Effects of Diatomite Filler on the Performance of Porous Asphalt Mixtures

Shaolong Huang
Department of Material Science and Engineering, Hubei University , Wuhan, Hubei, China

Fan Shen
Department of Material Science and Engineering, Wuhan University of technology , Wuhan, Hubei,, China

Qingjun Ding
Department of Material Science and Engineering, Wuhan University of technology , Wuhan, Hubei,, China

ABSTRACT: The paper presents the results of laboratory investigation of evaluating the effects of diatomite filler on the mix properties and performance of porous asphalt mixture using different testing methods. Porous asphalt mixtures containing 0%, 5%, 10% and 15% of diatomite by weight of particles passing No. 200 sieve in the mix gradation were prepared and studied through microstructure analysis and performance testing. The mix design results showed higher optimum asphalt content of porous asphalt mixture containing diatomite due to the low draindown caused by the high specifica surface area of diatomite, which can be proved by the SEM photograph. Compared with normal mix, porous asphalt mixtures prepared with diatomite resulted in better particle loss resistance, moisture damage resistance, rutting resistance and low temprature cracking resistance. Porous asphalt mixture with 10% diatomite replacement by weight of filler is determined to be the most effective mix.

KEY WORDS: Porous asphalt mixture; diatomite; optimum asphalt content; microstructure; performance evaluation.

1 INTRODUCTION

Porous asphalt mixture is a kind of pavement material contains air void content as high as 15 to 25 percent. It is widely used as friction coarses to improve friction, minimize hydroplaning, reduce splash and spray, improve night visibility, and lower pavement noise levels. These functions are achieved primarily by removing water from pavement surfaces during periods of rain. In order to get such high air void content, porous asphalt typically utilize a gap-grading for aggregates, which contains over 80 percent of cause aggregate, and a low percentage of filler. The combination of gap-grading and low percentage of filler leads to low asphalt content of the mix, which makes the mix a lower performance as normal dense-grade mix.(Kandhal PS., 1999, Mallick RB., 2000)To solve this problem, fibers, including mineral fibers, cellulose fibers and polyester fibers are used to increase the asphalt content and the performance of porous asphalt mixtures (Cooly A., 2000, Hassan F., 2005). However, the adding of fibers will increase the construction cost and slightly influence the connectivity of the inner void of the mixtures.

A new method to improve the performance of porous asphalt mixtures by using diatomite as the filler of the mix is introduced in this paper. Diatomite is a kind of nonmetallic mineral material. Due to its lightweight, high void content, low density and strong sorption performance, diatomite is often used as the filler of polymer. In recent years, diatomite was used to prepare modified asphalt binder by some researcher (Liu D., 2004, Bao Y., 2005). When it is added into asphalt binders, diatomite can absorb the asphalt binder effectively. Because of the special micro-pore structure of diatomite, inter-transfixion structure is formed between diatomite and asphalt binders, which leads to the performance improvement of asphalt binders and its mixtures. In this paper, diatomite is added as the filler of porous asphalt mixture. The micro-structure of asphalt containing different content of diatomite was studied with scan electron microscope (SEM) and Infrared Absorption Spectrum Analysis (IR). Then the effects of diatomite on the performance of porous asphalt mixture were evaluated through Cantabro test, wheel tracking test, moisture susceptivity test and bending beam test.

2 EXPERIMENTAL

2.1 Materials

SBS modified asphalt binder was used in this research, the performance of asphalt binder is shown in Table 1. Diatomite was obtained form Shenzhen Jitong diatomite Co. Ltd., the chemical ingredient of diatomite is shown in Table 2.

Then, after one blank line, aligned left, type the First Author’s name (first the initial of the first name, then the last name). If any of the co-authors have the same affiliation as the first author, add his/her name after an & (or a comma if more names follow). In the following line type the affiliation (Name of the institution, City, State/Province, Country). If there are authors linked to other institutions, after a blank line, repeat this procedure.

Table 1: Properties of SBS Modified Asphalt Binder

Test	Results
Penetration 25℃、100g、5s）/0.1mm	60
Softening Point /℃	72
Ductility （5℃、5cm/min）/cm	35
Ductility after TRFOT（5℃、5cm/min）/cm	33
Penetration after TRFOT /0.1mm	43

Talbe 2 Chemical Ingredient of Diatomite

Ingredient	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	LOS
Content	78.72	9.54	2.92	0.73	0.65	0.58	5.37

2.2 Mix Design

The diatomite was added directly into the mixtures with normal mineral filler during mixing. Three kinds of mixtures with different percentage of diatomite, 5%, 10% and 15% (by the weight of filler, particles passing No. 200 sieve in the mix gradation) were prepared in this research. When diatomite was added, the same weight of conventional mineral filler was reduced. The same aggregate gradation with nominal maximum aggregate size of 13mm was used for all kinds of asphalt mixture. The mix gradation is of porous asphat is shown in Table 3.

