height of the specimens was adjusted to 100mm.) Seven grooves 6mm wide and 6mm deep were cut at intervals of 32mm transversely across the center of the specimen.

The wheel-tracking test followed the standard method [4], with the shape of the grooves inspected at specified loading cycles during the test: at 100, 300, 1,000, 2,000, and 5,000 cycles. The raveling test was carried out at a temperature of 0°C, and groove volume was measured at specified times: 30 and 90 seconds, 5, 10, and 25 minutes.

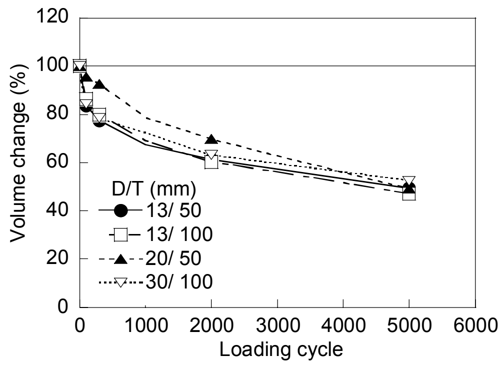


Figure 8 Volume change in wheel tracking test

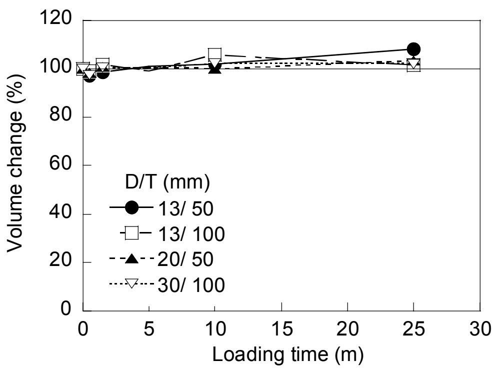


Figure 9 Volume change in raveling test

b) Test results

Results of both the wheel-tracking test and the raveling test were quantified in terms of the groove volume change, defined as the ratio of the pre- and post-test volume.

Figure 8 summarizes the results of the wheel-tracking test, showing that there was little difference in volume change according to maximum aggregate size. **Figure 9** gives the raveling test results, indicating that the groove shape in asphalt concrete containing the aggregate with a maximum size of 30mm is better preserved then in the case of conventional asphalt concretes. These tests demonstrate that groove durability in asphalt concrete containing large aggregate is equal or perhaps superior to that in conventional asphalt concretes.

5. SUMMARY AND CONCLUSIONS

Through a series of tests on asphalt concrete containing large aggregate particles, this material is shown to have better deformation resistance than conventional asphalt concretes. The fatigue resistance, aggregate stripping resistance, and permeability of the large-aggregate asphalt concrete are found to be almost equivalent to those of conventional asphalt concretes. Furthermore, the aging resistance and groove stability of the large-aggregate asphalt concrete is demonstrated to be equivalent to or somewhat superior to that of conventional asphalt concretes.

It is concluded that the thick-lift construction method is suitable for application in airport asphalt pavement surface courses, since load resistance is improved while construction time is reduced. An asphalt concrete layer constructed by the thick-lift method has suitable mechanical properties, surface characteristics, and bearing strength at thicknesses up to 10cm.

These results suggest that asphalt concrete containing large aggregate particles could be introduced for the surface courses of airport pavements, and that its applicability to taxiways is particularly good.

REFERENCES

[1]Osaka Airport Construction Office, Third District Port Construction Bureau, Ministry of Transport, "Pavement construction using modified asphalt concrete in Osaka International Airport", 22nd Annual Meeting on Airport Construction, 20p., 1987 (in Japanese).

[2]Yoshitaka Hachiya, Shuichi Umeno and Katsuhisa Sato, "Effect of Tack Coat on Bonding Characteristics at Interface between Asphalt Concrete Layers", Journal of Japan Society of Civil Engineers (JSCE), No.571/V-36, pp.199-209, 1997 (in Japanese).

[3]Civil Aviation Bureau, Ministry of Land, Infrastructure and Transport, "Standard Specifications for Airport Constructions", 1999 (in Japanese).

[4]Japan Road Association (JRA), "Guide for Pavement Tests", 1069p., 1988 (in Japanese).

[5]JRA, "Guide for Pavement Tests (Supplement)", 317p., 1996 (in Japanese).

[6]Japan Road Contractors Association, "Evaluation of Large-Sized Aggregate Asphalt Concrete Designed with Marshall Method", Road Construction, 3/5, pp.86-91, 1991 (in Japanese).

[7]Osamu Takahashi, Yoshitaka Hachiya and Hiroshi Abe, "Applicability of Large Stone Asphalt Mixture for Surface Layer of Airport Pavement", Journal of Pavement Engineering, JSCE, Vol.4, pp.187-197, 1999 (in Japanese).

[8]Osamu Takahashi and Yoshitaka Hachiya, "A Study on the Fatigue Resistance of Large Stone Asphalt Mixtures", 55th Annual Meeting, JSCE, V-015, 2000 (in Japanese).

[9]Teruhiko Maruyama, Takashi Watanabe and Kazuhiko Yoshihara, "Fatigue Failure Envelope of Asphalt Mixtures", Journal of JSCE, No.306, pp.71-78, 1981 (in Japanese).

[10]Kenji Himeno, Takashi Watanabe and Teruhiko Maruyama, "Fatigue Failure Characteristics of Asphalt Mixtures at Low Stiffness Modulus", Journal of JSCE, No.366/V-4, pp.143-151, 1986 (in Japanese).