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An Optimization of the Porous Asphalt Pavement Permeability Function Focusing on the Surface Free Energy of Polymer Fog-Coat Methods

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Abstract

Surface fog coating methods to porous pavements with a polymer, that contains MMA as a main ingredient, are being widely used in Japan and called 'Top-Coat Processes'. They have lots of effects such as to prevention of the pavement void choking, improvement of the water permeability of the pavements and so on. The purpose of this research is to show the characterization of the polymer to optimize the functions of the polymer fog-coat methods. This study focused on the difference of 'wetting' by water among polymers used for the fog coatings, and calculation the surface free energy from the water contact angle on each material. At the end, the water permeability test were conducted using porous asphalt mixtures that were coated with several kinds of polymers. The permeability was also measured on the specimens that were forcibly choked by muddy water and the resistance to choking was compared. It is concluded that the reduction of the surface free energy between water and a polymer improves the life of the permeability functions of porous pavements. Improvement of water permeation capacity and void-blocking controlling effects can be quantitatively evaluated using the interfacial tension (γsl) with water for the coating material (high-viscosity asphalt and hardening resin binder). Consequently, the smaller the γsl of the coating material the higher the water permeation capacity and void-blocking controlling effects of the porous asphalt pavements.

INTRODUCTION

Porous asphalt pavements (hereafter referred to as porous pavements) are being widely used in various places such as trunk roads, streets, etc. as a measure for environmental protection and traffic safety. It is used to reduce the running noise of vehicles and also to decrease slip as well as increase visibility on rainy days.

However, porous pavements also have problems such as reduction of functions due to choking by the penetration of earth and sand and damage due to raveling or stripping of aggregates at locations of severe load conditions such as near intersections with heavy traffic of large vehicles. Efforts are being made with a view to improving the durability of porous asphalt as countermeasures against such problems.

Polymer Fog-Coat Method (hereafter Draining top-coat process) is one of these methods, and in locations where this process was implemented, pavements with excellent resistance to abrasion by raveling together with excellent shear resistance at the surface are obtained, proving positive effects of this process [1-3].

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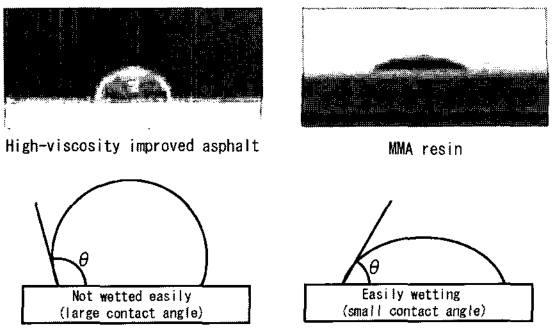
Moreover, it has been confirmed through indoor tests that pavements constructed with this process improve in permeability and also are effective in controlling choking with powdery material. Furthermore, it has been generally found on construction sites that pavements constructed using this process are protected against adhesion or even penetration of powdery material. In the case where choking occurs, the pavement can recover its functions easily with a method such as high-pressure cleaning [4].

However, it has not yet been clarified precisely why permeability improves and why the choking can be controlled with the implementation of this process [5-7]. The only clue given to explain this matter is a supposition, from the phenomenal aspect, that the difference in the way of "wetting" with water between the high-viscosity modified asphalt and MMA-based resin (draining top-coat process) is primarily related to the interfacial tension (of the respective materials) with water (surface free energy) (see Figure 1.)[6].

In the present study, we measured the contact angle θ, with water of several different types of resin used for draining top-coat process [8], and studied improvement of basic permeability (coefficient of permeability) and controlling effects of void blocking (residual volume of substance and residual permeability) from the results of



Contact angle meter is an instrument for measuring the contact angle in the above drawing (θ), as a method for evaluating how an object material "is wetted or not wetted" with a liquid.