The optimum asphalt contents (OAC) of porous asphalt mixtures were determined based on the draindown test and Cantabro test (JRA, 2005). Draindown test was conducted according to AASHTO T305.The porous asphalt mixture with OAC should meet following criteria(Ministry of Communications, China, 2004). 1) Abrasion Loss. The abrasion loss from the Cantabro test should not exceed 20 percent. 2) Draindown. The maximum permissible draindown should not exceed 0.3 percent by weight of total mixture. When the asphalt content meets the two requirements was not one point, the upper limit was preferred to be OAC because of the consideration of the durability of the porous asphalt mixture. For example, if asphalt content of 4.0%~4.4% meets all the requirements, 4.4%was determined to be OAC.

Table 3: Mix Gradation of Porous Asphalt Mixture

Seive No.	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Pencentage Passing	100	95.2	74.0	22.7	14.3	11.3	8.5	6.3	5.3	4.6

2.3 Test methods

2.3.1 Infrared Absorption Spectrum Analysis (IR)

IR test was performed on Nicolet Nexus Fourier Transform Infrared Spectroscopy. The resolution of the test was 4 cm-1, the testing range was from 400 to 4000 cm-1. Three samples were made by adding diatomite powder to hot asphalt by 5, 10 and 15 percent weight of the filler.

2.3.2 Scan Electron Microscope (SEM)

The SEM test of asphalt containing diatomite was conducted on JSM 5610LV and HITACHI S4800 Scan Electron Microscope. Test of the limestone filler and diatomite particles was performed on the former, test of asphalt containing diatomite was conducted on the latter. The samples of asphalt containing diatomite were prepared as follow. 1) the diatomite powder was added to hot asphalt by 15 percent weight of the filler and blend to uniformity; 2) brushing the asphalt mortar on tin paper; 3) erasing the exterior asphalt of the sample by using organic solvent until the white diatomite particles were revealed; 4)spraying the sample with conductive layer using HITACHI E1010 ion spurtter.

2.3.3 Contabro Test

Contabro test of three kinds of specimens, controlled, aged and soaked were conducted to evaluate the resistance to abrasion loss and moisture susceptivity of the mixtures. The specimens, compacted by Marshall compactor, were put into Los Angeles abrasion tester without steel balls and rotate 300 cycles at the speed of 30 r/min to 33 r/min. Aged specimens were conditioned by placing them into an oven at 60℃ 7 days, and soaked specimens were immersed into water at 60℃ for 48 hours. Both kinds of conditional specimens were cooled to room temperature and stored for 4 hours before testing. The limitation of National Center of Asphalt Technology (NCAT) requires percentage loss by weight must be less than 20% for unaged specimens and 30% for aged specimens (Mallick RB., 2000). The abrasion loss (ΔS) of the mixture was calculated as

$$\Delta S = \frac{m_0 - m_1}{m_0} \times 100 \tag{1}$$

Where m_0 is the weight of specimen before test, m1 is the weight of specimen after test.

2.3.4 Moisture Susceptivity Test

"Standard test for effect of moisture on asphalt concrete paving mixtures" (ASTM D4867-04) is modified to fit for porous asphalt. The air void of the samples were controlled to 20±2% instead of 6~8%. A minimum TSR of 70% is recommended for this test method. The samples were compacted using Marshall compactor.

2.3.5 Wheel TrackingTest

Wheel tracking test was taken to evaluate the rutting resistance property of the asphalt mixture. The specimen for wheel tracking test is 300 mm length, 300 mm width and 50 mm thickness, which is compacted by the slab compactor. The specimen is immersed in dry atmosphere at 60℃ for no less than 5 hours, and then a contact wheel pressure of 0.7MPa is loaded on the specimen to test for 60 min under 60℃circumstance. The wheel traveling distance of the wheel is 230 ± 10 mm at a speed of 42±1 cycles/min. Rut depth was measured per 20 s and dynamic stability (DS) was calculated as

$$DS = \frac{15N}{d_{60} - d_{45}} = \frac{42 \times 15}{d_{60} - d_{45}} \tag{2}$$

Where N is the wheel traveling speed, generally, N=42 cycles/min, d60 and d45 are the deflection at 45 and 60 min, respectively.

