J. Materials, Conc.Struct. Pavements, JSCE, No. 690/V-53, 175-179, 2001 November

APPLICATION OF PERMEABLE ASPHALT MIXTURES IN AIRPORT PAVEMENTS

Yoshitaka HACHIYA [1], Shisheng WU [2] and Osamu TAKAHASHI [3]

[1] Member of JSCE, Dr.-Eng., Chief, Runways Laboratory, Port and Harbor Research Institute, Ministry of Land, Infrastructure and Transport (1-1, Nagase 3, Yokosuka 239-0826, Japan)
[2] Dr. Eng., STA Fellow, Runways Laboratory, Port and Harbor Research Institute, Ministry of Land, Infrastructure and Transport (1-1, Nagase 3, Yokosuka 239-0826, Japan)
[3] Member of JSCE, Dr. Eng., Senior Research Engineer, Runways Laboratory, Port and Harbor Research Institute, Ministry of Land, Infrastructure and Transport (1-1, Nagase 3, Yokosuka 239-0826, Japan)

Water can cause increasingly severe damage to airport pavements as the magnitude and number of aircraft loads increase. A water drainage system can extend pavement life and is recommended for heavy-duty airport pavements. Characteristics of permeable asphalt base mixtures and porous asphalt surface mixtures, which are used to remove rainwater from pavement, were studied in laboratory tests. As a result, the applicability of both materials for airport pavements was fully confirmed.

Key Words: *asphalt mixture, permeability, airport pavement, aggregate, modified asphalt*

1. INTRODUCTION

Atmospheric precipitation enters pavement structures in several ways, including from the pavement surface through cracks and joints. As water can deteriorate pavement, drainage is one of the most important factors in pavement design. Unfortunately, this aspect has scarcely interested engineers until recently. However, adequate drainage becomes very significant as the severity of traffic loading increases.

The free water in a pavement can be drained both vertically through the subgrade and laterally through permeable layers. The latter is not required if infiltration into the pavement is less than the subgrade drainage capacity. This might not be the case for airport pavements on ground reclaimed from the sea where the groundwater table remains high. Therefore, a lateral drainage system with a subsurface layer must be provided in heavy-duty airport pavements.

Cedergren 1), Forsyth et al. 2), Ray and Christory 3), and others report that adequate subsurface drainage can extend the life of pavements significantly. Based on such research, the use of permeable asphalt base (PAB) mixtures for road pavements has recently increased in the USA4). Therefore, their applicability for airport pavements was investigated in this study.

As the rainwater must be removed quickly from the surface to retain adequate friction in rainy weather, porous asphalt surface (PAS) mixtures are often adopted to road pavements. Such mixtures have been used in many countries in Europe and the American Continent since the early 1980's. In Japan, their use commenced in the early 1990's and has currently become one of the standard work processes 5).

In airport runways, transverse grooving is generally used for the inner portions 6). To hasten water removal, PAS might be used in the outer portions including shoulders from an economical point of view. The applicability of this method in less trafficked portions of airport runways was examined in this study.

Characteristics of these two types of mixtures on both permeability and strength were studied through laboratory tests. As a result, the fundamental properties of such mixtures were determined.

2. PERMEABLE ASPHALT BASE MIXTURES

(1) Material

A maximum aggregate size of 30mm was used

Table 1 Marshall stability test results of PAB

Case	Target air void (%)	Actual air void (%)	Density (g/cm^3)	Asphalt content (%)	Stability (kN)	Flow (1/10mm)
30-1	20	21.2	1.987	4.0	3.22	32
30-2	23	23.1	1.946	3.8	2.96	29
30-3	26	27.1	1.850	3.6	2.49	23
30-4	29	29.0	1.805	3.5	1.69	23
30-5	32	32.8	1.735	2.5	1.28	17

