[Regular Paper]

Water/gas Permeability of Bituminous Mixtures and Involvement in Blistering Phenomenon

Iwao SASAKI[†1)]*, Akihiro MORIYOSHI[†2)], and Yoshitaka HACHIYA[†3)]

[†1)] Material and Geotechnical Engineering Research Group, Incorporated Administrative Agency Public Works Research Institute, 1-6 Minamihara, Tsukuba, Ibaraki 305-8516, JAPAN

[†2)] Div. of Built Environment, Graduate School of Engineering, Hokkaido University, North 13 West 8, Kita-ku, Sapporo 060-8628, JAPAN

[†3)] Airport Dept., National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure and Transport, 3-1-1 Nagase, Yokosuka, Kanagawa 239-0826, JAPAN

(Received June 29, 2005)

The blistering phenomenon is one of the major damages in bituminous pavement during a hot summer. The phenomenon was believed to be caused by water permeating from outside via channels of connected pores in bituminous mixtures. However, the surface course in bituminous pavement is not permeable to water, particularly near the blistering area. Therefore, permeation of liquid water is unlikely to be responsible for the water accumulation that causes the blistering phenomenon. Moisture vapor in the air is important in water intrusion into bituminous mixtures. This study examined moisture transfer mechanisms in bituminous pavements, focusing on the coefficient of permeability of pavement mixtures of both liquid water and humid air (*i.e.* air containing water vapor).

Keywords

Asphalt mixture, Blistering, Water permeability, Gas permeability, Vapor permeation

1. Introduction

Moisture damage to bituminous pavement occurs via several mechanisms, and appears in diverse forms such as blistering, stripping, and disaggregation. Blistering is a fulminating phenomenon in which the trapped moisture evaporates and upheaves the pavement surface layer within a few hours as a result of so-called blistering heat. In contrast, stripping and disaggregation are types of internal chronic damage. Disaggregation is caused by the stripping and resolution of binders, and is considered to be the ultimate irreversible damage, whereas stripping is considered to be reversible by retacking (healing) of the binders on the aggregates. All these types of damage are caused by water accumulated in bituminous pavement layers.

The mechanism of moisture intrusion into bituminous pavement may involve several factors[1)], for example, air void content, cracking of the surface course, poor execution, inadequate subsurface drainage, and high groundwater level. Extensive research on stripping at the University of Idaho[2),3)] has established that air voids in bituminous mixtures are probably saturated with water from the subgrade or subbase. Groundwater beneath the pavement body and/or water penetrating from side sections and/or surface cracking may be the source of the water, and the moisture is aspirated up to just beneath the surface course[4)]. Drainage by evaporation from the road surface may also be important.

Many investigations of the cause of blistering have simply examined the water impermeability of the surface layers. Although the ultimate cause of blistering certainly involves this factor, the mechanism of moisture intrusion into pavement layers is also important. Control of moisture movement in pavement structures is an important research target for practical solutions to deal with this phenomenon and also to develop adequate pavement design strategies.

Blistering is unlikely to be related to hydrological flow of liquid water, because even vapor cannot escape from the boundary of the surface and base course. Therefore, where and how does water permeate the pavement? Primary blistering, which is observed just after the completion of the pavement, is usually caused by water trapped within the pavement layers during paving operations[5)]. However, secondary blistering, which probably occurs in the hot summer following paving completion, has no definitive evidence to sug-

* To whom correspondence should be addressed.
* E-mail: isasaki@pwri.go.jp

Table 1 Outlines of Asphalt Mixtures

Specimen No.	A, B		C
	Surface	Base	(lab-compacted)
Type of mixture	Dense	Coarse	Dense
Max size of aggregate [mm]	13	20	13
Density [g/cm^3]	2.39	2.35	2.45-2.48
Air voids [%]	3	5.4	2.5-4.6
Asphalt content [%]	6.5	5.4	5.5-6.2 (every 0.05%)
Asphalt binder	Modified	StAs80/100	StAs80/100

StAs: Straight asphalt.

gest the mechanism of inbound penetration. Secondary blistering has previously[1),2)] been attributed to liquid permeation through surface cracks or water-bearing structures with inadequate subsurface drainage.

Investigation of moisture-related damage and suitable countermeasures will depend on fundamental analyses of moisture movement in the pavement structure. The mechanism of moisture intrusion into pavement is the primary issue in research on moisture damage. Investigations into the causes of blistering are likely to be closely related to the thermodynamic behavior of the moisture permeation mechanism.

Previously we investigated[6)] the mechanisms of water accumulation in bituminous mixtures with a new experimental system of moisture permeation that allows examinations of transitional moisture transfer. Evaluation of liquid and gaseous water permeability is essential for further analysis. This study investigated the characteristics of liquid/gaseous water penetration and the mechanisms of water accumulation in pavement mixtures.