2.3.6 Bending Beam Test

Three-point bending beam test was taken to evaluate the resistance to low temperature cracking of the mixtures. The test was performed using Material Testing System (MTS810) on the cuboid beam with 250mm in length, 30mm in width and 35mm in height, at -10℃. The specimen for bending beam test was cut from the specimen compacted by the slab compactor, which is 300 mm length, 300 mm width and 50 mm thickness. The strain value and bending strength were measured from the test. The bending strength and bending modulus were calculated to evaluate the resistance to low temperature cracking of the mixtures.

3 RESULTS AND DISCUSSION

3.1 Micro-Analysis of Asphalt Containing Diatomite

3.1.1 Infrared Absorption Spectrum Analysis

The result of infrared absorption spectrum analysis is shown in Figure 1. It can be indicated from the Figure 1(a) that $2924cm^{-1}$ and $2853cm^{-1}$ are the stretching vibration absorption bands of the alkyl of asphalt. $1461cm^{-1}$ and $1376cm^{-1}$ are the bending vibration absorption bands of the alkyl of asphalt. After different percentage of diatomite was added into asphalt, as shown in Figure 1(b), (c), and (d), the positions of absorption bands in the curves of samples containing diatomite are nearly the same. The only difference is the stretching vibration absorption band of Si-O appears at $1032cm^{-1}$, which is close to the Si-O stretching vibration absorption band position of diatomite according to Figure1(e). Besides this, no other new absorption band is appeared in the infrared absorption spectrum of asphalt containing diatomite. Therefore, it can be confirmed from the analysis of the infrared absorption spectrum that no complicated chemical reaction is occurred between asphalt and diatomite, the adding of diatomite merely leads to the physical mixing of asphalt and diatomite powers.

