Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 7(3):193-202

Investigation of Usability of Brucite Fiber in Asphalt Mixture

Bowen Guan[1+], Rui Xiong[1], Rui He[1], Shuanfa Chen[1], and Donghai Ding[2]

Abstract: The objective of this study is to investigate the usability of brucite fiber in asphalt mixture. In order to compare the characteristics of brucite fiber with other fibers usually used in asphalt mixtures, the water absorption test, oven heating test, Mesh-basket draindown test, and scanning electron microscopy are conducted on brucite fiber, lignin fiber, basalt fiber, and polyester fiber. Also, the Marshall test, wheel tracking test, low temperature bending test, water sensitivity test, and fatigue test are used to evaluate the performance of different fiber-reinforced asphalt mixtures. These experimental results show that brucite fiber has a good state of preservation in the moist storage environment, and its thermo-stability is better than lignin fiber. Its absorption and adhesion of asphalt is better than basalt fiber and polyester fiber. The best performance of asphalt mixtures are obtained for 0.40% brucite fiber content. Asphalt mixture prepared with brucite fiber also has excellent high temperature stability, water sensitivity, and fatigue property, especially low temperature properties. Addition of brucite fiber is feasible to improve major performance properties of asphalt mixture.

DOI:10.6135/ijprt.org.tw/2014.7(3).193

Key words: *Asphalt mixture; Brucite fiber, Reinforcement; Road performance.*

Introduction

Asphalt pavement has many advantages including cost efficiency, reduced noise pollution, improved safety and comfort, and recyclability. Asphalt mixture has been widely used in road pavements [1], and 90 percent of the paved roads in China are surfaced with asphalt mixture. However, asphalt mixture or coating layer shows severe durability problems, such as high temperature rutting, low temperature cracking damage, moisture damage, and fatigue. Therefore, asphalt mixture should be modified in some way to promote its further application [2]. The researchers that previously worked on this subject clearly indicated that the use of fiber strengthens pavements and asphalt mixtures [3-5]. Fibers can significantly enhance the road performance of asphalt pavement and extend its service life [6-8]. At present, several kinds of fibers are usually added in the asphalt mixture such as lignin fiber, basalt fiber, and polyester fiber. However, the low tensile strength of lignin fiber limits its application. Because of their high price, the basalt fiber and polyester cannot be used widely. Therefore, it is necessary to investigate the reinforcement potential of new fibers.

Brucite fiber is a possible reinforcing material and may be applied in asphalt mixture. As a naturally occurring fibrous mineral abundant in world, brucite fiber is a magnesium hydroxide mineral, $Mg(OH)_2$, crystallizing in the trigonal system [9]. Brucite fiber has been proven as a kind of harmless mineral to human body [10]. The investigation of Liu et al. (2004) indicates brucite fiber can improve durability of cement concrete greatly [11, 12]. Although the mechanical properties and durability of asphalt mixture may be improved by brucite fiber, those findings have not been reported until now.

In order to compare the characteristics of brucite fiber with other fibers usually used in asphalt mixture, the water absorption test, oven heating test, Mesh-basket draindown test, and scanning electron microscopy are conducted on brucite fiber, lignin fiber, basalt fiber, and polyester fiber. Also, the Marshall test, wheel tracking test, low temperature bending test, water sensitivity test, and fatigue test are used to evaluate the performance of different fibers reinforced asphalt mixtures. Then, the feasibility of using brucite fiber in asphalt mixture is assessed based on these comparative results.

Experimental Program

Materials

The asphalt type AH-90, produced by the Kelamayi Petrochemical industry in the Xinjiang Province of China, is used for all experiments. The physical properties of asphalt binder are measured following the ASTM standards, and are presented in Table 1.

Four kinds of fibers are studied in this paper, including the brucite fiber produced by the Deli Inc. in Shaanxi province, the lignin fiber produced by the TianCheng KenTelai Tec. Co. in Beijing, the basalt fiber produced by the Dacheng Advanced Material Tec. Co. in Ningbo, and the polyester fiber produced by Beimeifu New Materal Tec. Co. in Changsha. The basic physical properties of fibers are presented in Table 2.

Table 1. Physical Properties of Asphalt Binder.