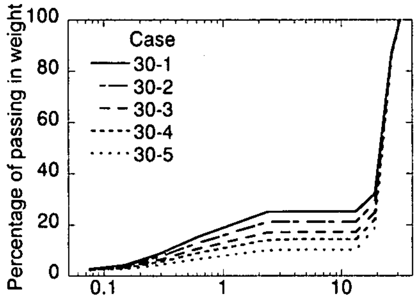

Fig. 1 Aggregate gradation of PAB

Table 2 Characteristics on aggregates of PAB

Case	D_{mean} (mm)	D_{10} (mm)	$P_{0.075}$ (%)
30-1	21.5	0.34	2.8
30-2	21.8	0.41	2.7
30-3	22.2	0.54	2.5
30-4	22.5	0.81	2.4
30-5	22.8	2.36	2.3

for permeable asphalt base (PAB) mixtures; that is, the aggregate consisted of single-sized crushed stone (S-30), coarse sand and filler. Conventional straight 60-80 asphalt was used.

Five air void ratios (20, 23, 26, 29 and 32%) were selected as target mix proportions. To determine optimum mixtures, tentative proportions with seven combinations of aggregates and three different asphalt contents were evaluated. The mix proportions were finally determined as shown in **Table 1**, based on Marshall stability tests along with asphalt runoff tests[7]. The gradation and characteristics of the aggregates are shown in **Fig. 1** and **Table 2**, respectively.

(2) Permeability

Water flow in PAB was investigated experimentally. The factors that influence the permeability were also analyzed.

A series of constant head permeability tests were conducted to measure the permeability of PAB. The apparatus for these tests is shown in **Fig. 2**. In the test, hydraulic gradients were varied from 0.005 to 1.0 by adjusting the height of the water tank.

Specimens with a diameter of 210mm and height of 500mm were prepared by compacting in several layers with 50 rammer blow cycles as well as the Marshall stability test. The diameter was appropriate for the maximum aggregate size used in the specimens, while the height allowed the hydraulic gradient to be varied.

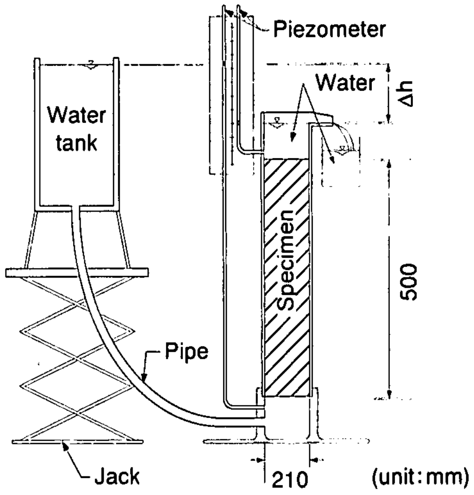

Fig. 2 Apparatus for permeability test

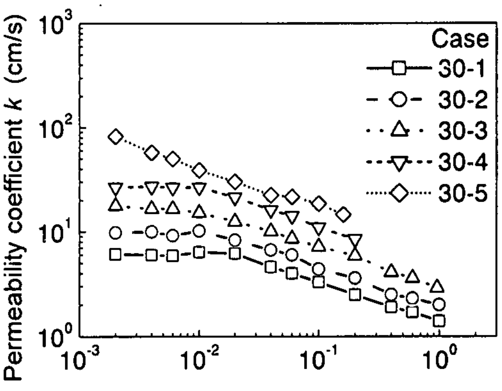

Fig. 3 Results of permeability test for PAB

The discharge velocity was expressed in a curved form, as a function of the hydraulic gradient for the asphalt mixtures considered. However, this is treated as linear in a low hydraulic gradient range. Therefore, the flow is in a laminar state in this range, while it is in a turbulent state in higher gradients. These conditions are expressed as Equations (1) and (2), respectively[8].

$$u = k \cdot i \qquad (i \le i_c) \tag{1}$$

$$i = c \cdot u^n \qquad (i \ge i_c) \tag{2}$$

where, u: discharge velocity,
k: permeability coefficient,

Table 3 Characteristics on permeability of PAB

Case	k (cm/s)	c	n	i_c	$k_{i=0.015}$ (cm/s)
30-1	6.1	0.598	1.61	0.02	6.1
30-2	9.8	0.354	1.6	0.015	9.8
30-3	16.5	0.176	1.57	0.012	14
30-4	26.8	0.083	1.63	0.01	22
30-5	-	0.042	1.6	-	34

