[Research Note]

New Test Method for Moisture Permeation in Bituminous Mixtures

Iwao SASAKI[†1)]*, Akihiro MORIYOSHI[†2)], Yoshitaka HACHIYA[†3)], and Noriyuki NAGAOKA[†4)]

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

[†2)] Div. of Urban and Environmental Engineering, 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

[†4)] Niigata Prefectural Government, Shinko 4-1, Niigata 950-8570, JAPAN

(Received November 18, 2004)

Water-related damage to bituminous pavement is considered to result from penetration of liquid water from the surface and/or subsurface. However, surface courses made of bituminous material such as runway pavements are usually not permeable for liquid water. Therefore, such phenomena may be caused by moisture vapor in the air. A new moisture permeation test apparatus was developed to analyze the mass transfer. Moisture permeation tests under typical hot summer conditions suggested that atmospheric moisture permeates and accumulates in bituminous mixtures through mass transfer by vapor diffusion despite the water impermeability of bituminous surface mixtures. The moisture permeation test provides an effective approach to analyze water storage mechanisms and moisture-related phenomena such as blistering in bituminous mixtures, although the test apparatus and condition settings require some improvement.

Keywords

Bituminous mixture, Moisture damage, Blistering, Moisture permeation

1. Introduction

Impermeable materials in civil structures are known to contain and retain water, although liquid water cannot penetrate these materials. Moisture damage such as blistering and disaggregation are a serious problem for bituminous pavement[1)]. In particular, blistering is one of the major water-related damages for airfield pavements[2)]. Blistering damage occurred in the runway of Nagoya airport in 2000. The runway surface course had been constructed with practically impermeable mixtures, but relatively permeable mixtures were applied to the surface after the incident in 2000. The occurrence of blistering was somehow stopped by this procedure, but the reason and mechanism are not well understood. Investigation into the water storage mechanism of bituminous mixtures is definitely important[3)] to study such pavement damages.

There are no established countermeasures to prevent moisture-related damage such as blistering. One of the reasons is the lack of understanding of water movement in bituminous mixtures, so fundamental study of moisture mass transfer mechanisms is necessary. Development of test methods for moisture movement analysis is the first step to clarify moisture transfer mechanisms and to evaluate material properties. Water damage to bituminous surfaces is believed to be caused by liquid water penetrating from the surface and/or subsurface. However, the surface course made of bituminous material is generally not permeable to liquid water. Therefore, water penetration may be caused by moisture vapor in the air.

Here we describe a newly developed moisture permeation test apparatus to analyze moisture transfer mechanisms. Moisture permeation tests using materials from near blistered and non-blistered pavement showed that water vapor penetrated and was retained in bituminous mixture within one day. The moisture permeation test is effective for the analysis of moisture transfer in bituminous mixtures, and vapor gas permeation is one of the main causes of moisture retention that may cause water damage to bituminous pavement.

2. Materials Tested

The bituminous mixture specimens (surface + base course) used in the moisture permeation test were taken from the in-service pavement of a runway and a national road using a diamond-bladed core cutter. The diame-

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

Table 1 Tested Asphalt Mixtures

Specimen No.	Runway		Road	
	Surface	Base	Surface	Base
Thickness [cm]	3	9	5	7
Type of mixture	dense	coarse	dense	coarse
Max size of aggregate [mm]	20	20	13	20
Asphalt binder	StAs60/80	StAs60/80	StAs80/100	StAs80/100
Asphalt content [%]	5.4	4.6	5.5	4.0
Density [g/cm^3]	2.373	2.378	2.353	2.397
Air voids [%]	3.5	4.7	4.7	4.7

The data are target or initial value at pavement construction. StAs: straight asphalt.

ter of both specimens was 10 cm, total thickness was 12 cm and weight was approximately 1.2 kg. The runway specimen was collected in the vicinity of a blistered area on the runway of Nagoya International Airport. The road specimen was collected from the pavement of national road without blistering damage.

The characteristics of the asphalt mixtures are shown in **Table 1**. The runway specimen had an air void content of 3.5% and the road specimen had an air void content of 4.7%. The water permeability of asphalt mixtures with 3.5% air void content is usually about 10^{-8} cm/s, and this water permeability is almost impermeable for liquid water[4)].

3. Moisture Permeation Test Apparatus

Based on the moisture permeation of bituminous mixtures under service conditions, the present study investigated the effects of the temperature difference between the surface and the bottom of specimens, and the changes in temperature with time phase gap between the surface and the bottom of specimens as well. A new experimental system, the Moisture Permeation Test Apparatus, was developed to investigate the transient behavior of water vapor permeation into the bituminous mixture.