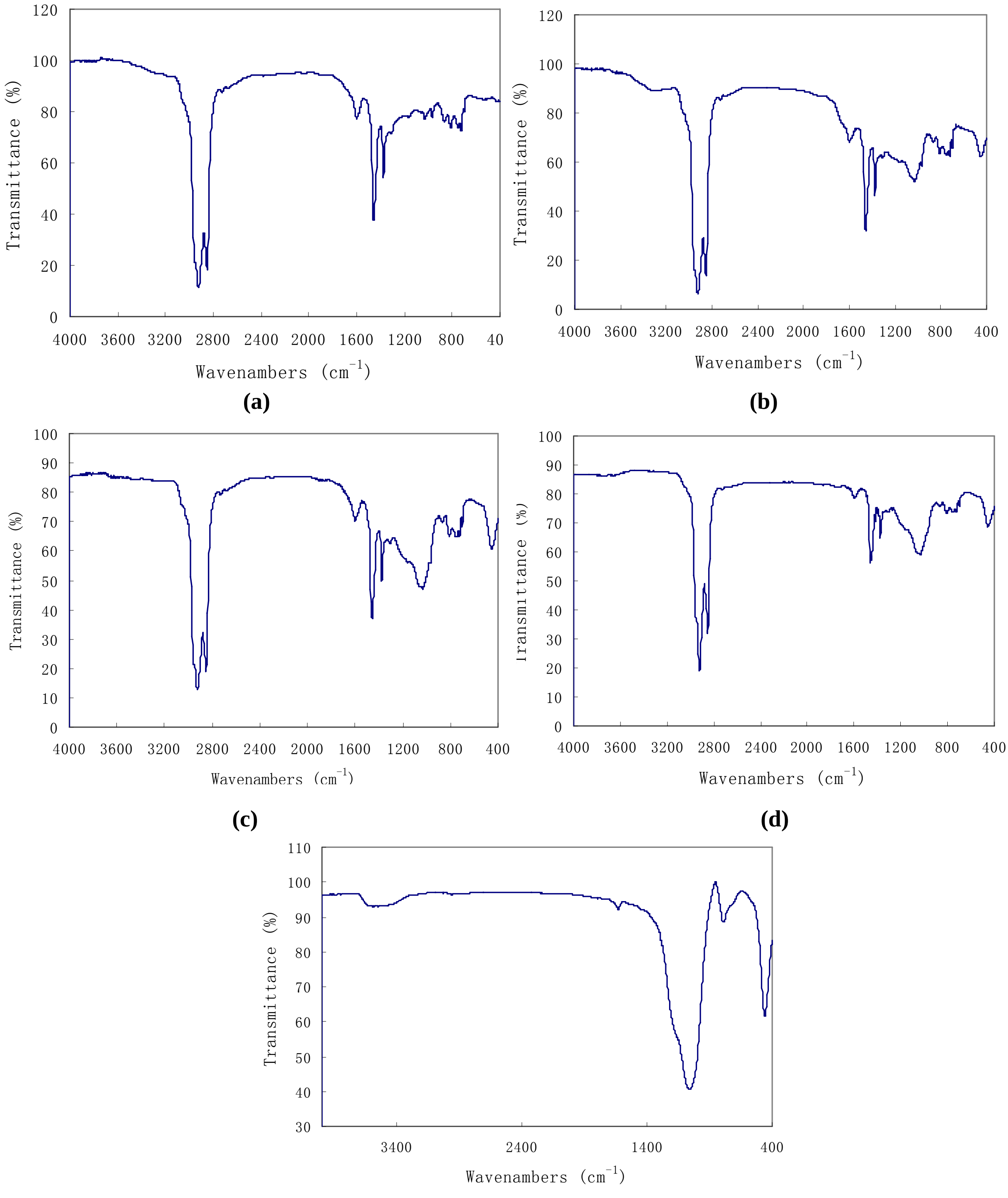

Figure 1: Infrared Absorption Spectrum of Diatomite and Asphalt Mastic Containing Different Percentage of Diatomite. (a) 0%; (b) 5%; (c) 10%; (d) 15%; (e) Diatomite Particles

3.1.2 SEM Analysis

The comparison of the microstructure of lime filler and diatomite is shown in Figure 2(a) and (b). Unlike conventional limestone filler, the particle of diatomite presented a microscopic porous structure, which made it some advantages as the filler of asphalt mixture. 1) the high specifica surface area due to the microscopic porous structure of diatomite enlarges the adhering area between asphalt and diatomite, which led to the increase of the asphalt film-thickness and improvement of the adhesive strength between asphalt binder and aggregate; 2) capillarity caused by the microscopic pore of diatomite could improve the interaction force between asphalt and diatomite; 3) the microscopic porous structure of diatomite may enhance the anti-shear property of asphalt mastic, which would improve high temperature stability of asphalt mastic and asphalt mixtures (Zhao Y., 2002).

The SEM photographs of asphalt containing diatomite were shown in Figure 2 (c) and (d). Compared with the particle size distributing of diatomite in Figure2(b), it can be indicated that the diatomite particles are equably dispersed among asphalt binders from Figure 2(a), 100 times magnifying of the sample. As shown in Figure 2(b), the SEM photograph of single diatomite particle after 2000 times magnifying, the interface between asphalt and diatomite was illegible. The asphalt binder was congregated towards and had trapped into the diatomite particle due to capillarity, which led to a better adhesion of the interface between two phases.