Table 4 Change of discharge time due to loading for PAB

Material	Air void (%)	Discharge time (s)	
		Before	After
Case 30-1	20.6	5.49	5.00
Case 30-2	23.3	5.13	4.83
Case 30-3	25.7	5.04	5.04
Case 30-4	29.4	5.09	5.03
Case 30-5	32.2	5.03	4.92

Table 5 Water rise time through CTB

Water level	Time (min)
20 mm from surface	3
10 mm from surface	8
Surface in partial	40
Whole surface	60

Table 6 Input data for permeability calculation

Item	Input data
runway width	80m (with shoulders)
crack/joint spacing	7.5m
hydraulic gradient	1.5%
PAB thickness	50mm
interval of rain	3 days
drain duration	7.2 hours

i: hydraulic gradient,
i_c: critical hydraulic gradient,
c, n: constant.

Fig. 3 gives the results of permeability tests for PAB. For the mixture with 32% air void, the flow is always in the turbulent state, while the flow state changes from laminar flow to turbulent flow with increasing hydraulic gradients for other cases. The permeability characteristics k, c, n, and i_c obtained through experiments are summarized in **Table 3**. In the table, the permeability coefficient at a hydraulic gradient of 1.5%, which is typical for airport runways [6], is also included.

Both proper gradation and density are vital to the permeability, and many kinds of relationships have been reported [9), 10), 11), 12), 13), 14)]. In general, the gradation can be characterized by the effective size D_{10}, mean aggregate size D_{mean}, and the percentage passing 0.075mm sieve $P_{0.075}$, while the density might be characterized by the air void V_a. As the transverse surface gradient of airport runways is specified as 1.5% or less, the hydraulic gradient of 1.5% is considered to be pertinent for permeability calculations. Based on regression analyses of their relationship, Equation (3) was obtained with a correlation coefficient of 0.99 (k: cm/s, D_{10}: mm).

$$k_{i=0.015} = 6.73\times10^{2}\cdot V_a^{\,2.79}\cdot D_{10}^{\,0.247} \qquad (3)$$

(3) Applicability to base course

a) Durability against repeated loadings

To study durability of PAB, which was defined here as the resistivity to permeability decrease, against repeated loadings, the permeability was measured before and after a wheel tracking test. The specimen for the test was made with two layers, a 50mm thick dense graded asphalt surface (DGAS) mixture and a 100mm thick PAB mixture, with 300mm length and 300mm width. Wheel loads were applied repeatedly to the specimen for one hour in accordance with a procedure that is similar to that described in reference 15) except that transverse wandering was provided. After the test and the removal of DGAS, the permeability of PAB was measured directly in accordance with reference 7).

The measured permeability was compared to that determined in the same way before the test. **Table 4** shows the result for the time required to discharge 400cm^3 of water. As the loading has little influence on the discharge time, the permeability of PAB might not decrease after opening to traffic.

b) Effectiveness against high groundwater

An immersed wheel tracking test was conducted to evaluate the effectiveness of PAB against a high groundwater condition. The specimen consisted of the same two bituminous layers as in the wheel tracking test; namely, 50mm thick DGAS and 100mm thick base material. Two types of base materials, PAB and cement treated base (CTB) material that satisfy the specification [16], were used as a base course.

After repeated load applications, the bottom of DGAS on the CTB was stripped at a stripping ratio of 3%, while no stripping was found in the PAB case. The former is caused by the capillary phenomenon through the CTB. This is shown in **Table 5**, which gives the time for the capillary water to rise to different heights in the CTB. Thus, PAB is appropriate for the high groundwater condition.

c) Recommended mixture proportion

Assuming that rainwater flows through PAB in the laminar state, the required permeability can be estimated with chart "A" of reference 17), which shows relationships between the design infiltration rate and the drain path length. As a result, the permeability coefficient of PAB must be 0.14cm/s or larger under the condition shown in **Table 6**, which is typical of Tokyo International Airport. PAB with 20% air void clearly satisfies this requirement as seen in **Fig. 3**, but PAB with smaller air void might not provide adequate ability to retain permeability, as supposed from test results on porous asphalt surface mixtures. Modified asphalt 5) should be used because even PAB with 20% air void does not have stability sufficient for a base course material 15).