The moisture permeation test apparatus consists of the temperature/humidity programmed-control chamber, cooling unit, electric balance, and data logging device (**Fig. 1**). The apparatus was designed to investigate one-dimensional moisture permeation. The specimen obtained by coring was sealed and wrapped with silicon adhesive and polyvinylchloride film except for the surface. The wrapped specimen was packed in thick thermal insulating material, and both the specimen and insulating material were wrapped again with polyvinylchloride film except for the surface.

The main characteristics of the moisture permeation test apparatus are as follows.

(1) Temperature/Humidity programmed-control chamber (Tokyo Rika Co., Ltd., KCL-1000): Room temperature and relative humidity are programmable in one hour units.

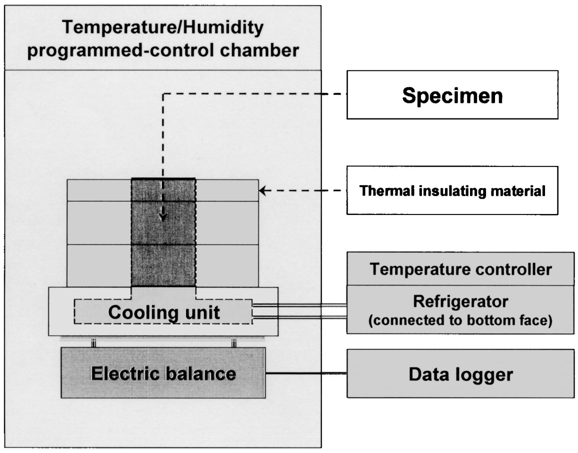

Fig. 1 Overview of Moisture Permeation Test Apparatus

(2) Cooling unit: The bottom of specimen is cooled with the cooling unit connected by elastic tubes to a refrigerator outside the chamber.

(3) Refrigerator (Haake Co., Ltd., F6-C35): The refrigerator can be programmed, but only with 6 patterns in 24 h. The refrigerator can control fluid temperature within ±0.1°C and has an inlet and outlet connected by elastic tubes.

(4) Electric balance (Sautrius Co., Ltd., LA8200s): Maximum capacity: 8 kg, minimum weight ±0.01 g.

(5) Thermal insulating material (Styrofoam): Formed polystyrene, 12 cm in thickness.

(6) Data Logger (Keithly Co., Ltd., 2700): Temperature, relative humidity, and weight of unit specimen can be recorded.

Room temperature in the chamber was assumed to be equivalent to the surface temperature of the specimen, and moisture content (relative humidity) were controlled using a programmed sequence in the conventional air conditioning chamber. The cooling unit simultaneously controlled the bottom temperature of the specimens.

The weight of the total unit specimen (specimen + thermal insulating material + cooling unit) was measured by the electric balance. The weight change of the unit

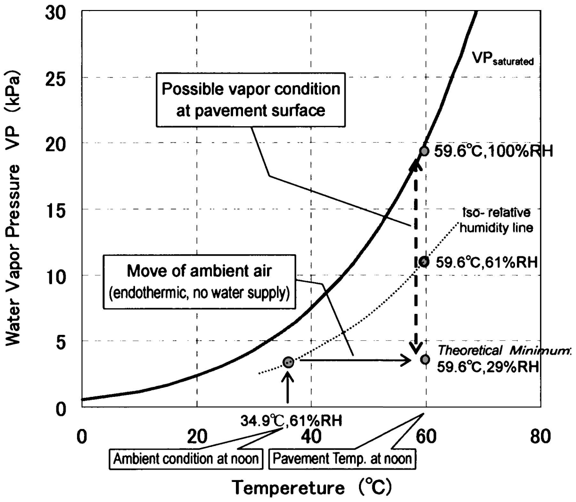

Fig. 2 Saturated Water Vapor Pressure/Temperature

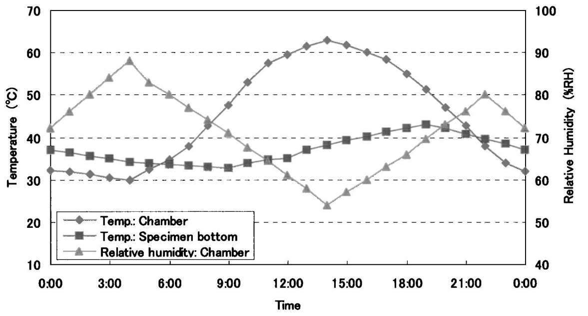

Fig. 3 Controlled Environmental Condition (temperature/relative humidity in the chamber, bottom temperature of specimen)

specimen was assumed to correspond to the weight of the permeated moisture. Therefore, the change of water content in the specimen was given by the weight change in the unit specimen.