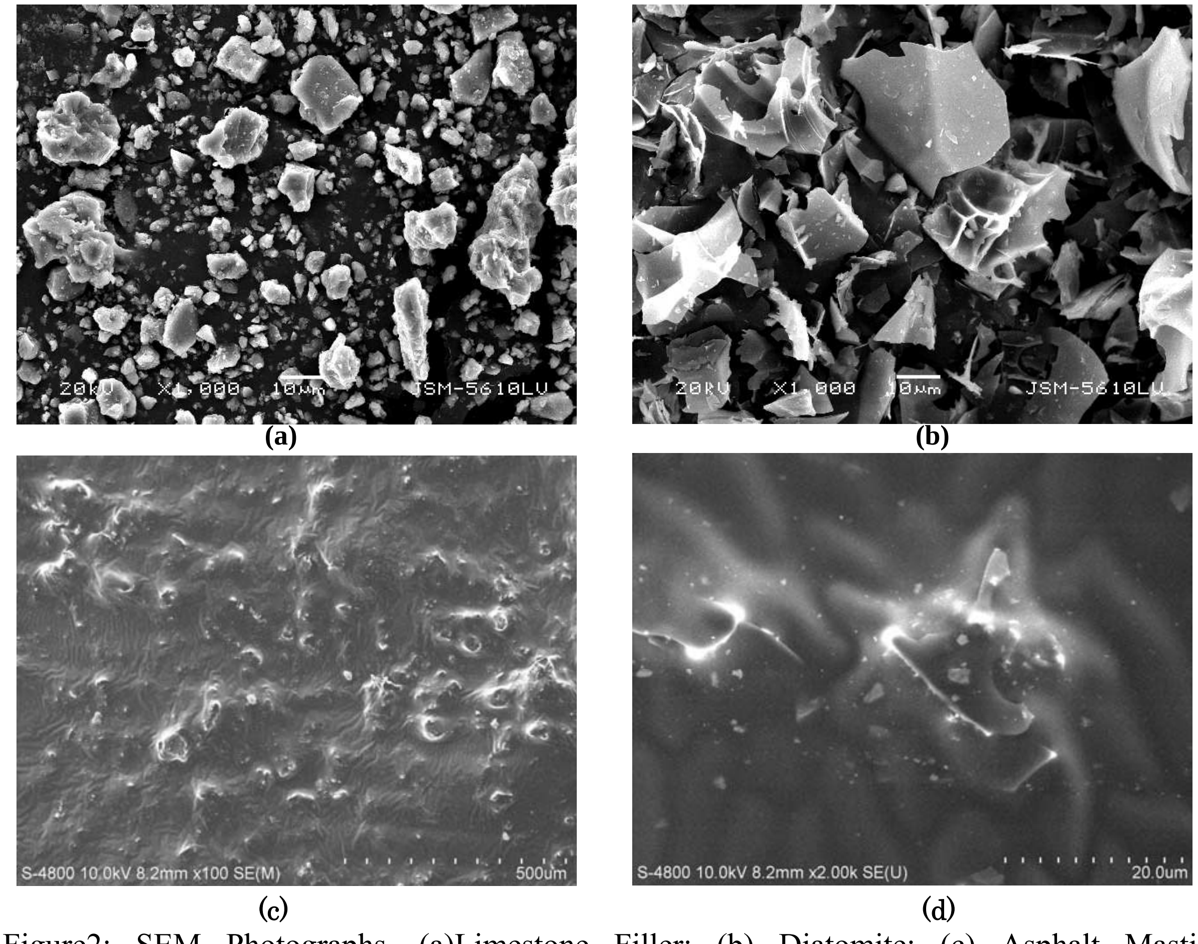

Figure2: SEM Photographs. (a)Limestone Filler; (b) Diatomite; (c) Asphalt Mastic Containing Diatomite ×100; (d) Diatomite Particle in Asphalt ×2000.

3.2 Effect of Diatomite on the OAC of Porous Asphalt Mixtures

The results of draindown test and Contabro test with different asphalt contents are shown in Figure 3 and Figure 4. OAC determined based on draindown test and Contabro test and the mix properties under OAC are listed in Table 4. It can be seen from Table 3 that the OAC of porous mixtures increased with the rising of adding amount of diatomite. The OAC reached 5.8% when the dosage of diatomite was 15% by weight of the filler, which was 1% higher than that of porous asphalt mixture without diatomite. This increasing of OAC could be mainly due to the low draindown caused by the high specifica surface area of diatomite.

Table 4: Mix Properties of Porous Asphalt Mixtures

Properties	Specification	Adding amount of diatomite (%)			
		0%	5%	10%	15%
Asphalt content /%	/	4.8	5.1	5.5	5.8
Unit weight /g/cm3	/	2.087	2.066	2.074	2.098
Air void /%	18~22	21.36	20.7	20.18	19.67
Draindown /%	≤0.3	0.293	0.287	0.292	0.29
Stability /kN	≥3.5	6.4	6.9	6.82	6.95

As shown in Figure 3, the corresponding asphalt content of the break point of draindown curve increased evidently, which proved the good asphalt adsorbing property of diatomite. Moreover, the air void dropped a little with the increasing percentage of diatomite. The same situation would occur when fiber was added (Wu S., 2006). At the integrative view of Figure 3 and Figure 4, draindown and abrasion loss of porous asphalt mixture containing diatomite were both reduced at the same asphalt content compared with normal porous asphalt mixture, which would prevent asphalt binder draining from a mix during transportation and lay down procedures and the aggregate raveling after the pavement open to traffic at the same time. As far as the adding amount of diatomite was concerned, it would be less effective when the dosage was higher than 10%. The results of 15% were only slightly changed compared with 10% dosage, especially at low asphalt content.