Test items	Unit	Value	Specification
Penetration at 25°C	0.1 mm	83.1	ASTM D5-97
Ductility at 15°C	cm	120	ASTM D113-99
Softening Point	°C	47.4	ASTM D36-06
Wax Content	%	1.86	ASTM D3344-90
Flash Point	°C	271	ASTM D92-02
Specific Gravity	Non	0.982	ASTM D70-76

[1] School of Materials Science and Engineering, Chang'an University, Xi'an 710061, China.
[2] College of Materials and Mineral Resources, Xi'an University of Architecture and Technology, China.
[+] Corresponding Author: E-mail guanbowen2001@163.com
Note: Submitted November 17, 2013; Revised January 15, 2014; Accepted January 17, 2014.

Table 2. The Physical Properties of Fibers (Provided by Manufacturers).

Items	Brucite Fiber	Lignin Fiber	Basalt Fiber	Polyester Fiber	Specification
Diameter (mm)	0.020*	0.045	0.013	0.020	ASTM D2130
Length (mm)	0.50*	1.10	6.00	6.00	ASTM D204
Length/Diameter Ratio (Mean)	250	24	416	300	N/A
Specific Surface Area (10^{-3} m^2/g)	150.3	118.1	174.7	14.8	N/A
Tensile Strength (MPa)	932	110	2000	531	ASTM D2256
Specific Gravity	2.30-2.60	1.14-1.16	2.60-3.05	>50	ASTM D3800
Melt Temperature (^oC)	>400	>1000	1500	>240	ASTM D276

*Mean value

Table 3. Aggregate Gradations for AC-13 Mixture Design.

	Percent of Aggregate Passing for a Given Sieve Size									
Sieve Size(mm)	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Percent Passing (%)	100	95.5	68	47.1	33.4	23.4	15.2	8.7	7.3	5.2

The aggregate is crushed basalt mineral, with a density of 2.98 g/cm^3 and maximal size of 16 mm. The gradation of mixing aggregates is shown in Table 3. Mineral filler is limestone type, with a density of 2.867 g/cm^3, and its particle size is in the range of 0–0.3 mm, with 81.2% by mass smaller than 75 μ m.

Sample Preparation

Asphalt mixtures are prepared by mixing the AC-13 graded aggregates. The dry blending method is used, in which the fibers are blended with hot aggregate and the filler before the binder is added. The optimum fiber content (by weight) is provided by the manufacturers as follows: lignin fiber 0.30%, basalt fiber 0.30%, and polyester fiber 0.25%. A series of tests are carried out to determine the optimum brucite fiber content. Brucite fiber asphalt mixture samples are produced using 0%, 0.2%, 0.4%, 0.6%, and 0.8% brucite fiber contents, respectively.

Test Methods

Testing Physical Properties of Fibers

Water Absorption

In this laboratory test, a fiber sample weighting 30 g is prepared and placed in a dry beaker, and its weight is measured with a precision of ±0.001 g [13]. Consequently, the beaker with fibers is placed in a curing chamber filled with air at a relative humidity of 90% at 20^{o}C. Afterwards, the shape and color of fibers are observed, and the total weight is measured at 5-h intervals. The amount of absorbed water can be calculated from the weight changes. This procedure is continued for five days, and three samples are tested for each fiber type.

Oven Heating Test

Fiber may coalesce and even decompose under high temperature when being mixed with AC mixture. Therefore, in order to evaluatea fiber's thermo-stability, this study uses a simple laboratory oven heating experiment designed as follows [13]. Three samples of each fiber (30 g per sample) are put in a beaker and then placed in an oven at 200^{o}C for 5 h. The weight variations of fibers are observed and recorded continuously.

Mesh-basket Draindown Experiment

A mix sample weighing 40 g is uniformly placed into a designed steel mesh basket with a sieve size of 0.25 mm. Afterwards, the basket is heated in an environmental chamber under at 165^{o}C for 2 h, and some asphalt binder melts, flows, and drops out under the heating effect. The sample weight is measured to determine the weight loss of asphalt binder [13].

Scanning Electron Microscopy (SEM) Analyses

In order to observe a fiber's microstructure characteristic and its spatial network in asphalt binder, the SEM analyses is conducted on fibers and fiber modified asphalts using the SEM EPMA (S-4800) equipment manufactured by the Hitachi Group.

Testing Physical and Mechanical Properties of Fiber Modified Asphalt Mixture

Marshall Test

The bulk density, volume of air voids (VV), voids in mineral aggregates (VMA), the optimum asphalt content (OAC), and the Marshall strength (MS) are obtained by the Marshall test. The performance tests including the low temperature bending test, the wheel rutting test, and the water stability test, are carried out according to ASTM D1559-76.