2. Materials Tested

The sample materials tested in this study were collected from pavements in service and lab-compacted specimens. The diameter of all core specimens was 10 cm, with thickness of 4 cm (surface course) + 4 cm (base course) for specimen series A and B, and 5 cm for specimen series C. The outlines of the asphalt mixtures are shown in **Table 1** as the target level of the mix design or the initial values at pavement construction. Detailed sampling locations and outlines of the specimens are as follows:

* Specimen series A: Osaka Airport – no blistering

The cores were collected from pavement sections on the runway of Osaka International Airport. The areas were distant from the blistering (see **Fig. 1**).

* Specimen series B: Osaka Airport – near blistering

The samples were collected in the vicinity of blistering on the runway of Osaka International Airport (see **Fig. 1**). The blistering had reached a maximum diameter of 50-100 cm and height of 2-5 cm. All blistering damage had occurred between the surface and base courses as usually observed[5)].

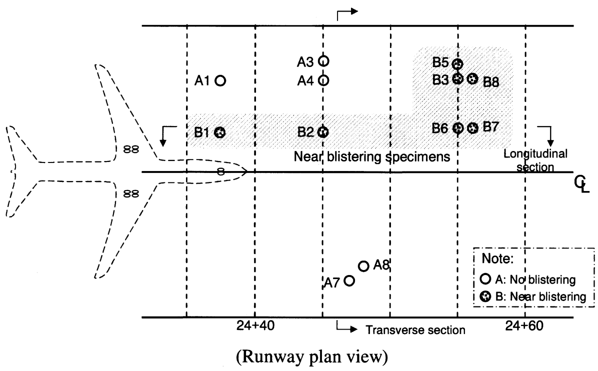


Fig. 1 Locations of Specimens Collected on the Runway of Osaka International Airport

* Specimen series C: Laboratory-made specimens

Laboratory mixtures were prepared as reference specimens for associated basic permeability measurements. The specimen series C consisted of 15 levels of asphalt content within the range 5.5-6.2%, and the other components were the same.

3. Test Methods

3. 1. Water Permeability Test

The coefficient of water permeability (k_w) is measured by a water permeability test according to Darcy's law. In this study, a constant water-head or nitrogen-gas pressurized permeameter was used under the range of normal atmospheric pressure for permeable specimens, but was applied up to 294 kPa for the impermeable specimens. A single layered specimen (surface course, base course, or laboratory compacted mixture) was used in this test.

Applied water pressure is an important factor in a water permeability test. Asphalt mixtures show creep deformation at ambient temperature, so excessive pressure may affect the pore structures of specimens. The applied water pressure should be matched to the actual water pressure. In general, k_w of asphalt concrete mixtures is inversely proportional to water pressure, although that of Portland cement concrete is usually proportional to the water pressure. Therefore, the water pressure of a water permeability test for asphalt concrete should be set around atmospheric pressure except for materials in hydraulic infrastructures.

3. 2. Gas Permeability Test

Permeation of liquid-phase water is strongly correlated with the diameter of the penetration path, particularly for microscopic porous materials. Previous studies[7),8)] suggest that permeation of liquid water is impossible due to surface tension if the pore diameter is below 4×10^{-3} cm. Water transfer through such impermeable micro-pores probably occurs only via evaporation in the pores. As a result, k_w declines by about three orders under the threshold diameter[7)]. A similar phenomenon is known in the field of geotechnical engineering, in which seepage water never flows under a threshold hydraulic gradient in cohesive soil[9)].

Bituminous mixtures have a micro-pore structure in which water permeation occurs. Furthermore, blistering occurs under such impermeable conditions. Therefore, a gas permeability test[9)] was performed to examine the permeation characteristics of the mixture.

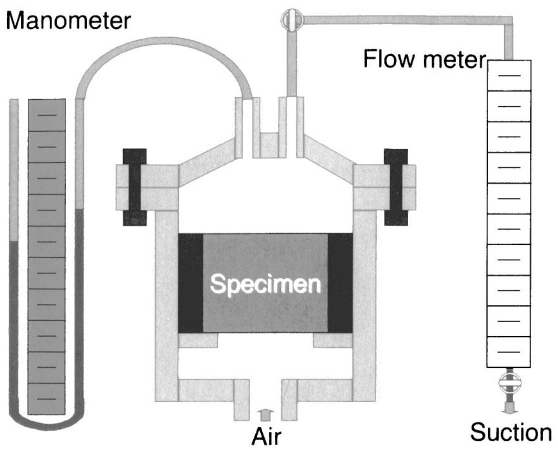


Fig. 2 Overview of Gas Permeability Tester

Figure 2 shows the gas permeability tester used in this study. A single layer specimen (surface course or base course) was used in this test. The specimen of bituminous mixture was inserted and the side face sealed using asphalt binder in a steel or acrylic-resin container with the bottom opened to the air. The container was connected to a gas flow meter. A water manometer was used to monitor the gas pressure gradient under the test. The coefficient of gas permeability (k_g) was calculated according to Darcy's law in the same manner as k_w.