Figure 1. State of "wetting" with water of fastening materials and principal of contact angle meter

that measurement, by using a separately studied permeability tester.

PURPOSE OF THE STUDY

"Void blocking" in porous pavements is believed to be caused by void blocking material getting into continuous voids of a mixture to stagnate and stick there [9] In the case where the high-viscosity modified asphalt (hereafter referred to as "high-viscosity asphalt") is used as binder of the mixture in standard porous pavements, it is believed that the material which stagnated there sticks, hence narrowing the void diameter of continuous voids and further increasing the degree of void blocking.

Porous pavements constructed with draining top-coat process using thermo-hardening resin such as MMA-based resin make it difficult for the void blocking material to adhere, considering the "wetting" on the surface of the binder, and therefore do not lose their water permeation function. This characteristic is believed to be related to wetting of the binder with water, i.e. interfacial tension between water and the material.

Taking into consideration the above fact, porous mixture specimens were prepared using various kinds of binder with different surface free energy values, and these measured the improvement of permeability (coefficient of permeability) and change in void blocking (residual permeability) at each void ratio.

OUTLINE OF THE TEST

Kinds of Resin Used

Characteristics of high-viscosity asphalt and various kinds of resin used for the test are shown below.

a) High-viscosity asphalt (As)

This is a modified asphalt, the viscosity of which was increased with a rubber based modifier such as SBS, and it is used as a standard material for porous pavements.

b) MMA-based resin (vinyl ester resin, VE)

Hydrophobic paraffin is added to the resin to secure hardening ability, and the surface of the hardened film is covered with paraffin. This material is hardening resin with flexible hardening ability and used generally in the drained top-coat process.

c) Epoxy resin (ES, EH)

Epoxy resin using hydrophilic amine as hardener. Two different types were selected because of a difference in polyamine content. The one is soft Soft epoxy resin (ES) that is highly flexible hardening resin, which used for resin mortar. Another is Hard epoxy resin (EH) that is hardening resin with excellent adhesion, which used for repairing materials in civil engineering work.

Measurement of Surface Free Energy

The measured value of surface free energy is analyzed and calculated using 2 to 3 different kinds of known liquid (the surface free energy value of which has already been analyzed), from their contact angles [8]. It is for this reason that we measured the contact angle for the respective resins at a room temperature of 22° C by using a FACE automatic contact angle meter CA-Z of Kyowa Surface Activity Science, Inc. Three different kinds of liquid were used, i.e. water, diiodomethane (CH_2I_2) and n-dodecane ($C_{12}H_{26}$) (see Fig. 2).

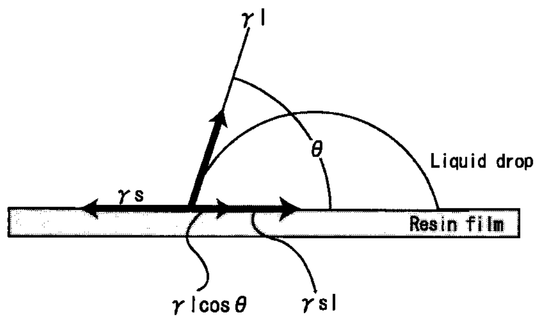


Figure 2. Meaning of Young' s formula showing interfacial tension between water and material

Preparation of Test Samples

The resin used for test samples were simulated with preparation of mixtures (Marshall specimen) using the binder concerned, instead of spraying (on the site), to homogenize the state of coat. The target void ratio of the Marshall specimen was set at 5 levels in the range of 18 to 22%, and one same blending ratio was adopted for the respective binder types. Moreover, as for the binder volume, the respective resins were blended in one same volume ratio after a conversion by specific gravity, because the specific gravity of the resin hardener is different from that of the high-viscosity asphalt. The compaction was made at normal temperature except for the high-viscosity asphalt, and the mixtures using the respective resins were adjusted to the number of times of compaction in order to have void ratios closer to one another because they have a higher density and a smaller void ratio compared to a mixture using high-viscosity asphalt (see Table 1).