Table 7 Marshall stability test results of PAS

Case	Target air void (%)	Actual air void (%)	Density (g/cm^3)	Asphalt content (%)	Stability (kN)	Flow (1/10mm)
13-1	17	17.0	2.047	5.5	5.49	38
13-2	20	19.9	1.985	5.2	5.09	38
13-3	23	23.2	1.906	5.1	4.29	39

3. POROUS ASPHALT SURFACE MIXTURES

(1) Material

In accordance with the specification 18), aggregates with a maximum size of 13mm were used for porous asphalt surface (PAS) mixtures; i.e., S-30 in PAB is replaced with S-13. Modified, high viscosity asphalt was used in consideration of its extensive use in road pavements.

Three air void ratios (17, 20 and 23%) were selected as mix proportions. The mechanical properties and aggregate characteristics are shown in **Table 7** and **Table 8**, respectively. The mix proportions were determined with asphalt runoff tests 7) and Cantabro tests 7) in addition to Marshall stability tests.

Table 8 Aggregates characteristics of PAS

Case	D_{mean} (mm)	D_{10} (mm)	$P_{0.075}$ (%)
13-1	7.61	0.40	4.6
13-2	7.94	0.65	4.4
13-3	8.13	1.17	4.3

(2) Permeability

Table 9 shows the permeability coefficient obtained with the procedure specified in reference 15) under turbulent flow conditions 19). The permeability increases with the air void as well as PAB, while all cases satisfy the specification as a porous surface course material for roads 5).

To clarify the influence of traffic loading on the permeability of PAS, the aforementioned in situ permeability tests were conducted before and after the immersed wheel tracking test. The results shown in **Table 9** indicate that the permeability drops after the test regardless of the air void, in contrast to PAB. Although permeability decreases markedly in the range of lower air voids, the mix with 23% air void was similar to that of the PAB. Therefore, PAS should have an air void of 20% or more by considering permeability.

Table 9 Permeability and discharge time of PAS

Case	Air void (%)	Permeability (cm/s)	Discharge time (s)	
			Before	After
13-1	17.5	0.09	7.94	16.95
13-2	19.9	0.28	6.25	9.04
13-3	22.9	0.45	5.32	5.87

(3) Applicability to surface course

As the Marshall stability of PAS is lower than the specified value for an airport pavement surface course material 16), other characteristics related to traffic loading were studied. **Table 10** shows the results of immersed wheel tracking test, raveling test 15) and wheel tracking test in comparison with data of DGAS mixtures for airport pavements 18).

Table 10 Mechanical properties of PAS

Case	Air void (%)	Stripping rate (%)	Wear rate (%)	Dynamic stability (cycles/mm)
13-1	17.0	0	1.8	6,600
13-2	20.0	0	2.1	6,450
13-3	23.2	0	2.6	3,791
DG	3.7	2.7	2.2	607

All PASs showed no stripping in contrast with DGAS, and their durability against traffic loading under high groundwater conditions was adequate. The modified, high viscosity asphalt can increase the bonding strength between the aggregates and asphalt.

The wear rate increases, and the dynamic stability decreases with an increase of air void. The wear rate for an air void of 23% is larger than that of DGAS, while the dynamic stability of PAS is much larger than that of DGAS, regardless of the air void. Therefore, PAS should have an air void of 20% or less to sustain sufficient durability against traffic loading under both hot and cold conditions.

4. CONCLUSIONS

The followings are the main conclusions of the applicability of permeable asphalt base (PAB) and porous asphalt surface (PAS) mixtures to airport runways.

1) The flow state in PAB changes from laminar to turbulent with an increase of hydraulic gradient in the range of tested air voids (less than 30%). As the critical hydraulic gradient is between 0.01 and 0.2, the flow state in PAB of airport runways is considered to be laminar.
2) The permeability coefficient of PAB is influenced by both the air void and the effective

size of aggregates, and that for a 1.5% of hydraulic gradient can be regressed with a high confidence level.