The gas pressure gradient between both sides of the specimens (ΔP) was maintained at 0.245 kPa for specimens A and B, and 1 kPa for specimens C. This gas pressure is, compared with that of the pressurized water permeability test, relatively close to the actual environmental conditions.

Gas permeability is usually measured in sufficiently dried specimens. However, in addition to the dried condition, k_g in the "wet" condition was measured for specimen series C after the water permeability test had been finished. In the wet condition, permeability was measured after water in the specimen was purged by the air under 40 kPa. Therefore, only part of the pore structures may have functioned because micro-pores in the specimens were still filled after the water permeation test although relatively large pores had been cleared by air pressure.

4. Results

4. 1. Water Permeability Test

Table 2 shows the measurements of k_w calculated from the water permeability test for specimen series A and B. All specimens of the surface course of series B

Table 2 Water and Gas Permeability Test Results (specimen series A and B)

		Surface course			Base course		
		Water permeability test	Gas permeability test		Water permeability test	Gas permeability test	
	No.	k_w [cm/s]	k_g [cm/s]	K [cm^2]	k_w [cm/s]	k_g [cm/s]	K [cm^2]
No blistering	A1	8.26×10^{-6} *p	9.21×10^{-7}	1.06×10^{-10}	7.87×10^{-6} *p	1.27×10^{-6}	1.46×10^{-10}
	A3	3.42×10^{-5} *p	3.33×10^{-6}	3.84×10^{-10}	1.34×10^{-3} *a	3.06×10^{-4}	3.54×10^{-8}
	A4	1.65×10^{-5} *p	1.59×10^{-6}	1.84×10^{-10}	Impermeable *p	3.96×10^{-8}	4.57×10^{-12}
	A7	4.86×10^{-4} *p	7.65×10^{-5}	8.83×10^{-9}	1.66×10^{-4} *p	3.32×10^{-5}	3.83×10^{-9}
	A8	8.08×10^{-7} *p	1.60×10^{-7}	1.84×10^{-11}	Impermeable *p	2.29×10^{-8}	2.64×10^{-12}
Near blistering	B1	Impermeable *p	1.90×10^{-8}	2.20×10^{-12}	Impermeable *p	4.17×10^{-8}	4.82×10^{-12}
	B2	Impermeable *p	3.15×10^{-8}	3.64×10^{-12}	4.81×10^{-5} *p	5.60×10^{-5}	6.47×10^{-9}
	B3	Impermeable *p	3.29×10^{-8}	3.80×10^{-12}	Impermeable *p	4.66×10^{-8}	5.38×10^{-12}
	B5	Impermeable *p	8.95×10^{-8}	1.03×10^{-11}	Impermeable *p	8.12×10^{-8}	9.38×10^{-12}
	B6	Impermeable *p	2.44×10^{-8}	2.81×10^{-12}	4.17×10^{-3} *a	4.06×10^{-4}	4.69×10^{-8}
	B7	Impermeable *p	5.26×10^{-8}	6.07×10^{-12}	Impermeable *p	1.40×10^{-7}	1.62×10^{-11}
	B8	Impermeable *p	1.49×10^{-7}	1.73×10^{-11}	Impermeable *p	1.24×10^{-8}	1.43×10^{-12}

k_w: coefficient of water permeability, k_g: coefficient of gas permeability, K: coefficient of symmetric permeability.
*a: tested at atmospheric pressure, *p: tested while pressurized.