Table 1. Specific gravity of blending ratio (%) and number of times of compaction of respective binders

Binder name			AS	VE	ES	EH
Specific gravity of binder			1.02	1.22	1.04	1.13
Blending ratio (%)	Target void ratio (%)	18	5.1	6.1	5.2	5.65
		19	5.0	6.0	5.1	5.5
		20	5.0	6.0	5.1	5.5
		21	5.0	6.0	5.1	5.5
		22	4.9	5.85	5.0	5.4
Number of times of compaction			50	45	40	45

Water Permeability Test

Coefficient of water permeability was studied by using a constant head permeability tester. However, this test method [10] is based on a laminar flow for which Darcy's law is established and has some problems with porous pavements. A study to resolve this matter is under way at the Japan Society of Civil Engineers [11]. For that reason, we calculated coefficient of water permeability "k" at a hydraulic gradient of i = 0.02 (same as road gradient) by using the equation given below proposed by Ohkawa et al: [12]

$$k = 2/(\alpha + \sqrt{\alpha 2 + 4\beta i}) \quad (1)$$

where

- k is the Coefficient of water permeability (cm/sec),
- α and β are the Constants,
- i is the Hydraulic gradient.

To apply this equation, it is necessary to measure the flow velocity at hydraulic gradient at several points in a constant head permeability test, express it with simulated curve of $i = \alpha v + \beta v^2$, and determine constants (α, β). What is important in determining this relational expression is to sufficiently remove the air remaining in the specimen. If a test is conducted without discharging this air, no accurate coefficient of permeability k can be calculated under the influence of the air. Moreover, we conducted the permeability test by hanging the difference in head as 3, 4, 5, 6 and 7 cm. It is to be noted that, in the equation proposed by Ohkawa et al., no correction of coefficient of permeability k is made for changes in specific gravity and viscosity of water due to temperature variation. Furthermore, because the value of surface free energy of a resin varies depending on the temperature, it is necessary to make measurements at a fixed temperature for more accurate evaluation. Therefore, we manufactured an apparatus composed of a water reservoir and a water receiving tank as indicated in Photo 1 to make those measurements. This apparatus is designed in such a way that water pumped up from a water reservoir with a submerged pump is sprayed on the top face of the specimen, while water overflowing from the top of the specimen and from the water receiving tank returns into the water reservoir. Water overflowing from the water receiving tank is made to flow out into a measuring instrument with switching of a 3-way valve on the way, for the measurement. We installed this apparatus in a thermostatic water tank, and made measurements under an ambient temperature of 20℃.

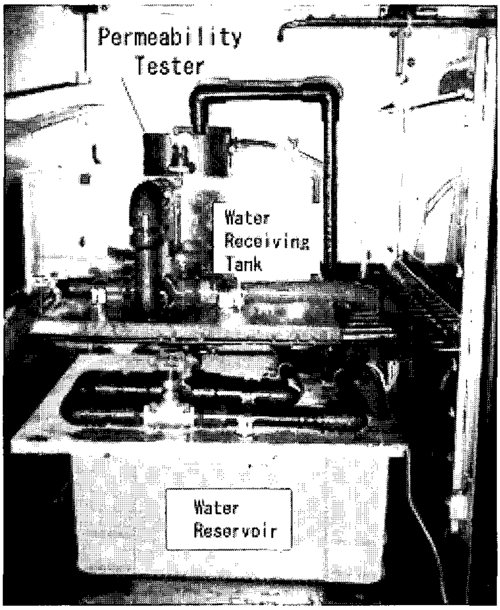


Photo 1. Water permeability tester

Measurement of Water Permeation Capacity by Means of Void Blocking Material

Specimens with a void ratio of 20% were used for measuring the degree of void blocking. The void blocking material was prepared by blending decomposed granite soil, which was dried after washing with water and screened with reference to the particle size [13] obtained on the site. 10g of the blended sample was dissolved in 100 ml of water and allowed to flow onto the surface of the specimen while being stirred and left for 10 minutes after complete water permeation, to cause choking. After repeating this process 5 times, the specimens were dried at 20℃ and 60℃, and submitted to permeability test. The number of times of pouring was limited to 30. After measuring coefficient of permeability k, the specimen was then dried at 60℃ and the difference between the weight before test and the weight after the test was considered as residual volume of void blocking.