Wheel Tracking Test

The wheel-tracking test is employed to measure rutting resistance of asphalt mixture. The specimens are prepared in the optimum asphalt content and compacted by the Plate Compactor according to the Marshall test. The square sizes of specimens are 300 mm in length, 300 mm in width, and 50 mm in thickness. Before the wheel tracking test, the specimens are dried at 60^{o}C for 6 h. The wheel pressure is 0.7 MPa, the wheel traveling distance is 230 ±10 mm at a speed of 42 ± 1 cycles/min, and the specimens are loaded to test for 60 min by a special solid rubber tire. Rut deflections are measured per 20 s, and dynamic stability (DS) is defined as

$$DS = \frac{15N}{d_{60} - d_{45}} = \frac{42 \times 15}{d_{60} - d_{45}} \tag{1}$$

where: N is wheel traveling speed, generally, N = 42 cycles/min; d_{60} and d_{45} is the tracking depth at 45 and 60 min, respectively.

Low Temperature Bending Test

Low temperature bending test is performed on a closed-loop controlled servohydraulic MTS 810 material test system equipped with an environmental chamber. Before the low temperature bending test, bitumen beams (250 mm × 30 mm × 35 mm) are submerged in a constant temperature bath and kept at test temperature -10°C for 1 h. The three-point bending method of loading is applied. The span length is 200 mm. The middle point of the beam is loaded. Loading is controlled at a constant rate of 50 mm/min, and the test temperature is controlled at -10°C±0.15°C. The maximum bending stress and the maximum bending strain are determined by midspan deflection as follows:

$$R_B = \frac{3LP_B}{2bh^2} \tag{2}$$

$$\varepsilon_B = \frac{6hd}{L^2} \tag{3}$$

where: R_B — the maximum bending stress, MPa;
ε_B — the maximum bending strain, $\mu\varepsilon$;
b — the width of the cross section, mm;
h — the height of the cross section, mm;
L — the span length, mm;
P_s — the maximum load, N;
d — midspan deflection, mm.

Water Sensitivity Test

AASHTO T-283 test is usually used to evaluate the water sensitivity of asphalt mixtures. The specimen of 101.6 mm in diameter and 63.5 mm in height are prepared and then tested under freeze–thaw cycles at a temperature between -18°C and 60°C. The indirect tensile strength of the conditioned and unconditioned specimens is tested at 25℃ with a loading rate of 50 mm/min. Water sensitivity of mixture can be evaluated using the tensile strength ratio (TSR) value as follows:

$$TSR = \frac{\overline{R}_{T2}}{\overline{R}_{T1}} \times 100 \tag{4}$$

where: TSR—the tensile strength ratio, %
R_{T1} —the average tensile strength of unconditioned specimen, MPa
R_{T2} —the average tensile strength of conditioned specimen, MPa

Table 4. Water Absorption of Fibers.

Fiber Type	Dry Weight(g)	Wet Weight(g)	Average Water Absorption (%)
Brucite Fiber	30.01	30.33	1.07
Lignin Fiber	30.02	34.67	15.49
Basalt Fiber	30.02	30.37	1.17
Polyester Fiber	30.01	30.74	2.43

Table 5. Thermo-stability of Fibers.

Fiber Type	Before Oven Heating (g)	After oven Heating (g)	Mass Loss (%)
Brucite Fiber	30.02	29.80	0.72
Lignin Fiber	30.01	29.46	1.84
Basalt Fiber	30.03	29.86	0.56
Polyester Fiber	30.01	29.73	0.95

Fatigue Test

Flexural fatigue tests are also performed by method of three-point bending using MTS810 Testing Machine. The dimension of specimen is 250 mm × 40 mm × 40 mm. During a complete repetition, the loading time is 0.1 s following by a rest period of 0.4 s. The fatigue tests are conducted at the temperature of 15°C. Three stress ratios (0.3, 0.4 and 0.5) are involved, which are defined as the applied bending stress amplitude divided by the maximum bending stress of asphalt mixtures.

$$R = \frac{S_1}{S_2} \tag{5}$$

where: R—the stress ratio, %
S_1 —the applied bending stress, MPa
S_2—the maximum bending stress, MPa

Results and Discussion

Fiber Properties

Water Absorption

Table 4 shows results of water absorption of fibers. It shows that the lignin fiber has absorbed more than other fibers after 5 days in a curing chamber. Its absorbed moisture can be detected by touch of finger. In this test, water absorption of brucite fiber is similar to that of basalt fiber and polyester fiber, and it is lower than that of lignin fiber. In the test, water absorption of lignin fiber is 14 times higher than that of brucite fiber.