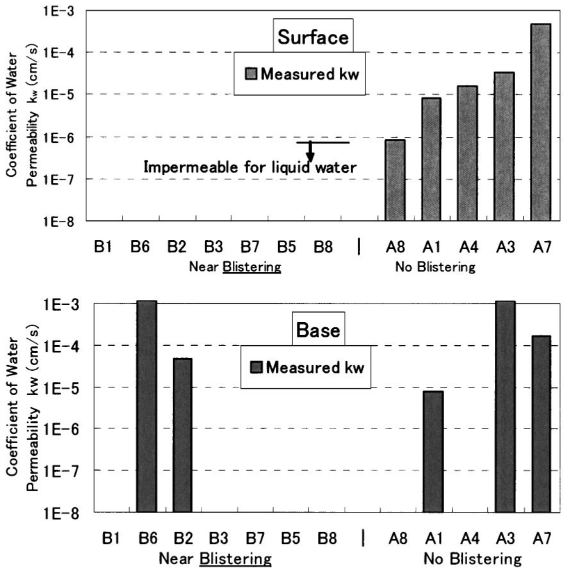


Fig. 3 Coefficient of Water Permeability k_w

(near blistering) were impermeable to liquid water even under pressurized test conditions. In contrast, k_w specimens in series A from the reference sections had k_w of around 10^{-5} cm/s which is the usual level for asphalt mixtures containing about 5% air voids[10]. The base course showed varying water permeability with no obvious relationship between k_w and blistering.

4. 2. Gas Permeability Test

Table 2 also shows the measurements of k_g for specimen series A and B (at ambient temperature). The coefficient k_g of the surface course of specimen series B (near blistering) was generally small, below 10^{-7} cm/s. In contrast, k_g for the surface course of specimen series A was at least one order higher. The measurements k_g for the base course varied from 10^{-8} to 10^{-4} cm/s, with no obvious relationship between k_g and blistering. The estimated combined k_g of surface and base courses can be derived from

$$\frac{t_{\mathrm{surface}} + t_{\mathrm{base}}}{k_{\mathrm{combined}}} = \frac{t_{\mathrm{surface}}}{k_{\mathrm{surface}}} + \frac{t_{\mathrm{base}}}{k_{\mathrm{base}}} \qquad (1)$$

where, t_{surface}, t_{base} are the thicknesses of the surface and base courses, respectively, and k_{combined}, k_{surface}, k_{base} are the coefficients of permeability of the combined, surface and base courses, respectively.

5. Discussion

5. 1. Water Permeability of Bituminous Mixtures and Blistering Damage

Figure 3 shows the k_w of specimen series A and B. There is a specific threshold of k_w between 10^{-7} and 10^{-6} cm/s as previous studies[11]. Whether blistering occurs or not can be clearly determined by the water permeability test results (upper graph in **Fig. 3**). It is obvious that blistering does not occur for a surface course with a larger coefficient of water permeability. In contrast, the effect of the water permeability of the base course is not obvious, because the permeability of the base course displays no such relationship.

Figure 3 shows an obvious threshold level of water permeability around 10^{-6} cm/s in which determines whether measurable liquid water can permeate, and the reason is important to be examined. Presumably this level is closely related to the limit of water permeation for the pore diameter of 4×10^{-3} cm as stated in section **3. 2.**

5. 2. Gas Permeability of Bituminous Mixtures and Blistering Damage

We previously found[6] that the mass transfer mode of gas (water vapor) permeation through the micro-pores of mixtures is extremely important in the process of water accumulation in bituminous mixtures. Therefore, gas permeability evaluation is essential to analyze moisture-related pavement damage. In this study, gas permeability testing was conducted using a permeameter as described in section **3. 2.** under various conditions of humid air.

The gas permeability test can measure k_w below 10^{-7} cm/s. **Figure 4** shows k_g for specimen series A and B, under 20-50% RH. The middle graph in **Fig. 4** shows the estimated combined k_g of the surface and base courses.

There was no relationship between k_g of the base course and blistering (lower graph in **Fig. 4**), as observed for k_w. The estimated combined k_g shows a relatively good relationship, but still does not show a clear threshold for blistering. However, the upper graph in **Fig. 4** illustrates a clear threshold of k_g of the surface course that determines whether blistering does or does not occur. The threshold k_g value is, as indicated in **Fig. 4**, on the order of 10^{-7} cm/s for the specimens used in this study. Although the threshold value should be examined carefully, the gas permeability test may provide quantitative data to evaluate the causes of blistering. Moreover, the gas permeability test can provide essential information about the mechanisms of moisture transfer analyses.

The blistering phenomenon almost always occurs at the interface between the surface and base course, probably because the water vapor pressure cannot lift both layers even though the base is impermeable. This may be the reason why the gas permeability of surface course is the only factor controlling the blistering phenomenon.