4. Test Methods

This study attempted to simulate moisture transfer to investigate the mechanism of water damage to bituminous mixtures. Therefore, temperature and moisture conditions were based on the service conditions of pavement.

Climatic data for atmospheric temperature and pavement surface temperature were obtained from observatory records. Blistering occurred between the surface course and base course on the runway of Nagoya Airport on July 2, 2000. The test conditions for pavement surface temperature used in this study were based on the recorded data for July 2, 2000. The bottom temperature of the base course was estimated from the surface temperature and pavement structure using the data obtained from similar pavement at the pavement test sections of the National Institute for Land and Infrastructure Management.

Estimation of the water vapor conditions around the pavement surface is one of the most difficult issues, because vapor transfer near the pavement surface is not an ideal thermodynamic phenomenon and depends on specific local conditions. For example, ambient temperature, ambient humidity, and pavement surface temperature at noon on July 2, 2000 were 34.9°C, 61% RH, and 59.6°C, respectively. If ambient air moves endothermically to the pavement surface, the air temperature increases but the absolute vapor content does not change. Saturated vapor pressure at 59.6°C is fairly high compared to that at 34.9°C. As a result, the humidity may be about 29% RH at 59.6°C as shown in **Fig. 2**. This humidity was taken as the minimum value for the pavement surface. However, the actual vapor movement may not follow such ideal endothermic steady transfer, and water vapor may concentrate around the surface, particularly at damaged areas. If water droplets at the surface or residual pore water in the pavement mixture evaporate, the surface humidity will become nearly 100%. Therefore, the water vapor conditions at the pavement surface will range between 100% RH and the theoretical minimum humidity. Using ambient relative humidity at the pavement surface temperature is one of the possible condition settings, because the relative humidity obtained by shifting along the iso-relative humidity curve is within the possible range of vapor conditions.

This study was mainly intended to establish the methodology for mass transfer mechanism analysis, preferably using an accelerated test method for material evaluation, rather than investigating the blistering damage at Nagoya airport. Therefore, the combination of surface temperature and ambient humidity was adapted to the environmental test conditions of the moisture permeation test in this study, and the control of the surface conditions and moisture content of mixtures should be considered as preconditioning.

The moisture permeation test apparatus can accurately simulate the environmental conditions for 24 h. Environmental test conditions, *i.e.* room temperature in the chamber, relative humidity, and the bottom temperature of specimens (at the depth of 12 cm from the surface), are shown in **Fig. 3**. Prior to the moisture permeation test, preconditioning (initial condition at 0:00 h maintained for 12 h) was conducted for all test conditions. Environmental test conditions were controlled in one hour units and the weight change of the unit specimen was recorded at 5 min intervals using the data logger.

5. Test Results

Figure 4 shows the weight change of the unit specimens and experimental conditions. The weight of unit

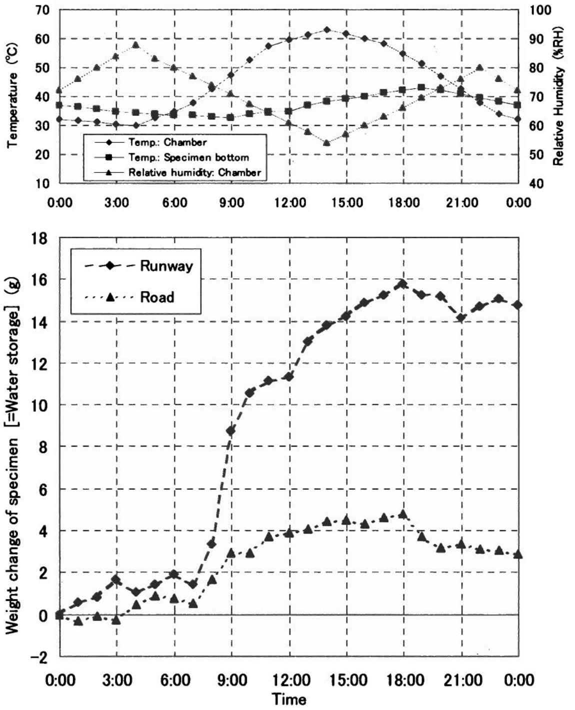

Fig. 4 Environmental Conditions (upper graph) and Weight Change (lower graph) under Moisture Permeation Test

specimen was basically stable during the initial 6 h, although there were some fluctuations. After the temperature of the chamber exceeded the bottom temperature of the specimens, the weight started to increase at 8 h and this steady increase continued until 18 h. During the night, the weight change leveled off. These results suggest that the runway specimen near the blistered area absorbed fairly large amounts of water, approximately 15 g, in one day, and the national road specimen also absorbed water, approximately 5 g, under hot summer conditions. In fact, many water droplets were observed on the bottom of the specimens as well as inside the thermally insulating sheets under the transient environmental conditions. These observations indicate that moisture in the air was accumulated within the specimens after only about half a day, despite impermeability of the surface for liquid water.