The reason why we dried the specimen is as follows:

As it was mentioned earlier, in order to use Ohkawa's formula it is necessary to sufficiently remove air (from the specimen) in advance. However, if you immerse a specimen in water in which any void blocking material exists and eliminate air with depressurization, the void blocking material can be disordered with foaming. As a method for eliminating air, we poured water (on the specimen) so that the height of water depth in the specimen rises at a rate of 5 mm/min, and impregnated the specimen with water from the bottom, because, if the void blocking material contains water at that time, there is no way out for the air and therefore no sufficient removal can be made.

The residual coefficient of water permeability kr was determined by the following equation:

$$kr = (kn/k0) \times 100 \qquad (2)$$

where,

- kr is the Residual coefficient of water permeability (%),
- kn is the Coefficient of water permeability at "n"th pouring time,
- k0 is the Coefficient of water permeability with 0 time of pouring.

As we determined, residual coefficient of water permeability kr from the coefficient of water permeability k at hydraulic gradient i = 0.02, some of the specimens with little change in residual coefficient of water permeability kr indicated a figure of 110 ~ 120%. This is probably because we measured the hydraulic gradient in the range of approximately 0.5~1, determined the constants α and β by approximate expression, and estimated the coefficient of water permeability k at i = 0.02. For that reason, we fixed the average flow velocity v in the measured range, and determined the hydraulic gradient i at that time from $i = \alpha v + \beta v^2$ (where, α, β: constants, v: average flow velocity) [14] together with the determined α, β. If the water permeation capacity of the specimen drops, with fixing of the average flow velocity v, the hydraulic gradient i goes up. Therefore, by substituting i determined in the equation (1), we obtain the dropped coefficient of water permeability k. The average flow velocity v to be fixed was set at 0.25 cm/sec, because the measured values were in the range of 0.01 ~ 0.5 cm/sec. In this method, in which the initial water permeation capacity was measured by sufficiently eliminating air, there is no influence of any residual air in the specimen. On the other hand, in specimens on which void blocking material was poured while measurement was made by eliminating the air as much as possible, we cannot fully deny some influence of this air and therefore there is a possibility of some underestimation.

MEASURED RESULTS AND ANALYSIS

Measured Results of Surface Free Energy Value

Table 2-line 1 indicates the measured results of contact angle θ° between high-viscosity asphalt and various kinds of resin and water, measured by the method described in

3.2, while table 2-line 2 shows the results of surface free energy value (γs). The surface free energy value γs was determined from the value analyzed by using equation (3) from the measured results of contact angle of three different kinds of liquid. Since the relation between the surface free energy value γs and the contact angle θ° of water can be explained with Young's formula (4) [14], we determined the interfacial tension γsl by using the equation (5) from the relation between the binder and water., and indicated the results in table 2-line 3.

$$\gamma s=\gamma^{a}s+\gamma^{b}s+\gamma^{c}s \qquad (3)$$

where,

- γs is the Surface free energy (mN/m)
- $\gamma^{a}s$ is the Dispersion force (mN/m)
- $\gamma^{b}s$ is the Polarity (mN/m)
- $\gamma^{c}s$ is the Hydrogen bonding power (mN/m)

Moreover,

$$\gamma s=\gamma l\cos\theta+\gamma sl \qquad (4)$$

From this,

$$\gamma sl=\gamma s-\gamma l\cos\theta \qquad (5)$$

Table 2. Measurement result of Boundary tension between various kinds of binder and water (γ s l)