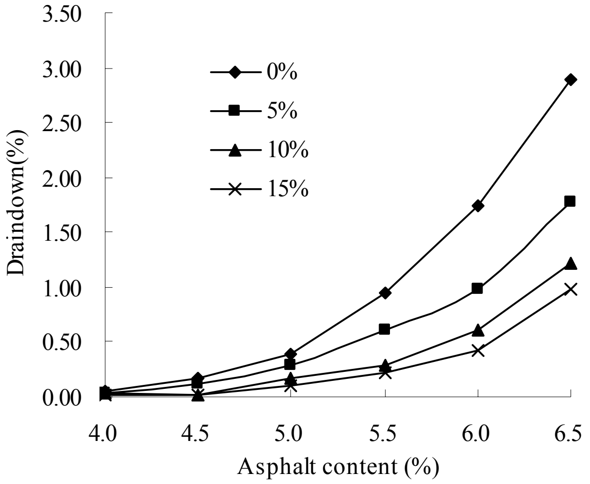

Figure 3: Results of Draindown Test under Different Asphalt Content

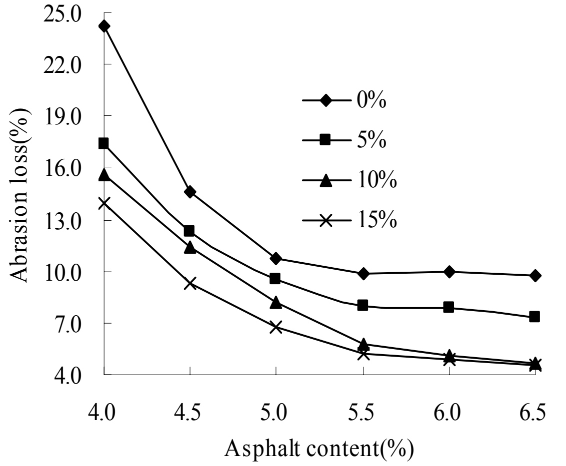

Figure 4: Results of Cantabro Test under Different Asphalt Content

3.3 Effect of Diatomite on the Performance of Porous Asphalt Mixtures

3.3.1 Particle loss resistance

Figure 5 shows the results of Cantabro test of unaged and aged specimens under OAC. All values of Cantabro tests fully satisfied the specification. The abrasion loss of unaged specimens dropped below 10% when diatomite was added, much lower than that of normal specimens. When aged condition was concerned, the abrasion loss of all kinds of mixtures was increased because of the harden of binder and loss of adhesive strength. However, the abrasion loss increasing due to aging of specimens containing diatomite dropped to only 5% or even less. This mainly owing to the bigger binder film thickness caused by the adding of diatomite (Kumar, A., 1997). In summary, it can be inferred from the results that the adding of diatomite results in good particle loss resistance under both unaged and aged conditions.