Bituminous mixtures with very low gas permeability undergo upheaval stress, and may also form a barrier to prevent the escape of accumulated water from pavement layers. This is one of the two causes of the blistering phenomenon. Moreover, if k_g is below about 10^{-7} cm/s, which is equivalent roughly to $k_w < 10^{-6}$ cm/s, pore network blockage certainly occurs in such surface

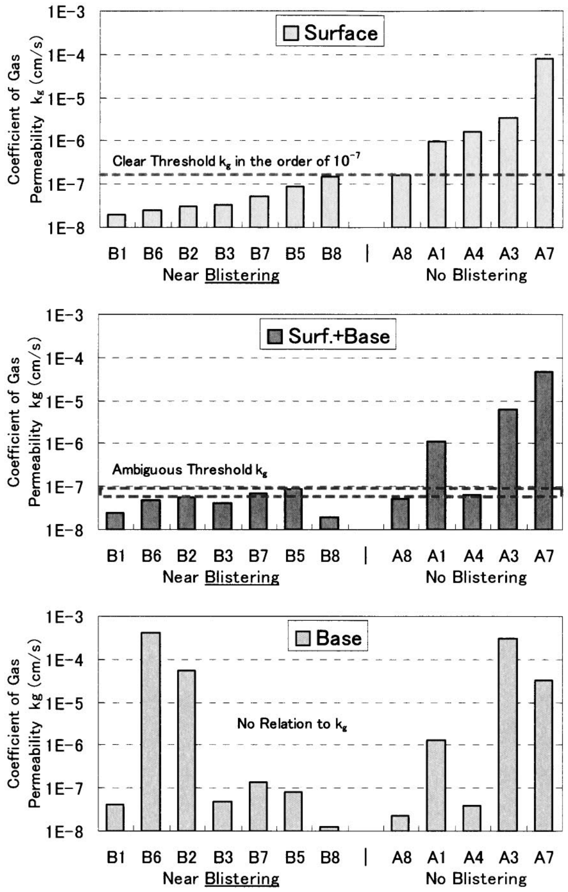


Fig. 4 Coefficient of Gas Permeability k_g

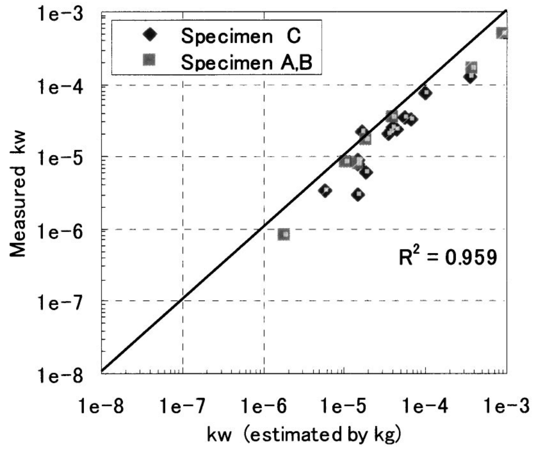


Fig. 5 Measured and Estimated Water Permeability k_w

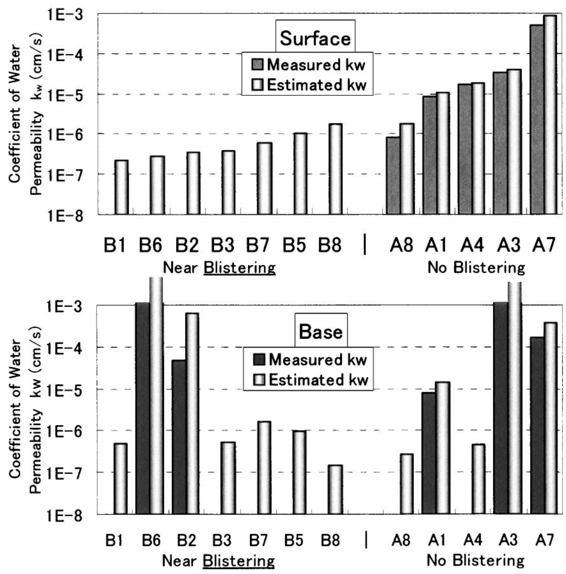


Fig. 6 Coefficient of Water Permeability k_w

layers because of liquid water impermeability as discussed in section **5. 1.**

The gas permeation test, particularly for the surface course, is essential to analyze moisture-related damage issues in bituminous pavement, because vapor state moisture transfer is an important factor[6].

5. 3. Conversion from Gas Permeability to Water Permeability

In general, the permeability test primarily measures the flow rate Q and the coefficient of symmetric permeability (K) can be calculated from Eq. (2) based on Darcy's law. As long as we assume laminar flow in the pores of bituminous mixtures, the coefficient of absolute permeability (k) is proportional to K and the density ρ, and inversely proportional to the kinetic viscosity η of the objective fluid[12].