Line	Item		AS	VE	ES	EH
1	Contact angle (θ°)	Water	99.5	90.2	15.9	80.6
		CH_2H_2	46.6	42.8	36.6	37.6
		$C_{12}H_{26}$	27.5	13.9	Immeasurable	Immeasurable
2	Surface free energy value (mN/m)	$\gamma^{a}s$	22.6	24.7	25.4	25.4
		$\gamma^{b}s$	26.7	25.3	32.0	30.4
		$\gamma^{c}s$	0.0	0.3	33.7	1.9
		γs	49.3	50.3	91.1	57.7
3	Boundary tension (mN/m)	γsl	61.3	50.6	45.8	21.1

Measured Results of Coefficient of Water Permeability

Table 3 indicates measured results of coefficient of water permeability k calculated by using the respective void ratios and equation (1) given above, on all mixtures with various kinds of binder.

Relation between Void Ratio and Coefficient of Water Permeability

Figure 3 indicates the result of coefficient of water permeability k at hydraulic gradient i = 0.02 (Table 3), of the respective specimens with varied void ratios. Moreover, we determined and indicated approximate straight lines in this figure in the correlation between void ratio and coefficient of water permeability k of various kinds of resin. About the same trend was previously obtained in Figure 4 [5].(Hard asphalt in Figure 4 corresponds to AS in Figure 3, and MMA resin in Table 5 corresponds to VE in Figure 3.) Figure 5 indicates the value of coefficient of water permeability k at respective points for void ratios of 18, 20, and 22% in relation to the interfacial tension (γsl) shown in Table 2 and Table 3 (correlational expression).

From this, we can see that the water permeation

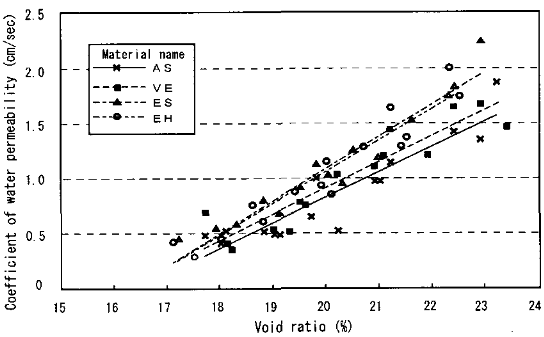


Figure 3. Relation between void ratio and coefficient of water permeability of mixtures at hydraulic gradient i = 0.02

Table 3. Relation between void ratio and coefficient of water permeability k (at i = 0.02) of mixtures usingvarious kinds of binder

Material name	AS		VE		ES		EH	
Target void ratio(%)	Void ratio(%)	Coefficient of water permeability k (cm/sec)	Void ratio(%)	Coefficient of water permeability k (cm/sec)	Void ratio(%)	Coefficient of water permeability k (cm/sec)	Void ratio(%)	Coefficient of water permeability k (cm/sec)
18	17.7	0.46	17.7	0.69	17.2	0.46	17.1	0.44
	18.0	0.41	18.1	0.42	17.9	0.56	17.5	0.30
	18.2	0.52	18.2	0.37	18.3	0.59	18.1	0.45
19	18.8	0.51	19.0	0.54	18.8	0.81	18.6	0.76
	19.0	0.50	19.3	0.52	19.1	0.69	18.8	0.61
	19.1	0.49	19.5	0.79	19.5	0.92	19.4	0.88
20	19.7	0.64	19.6	0.76	19.8	1.15	19.9	0.94
	19.8	1.01	20.2	1.05	20.1	1.04	20.0	1.16
	20.2	0.51	20.9	1.12	20.3	0.94	20.1	0.86
21	20.9	0.98	21.1	1.22	20.5	1.26	21.2	1.28
	21.0	0.98	21.2	1.45	21.0	1.20	21.5	1.38
	21.2	1.15	21.9	1.22	21.6	1.54	20.7	1.46
22	22.4	1.42	22.4	1.65	22.9	2.26	21.4	1.30
	23.0	1.35	22.9	1.68	22.3	1.75	22.3	2.01
	23.2	1.87	23.4	1.47	22.4	1.84	22.5	1.76
Correlational expression (void ratio,coefficient of water permeability)	y=0.23x-3.80		y=0.23x-3.71		y=0.29x-4.78		y=0.28x-4.58	
Coefficient of correlation	0.925		0.928		0.963		0.953	