In this experiment, water content in the specimen was assumed to be equal to the weight increase of the unit specimen. Considering the test apparatus, water may also be adsorbed by the test fixtures (*e.g.* thermal insulating materials, elastic tubing), which will introduce systematic errors, so the absolute value of water storage should be adjusted by blank testing. However, the error should be the same for both test specimens in this study. Therefore, the results definitely suggest that the water accumulation depends on the properties of the bituminous mixture.

The applied test conditions were designed to simulate the typical hot summer environment that may induce blistering damage, but the absolute amount of transferred water may not correspond to the actual phenomenon because moisture conditions around the pavement surface area require certain assumptions such as moisture content at the surface. The experiment may require appropriate adjustment for test conditions and data processing, but the moisture permeation test can give valuable information on moisture-related damage assessment and material properties in terms of moisture transfer characteristics.

The results show that bituminous pavement mixtures do absorb and desorb significant amounts of water every day through vapor-state permeation via connected micropores, even though the surface course is practically impermeable for liquid water.

6. Conclusions

The following conclusions were obtained in this study.
(1) The moisture permeation test under typical hot summer conditions suggested that water was absorbed from moisture in the air which easily permeated bituminous pavement specimens taken from an in-service national road and runway pavement near blistered areas, even though the surface course is practically impermeable for liquid water.
(2) The moisture permeation test is effective to study moisture transfer in bituminous mixtures, because a considerable difference was observed between the amount of water in the specimen of the national road and the runway specimen under test conditions simulating typical hot summer weather.
(3) Bituminous pavement mixtures respire (breath) significant amounts of water every day in the hot summer environment as vapor-state permeation via connected micropores despite the impermeability to liquid water.
(4) Measurement of the absolute value of water content requires some improvement of the test apparatus and methods such as water adsorption on test fixtures and test conditions.

Acknowledgments

The authors gratefully thank the Civil Aviation Bureau office of Nagoya International Airport for providing valuable core specimens collected from the runway. The authors also thank the students for their contribution to the performance of the moisture related experiments.

References

1) Lottman, R. P., "Predicting Moisture-Induced Damage to Asphaltic Concrete," University of Idaho, Moscow, Idaho, "National Cooperative Highway Research Program Report," 192 (1978).

2) Kawashima, Y., Matsuura, S., "Questions and Answers on Pavement Technology," Vol. 5, Kensetsu-tosyo, Tokyo (1987), chap. 6-8, chap. 6-9.
川島義昭，松浦精一，"舗装技術の質疑応答，" 第5巻，建設図書，東京 (1987)，chap. 6-8，chap. 6-9.
3) Kandhal, P. S., Lubold, C. W., Roberts, F. L., *The Journal of the Association of Asphalt Paving Technologists*, **58**, 40 (1989).
4) Japan Society for Civil Engineers, "Hoso-kogaku," Maruzen, Tokyo (1995).
土木学会編，"舗装工学，" 丸善，東京 (1995).

....

要　旨

歴青系舗装の新しい透湿試験方法

佐々木　厳[†1)]，森吉　昭博[†2)]，八谷　好高[†3)]，永岡　紀行[†4)]

[†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都市環境工学専攻，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
[†4)] 新潟県庁，950-8570 新潟市新光町4-1

水分による歴青系舗装の損傷は，表面や路床から液状浸入した水が原因であると考えられてきた。しかし，滑走路等のアスファルト舗装表層は実質的に不透水であることが多い。したがって，著者らは大気中の水蒸気（湿気）がこれらの要因であると考え，この検証のために新しい透湿試験装置を開発した。透湿試験から，たとえ表層材料が実質的に不透水性であっても，典型的な夏の暑い日の気象条件においては水蒸気透過による物質移動により大気中の水分が透過し，凝縮した水分が混合物中に多量に蓄積しうることが明らかとなった。試験装置や試験条件に関してさらなる改良を加えることが必要であるものの，透湿試験は水分蓄積メカニズムの解明とブリスタリング現象等の水分に関連する損傷を評価する有効な試験方法である。

....