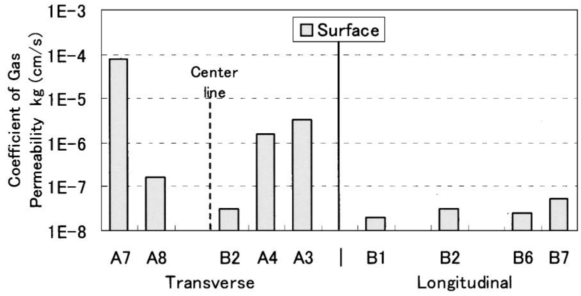
$$Q\left(\mathrm{cm}^3/\mathrm{s}\right) = \frac{K \cdot \Delta P \cdot A}{\rho \cdot L}, \quad k = K\frac{\rho_{\text{objective fluid}}}{\eta_{\text{objective fluid}}} \qquad (2)$$

where, Q (cm^3/s) is the flow rate of objective fluid flux, A (cm^2) and L (cm) are the area and length of the specimen, respectively, k (cm/s) is the coefficient of absolute permeability, $\rho_{\text{objective fluid}}$ (g/cm^3) is the density of the objective fluid, K (cm^2) is the coefficient of symmetric permeability, and $\eta_{\text{objective fluid}}$ (μPa·s) is the kinetic viscosity of the objective fluid.

Applying this conversion, the coefficient of absolute permeability (k) can be derived from the coefficient of symmetric permeability for any fluid, using the fluid properties of humid air and liquid water.

Figure 5 shows k_w converted from the gas permeability test result for all specimens tested in this study except for the water impermeable mixtures. Estimated water permeability had a linear correlation with the measured values. The results suggest that estimated water permeability is consistent with the measured results of the water permeability test. Therefore, the gas permeability test may also indicate the water permeability.

However, as shown in **Fig. 6**, estimated k_w for specimens near the blistering area showed no correspond-



Along the transverse and longitudinal sections in Osaka runway indicated in Fig. 1.

Fig. 7 Distribution of the Coefficient of Gas Permeability k_g

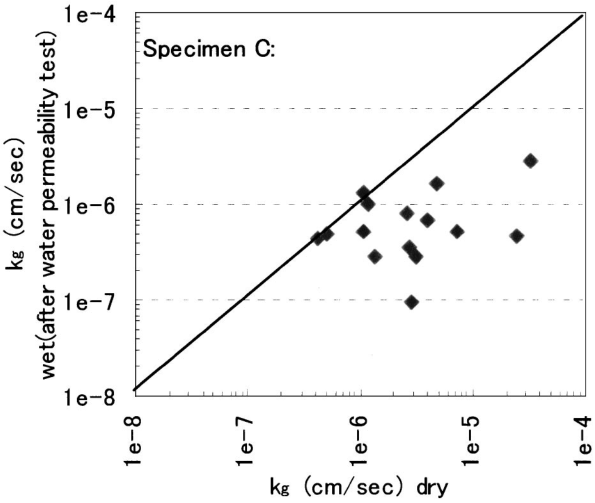


Fig. 8 Decline in Gas Permeability k_g due to Accumulated Water in Bituminous Mixtures

ence to the measured values because of the liquid water impermeability, despite the good correlation of estimated water permeability for specimens from non-blistered (*i.e.* liquid water permeable) areas. This means that liquid water cannot permeate into the pore structure of such bituminous mixtures below the threshold level of permeability described in section **5. 1.**, although there are connected micro-pores in the mixture allowing water vapor to transfer to the other side of specimen. Certain properties of fluid other than viscosity and density, probably the interfacial tension of water[7)], may result in the impermeability of the pore structures. The barrier for liquid water implies a significant factor for the one-way moisture transfer mechanism for bituminous mixtures.

The facts that water cannot permeate whereas vapor can permeate are definitely important for moisture accumulation. If pore water condenses in the surface course of the pavement under specific environmental conditions, pore water may act as a plugging material for the connected pore network and constitutes a barrier for both in- and out-bound moisture transfer in pavement mixtures.

5. 4. Causes of Decrease in Permeability

This section discusses the causes of decrease in permeability, focusing on the gas permeability, from the viewpoints of mixture properties, pore blockage, and fluid properties.

5. 4. 1. Consolidation due to Traffic Loading

Discussion of the impermeability of the surface course must first consider the initial design composition of the mixture. The water permeability is correlated with the air void ratio of bituminous mixtures[10)], and consolidation due to kneading by traffic is also one of involved.

Figure 7 shows the distribution of k_g for the transverse and the longitudinal sections of the Osaka runway indicated in **Fig. 1**. The left half in **Fig. 7** has a concave shape, indicating that the parts around the centerline have lower k_g than the side areas of the runway.

Furthermore, the right half in **Fig. 7** shows the longitudinal distribution of gas permeability along the section indicated in **Fig. 1** (*i.e.* area to the centerline). Clearly, k_g becomes very low along the centerline due to the concentrated traffic load.