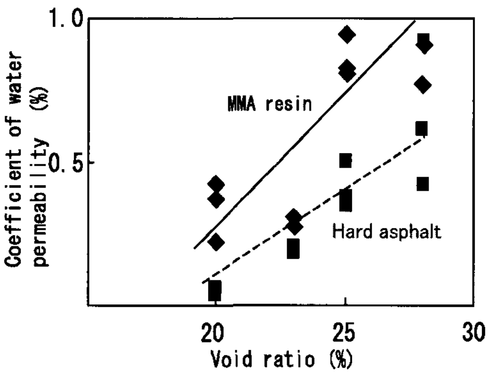


Figure 4. Relation between coefficient of water permeability and void ratio of mixtures at hydraulic gradient i = 0.02

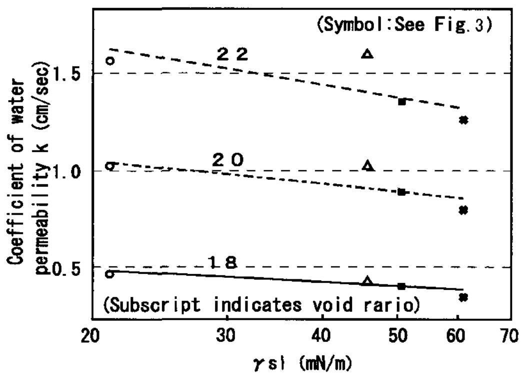


Figure 5. Relation between boundary tension ($\gamma 1$) with water and coefficient of water permeability

capacity of porous pavements is correlated with the amount of interfacial tension (γsl) between the coating material (binder) and water, and that the smaller the γsl (more easily wetted) of the material as in the case of a resin based material, the larger the coefficient of water permeability k. In other words, we may say that porous pavements provided with draining top coat with MMA resin, etc. have a better water permeation capacity compared to ordinary porous asphalt without any such draining top coat.

Relation between Coefficient of Water Permeability and Pouring of Void Blocking Material

To check influences of temperature on the changes of water permeation capacity due to choking, testing was performed at normal temperature range (20℃) and high-temperature range (60℃).

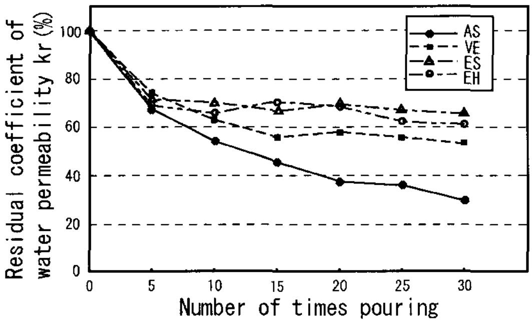


Figure 6. Relation between number of times of pouring and residual coefficient of water permeability at 20° C dry

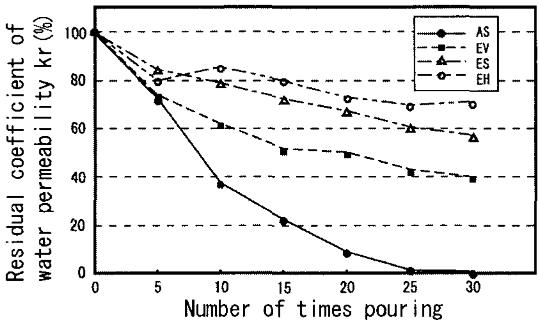


Figure 7. Relation between number of times of pouring and residual coefficient of water permeability at 60° C dry