3) PAB maintains a sufficient permeability after repeated loading, and shows no stripping in immersed wheel tracking tests. PAB with 20% air void that contains high viscosity, modified asphalt could be used in heavy-duty airport runways even under high groundwater conditions.
4) PAS with 20% air void has not only sufficient permeability but also high durability against repeated loading when high viscosity, modified asphalt is used. Therefore, PAS could be used for the less trafficked portions of airport runways, even under high groundwater conditions.

REFERENCES

1) Cedergren, H.R.: *Seepage, Drainage, and Flow Nets*, John Wiley & Sons, Inc., 534p., 1977.
2) Forsyth, R., Wells, G.W. and Woodstrom, J.H.: Economic impact of pavement subsurface drainage, *Transportation Research Record (TRR)*, No.1121, pp.77-85, 1987.
3) Ridgeway, H.H.: Pavement subsurface drainage systems, *National Cooperative Highway Research Program (NCHRP), Synthesis of Highway Practice*, No.96, 38p. 1982.
4) Christopher, B.R. and McGuffey, V.C.: Pavement subsurface drainage systems, *NCHRP, Synthesis of Highway Practice*, No.239, 50p., 1997.
5) Japan Road Association (JRA): *Manual for asphalt pavements*, 324p., 1992 (in Japanese).
6) Civil Aviation Bureau, Ministry of Transport (CAB, MOT): *Specification for Airport Civil Engineering Facilities*, 1997 (in Japanese).
7) JRA: *Guide for Pavement Tests (Supplement)*, 317p., 1996 (in Japanese).
8) Japan Society of Civil Engineers (JSCE): *Reports on activities of pavement engineering research committee*, 1997 (in Japanese).
9) Huang, Y.H.: *Pavement analysis and design*, Prentice Hall, Inc., 805p., 1993.
10) Crovetti, J.A. and Dempsey, B.J.: Hydraulic Requirements of Permeable Bases, *TRR*, No.1425, pp.28-36, 1993.
11) Randolph, R.W., Cai, J., Heydinger, A.G. and Gupta, J.D.: Laboratory study of hydraulic conductivity for coarse aggregate bases, *TRR*, No.1519, pp.19-27, 1996.
12) Yin, J. and Hachiya, Y.: Permeability of drainage base course materials at laboratory tests, *Journal of Pavement Engineering, JSCE*, Vol.3, pp.175-182, 1998.
13) Xie, H., Yao, Z., Tian, S. and Zhuang, S.: Permeability of asphalt treated permeable base materials, *Chinese Journal of Highway and Transport*, Vol. 13, No.2, pp.20-23, 2000 (in Chinese).
14) Yao, Z. and Xie, H.: Design of the asphalt treated subdrainage systems, *4th Annual Meeting of Shanghai Highway Society*, pp.1-6, 1999 (in Chinese).
15) JRA: *Guide for pavement tests*, 1069p., 1988 (in Japanese).
16) CAB, MOT: *Guideline on Airport Pavement Design* , 147p., 1999 (in Japanese).
17) American Association of State Highways and Transportation Officials: *AASHTO Guide for Design of Pavement Structures, Volume 2*, 1986.
18) CAB, MOT: *General specifications on Airport Civil Engineering Facility Constructions*, 1999 (in Japanese).
19) Ohkawa, H., Sato, T. and Hokari, K.: Study on the estimation of permeability coefficient of drain asphalt, *Journal of JSCE*, No.478/V-21, pp.101-108, 1993 (in Japanese).

(Received March 26, 2001)

透水性アスファルト混合物の空港舗装への適用性

八谷　好高・伍　石生・高橋　修

航空機の大型化ならびに運航回数が増加するにつれ，空港舗装が水により受ける影響も著しいものとなる．排水システムを用いることにより舗装の寿命を延ばすことが可能となるため，交通量の多い大規模空港の舗装ではこのシステムが必要になる．本論文では，舗装から雨水を排水するために用いられる透水性アスファルト路盤材料と透水性アスファルト表層材料の特性について，室内試験により検討した．その結果，両材料の空港舗装への適用性が明らかになった．