5. 4. 2. Micro-pore Blockage by Accumulated Water in Mixtures

Figure 8 shows the relationship between k_g-dry and k_g-wet just after a water permeability test for the specimen series C. Most specimens became quite impermeable in the wet condition after water permeability testing, because the internally connected pores were blocked (plugged) by water. This sealing effect is certainly one of the causes of permeability reduction.

Liquid water has fairly large interfacial tension and viscosity, so once water has filled the micro-pores in a bituminous mixture, such liquid pore water cannot be easily eliminated by low pressures, particularly for heavily consolidated mixtures with permeability below 10^{-6} cm/s. The observation in section **5. 1.** that water cannot permeate below the threshold may be evidence to support the reduction of gas permeability.

In the field pavement, water is likely to condense in surface mixtures mainly in the night hours, and the pore water remains in the surface course until morning under specific climatic conditions. As the above results prove, pore water definitely becomes an obstacle to water elimination by vapor evaporation from pavement layers.

It is important that the actual conditions of water condensation should be considered for the permeability evaluation of pavement mixture, and for test conditions in the laboratory as well.

5. 4. 3. Viscosity Increase due to Temperature Change

Viscosity and the density of fluids are usually considered to be constants and the effects neglected in previous studies. The viscosity of water η_w usually decreases with increased temperature. However, the

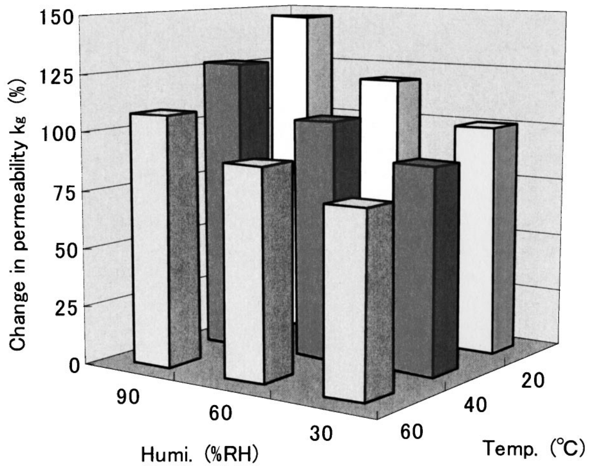


Fig. 9 Change in Permeability k_g Depending on Air Temperature and Humidity (k_g at 20°C 30%RH = 100%)

viscosity of gas (water vapor) η_g increases with temperature. This means that permeation of vapor becomes more difficult at higher temperatures.

Figure 9 shows the change in permeability k_g under various temperature and humidity conditions when k_g at 20°C 30%RH is 100%, by calculating the viscosity and density of air containing the designated amount of water vapor. During the daytime when the temperature becomes high, it becomes relatively difficult for vapor to permeate bituminous mixtures. Therefore, moisture escape from the pavement may be slower at high temperatures. In contrast, during the nighttime when the temperature falls and humidity increases, moisture vapor can permeate into pavement mixtures because the vapor permeability is higher.

The viscosity increase with temperature may not be a critical factor that controls moisture accumulation in pavement layers because the change in the coefficient of vapor permeability is around ±30%. However, this change must accelerate in-bound moisture transfer to a pavement considering the daily climatic cycle around the pavement.

6. Conclusions

The following conclusions were obtained in this study.

(1) The blistering phenomenon depends upon the coefficient of water/gas (vapor) permeability of the surface course of the bituminous pavement.

(2) If the coefficient of water permeability k_w of the surface course is below a certain threshold (about 10^{-6}cm/s or less), liquid water cannot permeate and blocks the pores as pore water, so the blistering phenomenon in bituminous pavement can occur under hot summer conditions.

(3) Even if a surface course is practically impermeable to liquid water, moisture in the air can easily permeate into the bituminous mixture by water vapor transfer.

(4) The permeability is determined not only by the original mixture properties but also by consolidation due to kneading by traffic.

(5) Penetrated or condensed water in the pore structure acts a barrier to vapor permeation in bituminous mixtures, and the sealing effect of pore water should be analyzed considering the climatic conditions.

(6) The coefficient of gas permeability changes according to the temperature and humidity of the gas, mainly affected by the viscosity, so the pavement is relatively impermeable during daytime and relatively permeable during nighttime.

7. Recommendations

Moisture damage in pavement layers is one of the major requirements for the favorable maintenance of pavement structures, especially in Japan where precipitation is high and temperature and humidity ranges are wide.

The present and previous[6)] studies have concluded that the surface and base courses respire (breath) every day. Ambient moisture can permeate in the vapor state via connected micro-pores, and accumulate in bituminous mixtures of runways and highways. Consideration of this respiring mechanism is crucial for the design of waterproofing measures for bituminous pavement, as well as for the selection of materials for the repair of bituminous pavement. Excessively impermeable surface mixtures can be subject to blistering damage, particularly bridgedeck pavements or multilayered high-class pavements used in airports and highways.