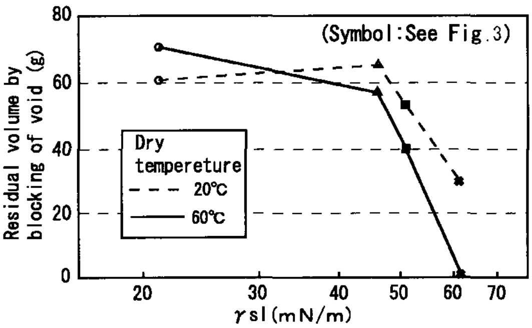


Figure 8. Relation between boundary tension (γs1) and coefficient of water permeability

Figure 6 and Figure 7 indicate changes in residual coefficient of water permeability kr due to pouring of void blocking material at the two different temperatures. Figure 8 indicates the relation between values of interfacial tension (γs1) between various kinds of resin and water, obtained from the above results.

From this, we can see that the residual coefficient of water permeability can also be evaluated with γs1 of the coating material. Figure 9 indicates, for the respective binders, the residual volume by blocking voids of specimens after 30 times of pouring. Figure 10 shows also existence of a quantitative relation between the residual volume by blocking of voids and the interfacial tension γs1. A study from interfacial tension γs1 on the difference in choking due to difference of test temperature remains as a future task.

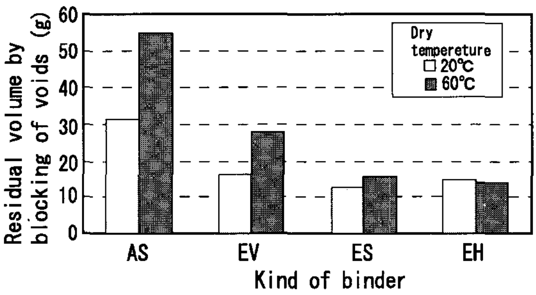


Figure 9. Residual volume by choking

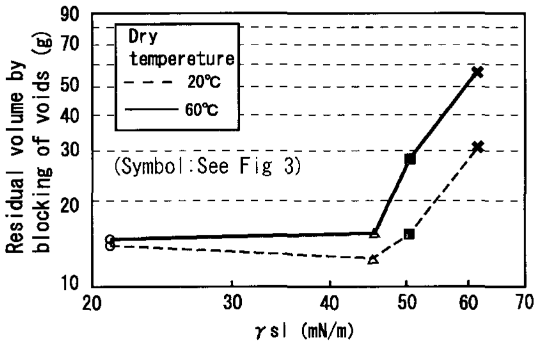


Figure 10. Relation between interfacial tension (γs1) and residual volume by choking

CONCLUSION AND SUMMARY

With regards to drained mixtures using high-viscosity asphalt and hardening resin binders, the authors the measured improvement of coefficient of permeability k and void blocking controlling effects (residual coefficient of water permeability) in order to examine the effect of draining top-coat process on the improvement of porous pavement function.

Results obtained in this study are as follow:

1) A porous asphalt pavement with draining top-coat process has a better water permeation capacity (coefficient of permeability k) compared to ordinary porous asphalt without any such draining top coat.
2) A porous asphalt pavement provided with draining top-coat process has a small amount of void blocking and, even if void blocking occurs, there will only be a small drop of its water permeation capacity (large residual coefficient of permeability k).
3) Improvement of water permeation capacity and void blocking controlling effects can be quantitatively evaluated using the interfacial tension ($\gamma s1$) of the coating material with the water (high-viscosity asphalt and hardening resin binder).

Consequently, the smaller the $\gamma s1$ of the coating material the higher the water permeation capacity and void blocking controlling effects of the porous asphalt pavements.