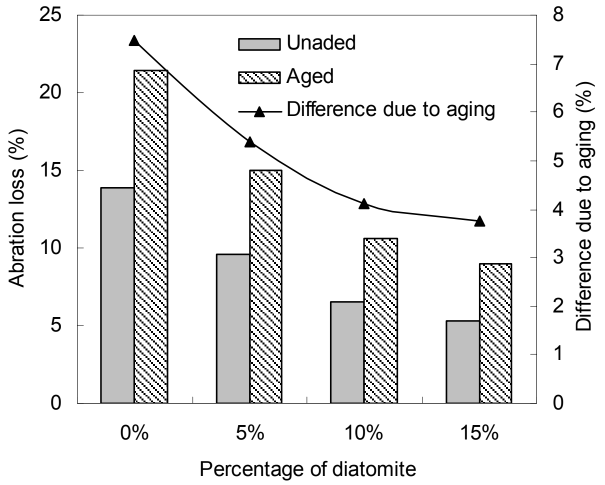

Figure 5: Results of Cantabro Test

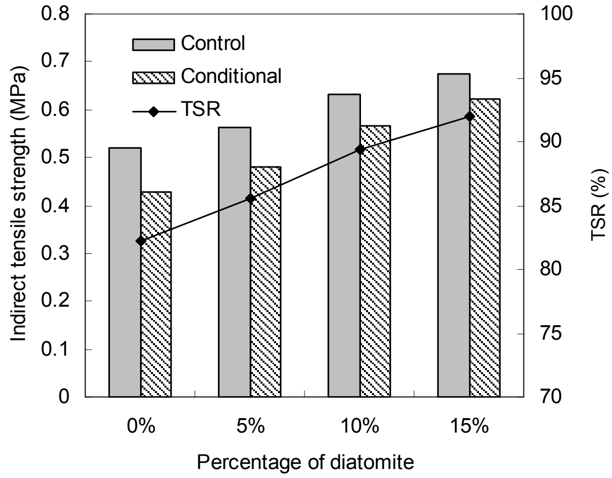

Figure 6: Results of Tensile Strength Ratios

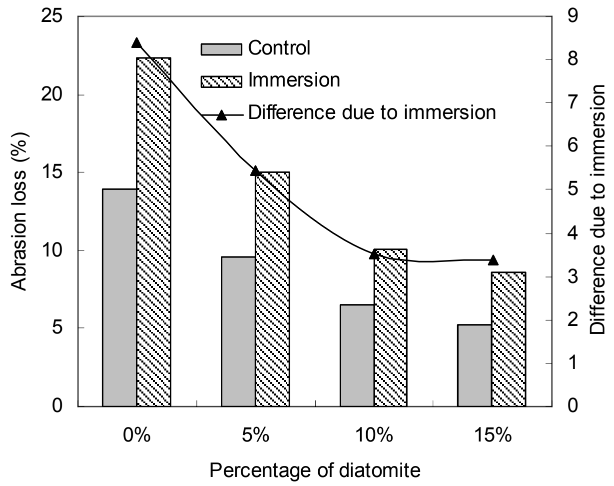

Figure 7: Results of Immersed Cantabro Test

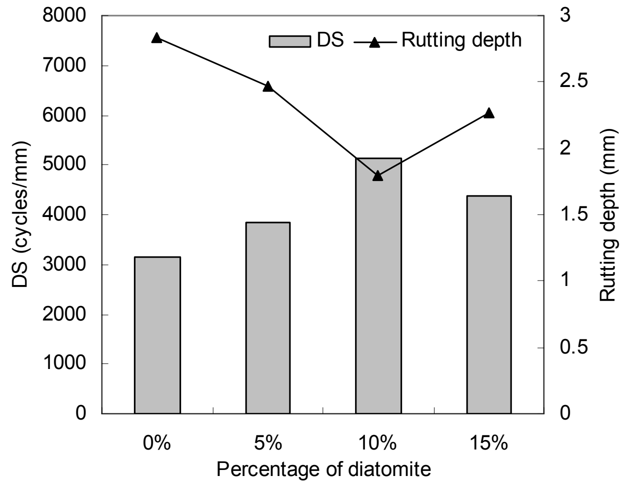

Figure 8: Results of Wheel Tracking Test

3.3.2 Moisture susceptivity

ASTM D4867 test and immersed Cantabro test were conducted to evaluate the moisture susceptivity of porous asphalt mixture. The results of calculated TSR and abrasion loss are shown in Figure 6 and Figure 7. As shown in Figure 6, the TSR values obtained from all the four mixes is higher than 80%, which satisfied the specification. It can be indicated from the results that the higher percentage of diatomite led to better moisture damage resistance property due to high asphalt content of the mix. A similar result is observed from Figure 7, the abrasion loss dropping caused by moisture decreased with the increasing dosage of diatomite. Further more, both of TSR and immersed abrasion loss value only slightly improved when the dosage of diatomite increased from 10% to 15%, which indicated that, as mentioned above, it is less effective when the dosage is higher than 10%.

3.3.3 Rutting resistance

Figure 8 shows the results of wheel tracking test. The rutting depth was measured and DS was calculated to evaluate the permanent deformation resistance of the mixes. As shown in Figure 8, the results of rutting depth and DS were both improved when diatomite is added. The increasing of rutting resistance may attribute to the high anti-shear strength of asphalt mastic containing diatomite. However, the rutting resistance performance would decrease when the percentage of diatomite was more than 10%. It was mainly because the high volume asphalt content at high diatomite percentage affected the stability of aggregate skeleton.

3.3.4 Bending Beam Test

Figure 9 shows the results of bending beam test. The results showed that the high percentage of diatomite led to both higher bending strength and bending strain, which indicated the better cracking resistance performance under low temperature.