Pavement impermeability of bituminous mixtures is basically intended to prevent damage to granular subbase materials. Therefore, minor water penetration does not cause serious problems. A perfect barrier against moisture intrusion cannot be attained on actual pavement sites because of vapor permeation as stated in this paper, so water and vapor channels must be prepared and material design must be carefully considered.

Based on the findings of this study on mass transfer in bituminous mixtures, further studies are needed to analyze dew condensation mechanisms focusing on temperature distribution in pavement layers, and to identify water accumulation conditions by themodynamic consideration of the temperature differences and chronological changes. Understanding of the water accumulation mechanisms will help to overcome the mechanisms causing moisture damage to bituminous pavement.

Acknowledgments

The authors gratefully thank the Civil Aviation Bureau office of Osaka International Airport for provid-

ing valuable core specimens collected from their runways. The authors also thank the students for their contribution to the performance of the moisture related experiments.

References

1) Kandhal, P. S., Lubold, C. W., Roberts, F. L., *The Journal of the Association of Asphalt Paving Technologists*, **58**, 40 (1989).
2) Lottman, R. P., *Am. Chem. Soc.*, **16**, (1), (1977).
3) Lottman, R. P., *National Cooperative Highway Research Program Report*, **192**, (1978).
4) McKesson, C. L., *Proceedings on the Association of Asphalt Paving Technologists*, **18**, (1949).
5) Kawashima, Y., Matsuura, S., "Questions and answers on pavement," **5**, (6-8), (6-9), Kensetsu-tosyo, Tokyo (1987), p. 142.
川島義昭，松浦精一，"舗装の質疑応答，" **5**, (6-8), (6-9), 建設図書，東京 (1987)，p. 142.
6) Sasaki, I., Moriyoshi, A., Hachiya, Y., Nagaoka, N., submitted for the *Journal of the Japan Petroleum Institute*.
7) Yamamoto, T., *ESPEC TECHNOLOGY REPORT*, **17**, 8 (1999).
8) MIL-STD-202, "International Series of Monographs on Electronics and Instrumentation," 5, Pergamon Press, (1962).
9) Japanese Society of Soil Mechanics and Foundation Engineering, "Doshitsu shiken no houhou to kaisetsu," Maruzen, Tokyo (1990), p. 271.
土質工学会編，"土質試験の方法と解説，" 丸善 , 東京 (1990), p. 271.
10) Japan Society for Civil Engineers, "Hoso-kogaku," Maruzen, Tokyo (1995), p. 444.
土木学会編，"舗装工学，" 丸善，東京 (1995)，p. 444.
11) Ito, M., Nitta, H., "Research Report on the Priority Research Projects," Public Works Research Institute, (2004), p. 653.
12) Al-Omari, A., Tashman, L., Masad, E., Cooley, A., Harman, T., *The Journal of the Association of Asphalt Paving Technologists*, **71**, 30 (2002).
13) Matsuura, S., "Questions and answers on pavement," **6**, (4-15), Kensetsu-tosyo, Tokyo (1991), p. 109.
松浦精一，"舗装の質疑応答，" **6**, (4-15), 建設図書 , 東京 (1991), p. 109.

要　旨

歴青系舗装の透水および透気性状とブリスタリング現象との関係

佐々木　厳[†1)]，森吉　昭博[†2)]，八谷　好高[†3)]

[†1)] (独)土木研究所　材料地盤研究グループ，305-8516 茨城県つくば市南原1-6

[†2)] 北海道大学大学院工学研究科環境創世工学専攻，060-8628 札幌市北区北13条西8丁目

[†3)] 国土交通省国土技術政策総合研究所　空港研究部，239-0826 神奈川県横須賀市長瀬3-1-1

ブリスタリング現象は，夏季の特に暑い時期に生じるアスファルト舗装の主要な損傷の一つである。この現象は，アスファルト混合物中の連続空隙を通して外部から浸入した雨水が原因であるとされてきた。しかしながら，アスファルト舗装の表層，特にブリスタリング等の損傷が生じる箇所周辺は不透水である。つまり，ブリスタリング現象を引き起こす滞留水の要因として，液体状態での水の浸透は考えにくい。著者らは，大気中の湿気が水蒸気として透過し結露することが舗装体内への水分浸入の鍵を握る現象であることを既報で指摘した。本研究では，アスファルト舗装混合物中の水分移動機構の検討として，水および湿潤空気の透過係数に注目することにより，ブリスタリング現象において鍵となる水分浸入の要因を実験検討した研究成果を報告する。