AFTERWORD

It has been found that a draining top-coat process applied to porous asphalt pavements [15] contributes to improvement of functions such as water permeation capacity. It is our wish to continue, on the basis of such findings, further in-field verification of effects such as ease of function recovery [16] by such methods as high-pressure cleaning. We will also continue with other studies regarding porous asphalt pavements, through indoor tests, toward multifunction and sophistication [17] such as improvement of water holding function for heat control.As for improvement of water permeation capacity examined in the present study, there still remain, as subjects of study in the future, finding resin material with more conformable interfacial tension ($\gamma s1$), as draining top-coat material.

REFERENCES

1.Masaru Ohmichi,Hiroshi Yamanokuchi and Teruhiko Maruyama,"A study on the applicability of multifunctional and advanced porous pavement" The 8th Hokuriku road pavement conference,pp.37-40,2000.6

2. Atuo Kadono,Hiroatu Katuura and Kazuya masui "A study on the testing method for evaluation of local aggregate used in high performance pavement" The 23th The Japan Road conference(C),pp.4-5,1999.10

3. Tetuo Tanaka,Hirosi Yamanokuchi and Makoto Fukutomi "Performance and applicability of drained topcoat process" The 23th The Japan Road conference (C),pp.260-261 ,1999.10

4. Yasusi Yano,Sigeo Kobayasi and Masazumi Mituyasu "Example of application of drained topcoat process after function recovery by high pressure washing" The 23th The Japan Road conference(C),pp.356-357 ,1999.10

5. Katuya Hosaka,Teruhiko Maruyama "A study on the improvement of porous asphalt functions" Material of Nagaoka Technological University of environment construction system road laboratory,2000.3

6. Tetuo Tanaka,Masazumi Mituyasu and Teruhiko Maruyama

"Effectiveness of drained topcoat process on advancing functions of porous asphalt pavement" The 8th Hokuriku road pavement conference,pp.45-48,2000.9
7. Nobuyuki Nemoto,Kunihiro Akiba and Shinya Ueno "A study on function of porous asphalt using resin dust removal" The 54th Japan Civil Engineering association annual science lecture, pp.352-353,1999.6
8. Yasuaki Kitazaki,Toshio Hata "Evaluation of extending Fowkes function and surface tension of polymer solid" Japan bonding society magazine,vol.8, No.3,pp131-141,1972
9. Shouji Okada,Teruhiko Maruyama and Osamu Takahashi "A study on the improvement of functions of porous pavement that uses filter layer" The 25th Civil Engineering association Kanto branch symposium, 1998.3
10. Japan Road Association, Pavement examination method handbook,Maruzen, pp.897-902,1988.11
11.Civil Engineering association pavement research subcommittee "Report of Porous pavement section hydraulic characteristic WG", 2000.6
12. Hideki Ookawa,Takahiro Satou and Kouzou Hokari "A study to evaluate estimation of coefficient of water permeability of porous asphalt pavement" Civil Engineering association papers,pp.101-108 1993.11
13. Yukie Masuyama,Noritugu Kusakari and Youji Fukui "Current state of function recovery of porous asphalt pavement" Road Construction, No.581,pp.33-41,1996.6
14. Minoru Imoto "For the understanding of the surface tensity" Polymer publication association Ltd., pp.73-93,1992.3
15. Nissin-kasei Ltd. "Our new technology "porous coat" Pavement, vol.35.No.6,pp.34,2000.6
16. Tuyoshi Kosasa,Masaru Ohmichi " A study on multifunctioning porous asphalt pavement" The 23th The Japan Road conference (C),pp.48-19,1999.10
17. Masaru Ohmichi,Mutushi Kojima and Hiroshi Yamanokuchi "Experimental research on multifunctional and advanced porous pavement" The 54th Japan Civil Engineering association annual science lecture,2000.9

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