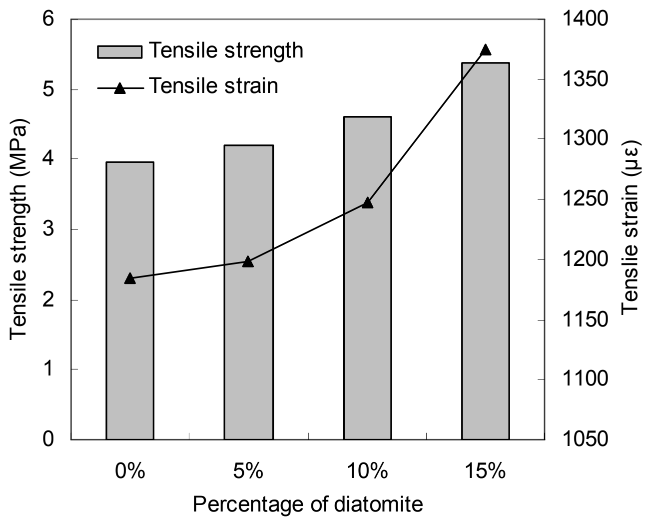

Figure 9: Results of bending beam test

4 CONCLUSION

This study was focused on the investigation of the effect of diatomite on the performance of porous asphalt mixture. Based on several laboratory tests and analysis, main conclusions are summarized as below:

1) When diatomite is added, better interface adhesion between asphalt binder and filler particle is achieved due to the high specifica surface area and micro-pores structure of diatomite, which can be proved by the SEM analysis.
2) No chemical reaction is occurred between asphalt and diatomite through infrared absorption spectrum analysis, the adding of diatomite merely leads to the physical mixing of asphalt and diatomite podwers.
3) Optimum asphalt content of porous asphalt mixture containing diatomite was higher than that of normal porous asphalt due to the low draindown caused by the high specifica surface area of diatomite.

4) The adding of diatomite results in good particle loss resistance under both unaged and aged conditions because of the bigger binder film thickness caused by the adding of diatomite.
5) High percentage of diatomite leads to better moisture damage resistance based on the analysis through ASTM D4867 test and immersed Cantabro test.
6) Rutting resistance of porous containing diatomite is improved due to the high anti-shear strength of asphalt mastic. A little drop of rutting resistance performance when the percentage of diatomite was more than 10%, which is mainly because the high volume asphalt content at high diatomite percentage affected the stability of aggregate skeleton.
7) The adding of diatomite results in the better cracking resistance performance under low temperature.
8) The percentage of diatomite has remarkable effect on the performance of porous asphalt. Porous asphalt mixture with 10% diatomite replacement by weight of filler is determined to be the most effective mix.

ACKNOWLEDGEMENTS

The authors would like to appreciate the financial support of "Hi-tech Research and Development Program of China", Ministry of Science and Technology, China. (Project number: 2006AA11Z117)

REFERENCES

Bao Y., 2005. *Study on the diatomite modified asphalt*. Master thesis. Chang'an university, Xi'an, China. (in Chinese).

Cooly A., 2000. *Evaluation of OGFC mixtures containing cellulose fibers*. Report NO.2000-05. National Center of Asphalt Technology (NCAT), Auburn, Ala.

Hassan F., 2005. *Effect of organic fibers on open graded friction course mixture properties*. International Journal of Pavement Engineering, 2005,6(1): 67-75.

Japan Road Association (JRA), 2005. *Guideline for porous asphalt pavement*. JRA Publication.

Kandhal PS., 1999. *Design of new-generation Open-graded Friction Courses*. Report NO.99-3. National Center of Asphalt Technology (NCAT), Auburn, Ala.

Kumar, A., 1997. *Asphalt hardening as affected by film thickness, voids and permeability in asphaltic mixtures*. Vol. 46. Proceedings Association of Asphalt Paving Technologists. 1977.

Liu D., 2004. *The performance and application of diatomite modified asphalt*. Journal of Changsha university of Sci. & Tech. (nature science) Vol. 1 No.2: 7-12 (in Chinese).

Mallick RB., 2000. *Design, construction and performance of new-generation Open-graded Friction Courses*. Report NO.2000-01. National Center of Asphalt Technology (NCAT), Auburn, Ala.

Ministry of Communications, China, 2004. *Technical specification for construction of highway asphalt pavement*. (in Chinese)

Wu S., 2006. *Effect of fiber types on relevant properties of porous asphalt*. Trans. Nonferrous Met. SOC. China Vol. 16: 791-795.

Zhao Y., 2002. *Permanent Deformation Characterization of Asphalt Concrete Using a Viscoelastoplastic Model*. Ph. D. thesis, Department of Civil Engineering, North Carolina State University.