Thermo-stability

Table 5 shows the oven heating test results of fibers. It shows that mass loss of lignin fiber is higher than that of other fibers. It implies that brucite fibers have higher thermo-stability than the other fibers. Fibers have obvious changes in color. The color of lignin fiber changes from light gray to brown. Polyester fiber changes its color from white to light yellow. Brucite fiber and basalt fiber do not have obvious color changes. The reason is that the compositions of these

Table 6. Mesh-basket Draindown Experiment Results.

Fiber Type	Asphalt Separation (%)
Brucite Fiber	8.17
Lignin Fiber	3.04
Basalt Fiber	12.32
Polyester Fiber	18.13

fibers are different, resulting in various thermo-stabilities. Lignin fiber is composed of wood and other plants, so its thermo-stability is the worst. Polyester fiber is organic so its thermo-stability is worse than that of brucite fiber and basalt fiber, which are inorganic. It indicates that brucite fiber and basalt fiber are more stable when being mixed with asphalt mixture.

Absorption and Adhesion of Asphalt

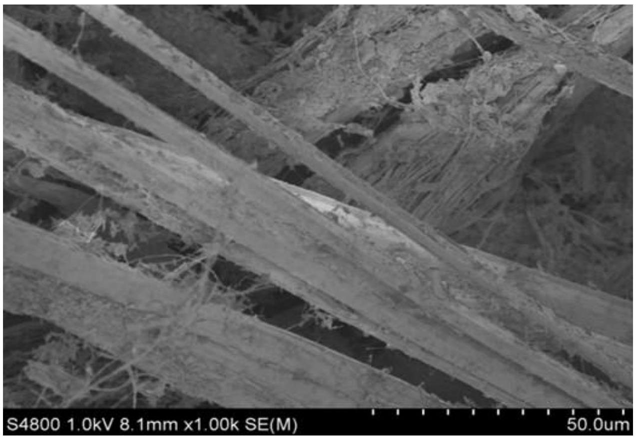
Table 6 shows that the asphalt drop and separation of lignin fiber is lowest—in other words, its asphalt absorption and stabilization is highest—followed by brucite fiber, basalt fiber, and polyester fiber. According to the physical properties of fibers, basalt fiber has larger specific surface; however, it has poor absorption and adhesion of asphalt. The main reason is that surface texture is the most important factor affecting the bonding strength between asphalt and fiber. The rough surface results in high bonding strength. The surface texture of the artificially synthesized basalt fiber and polyester fiber are smoother than the natural brucite fiber and lignin fiber. It is deduced that brucite fiber and lignin fiber have higher bonding strength between asphalt and fiber. In this test, absorption and adhesion of asphalt of brucite fiber is better than that of basalt fiber and polyester fiber.

Microstructure Characteristics

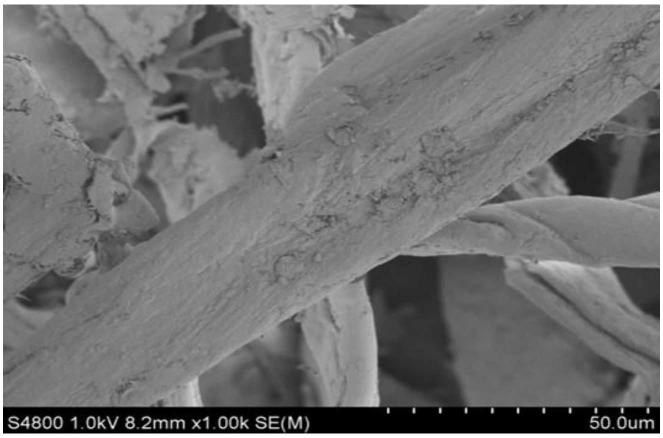
Fig. 1 displays the SEM scanned microstructures of fibers. It shows that the appearance of brucite fiber is different from other types of fibers. From Fig. 1, it can be seen that the grade 7 of brucite fiber is produced in bundles. Fiber bundles are formed by a number of single fibers, which have diameters in the nanometer level. Lignin fiber is an irregularly shaped fiber, which has diameters falling within a range of about 10 -30 μm. Because basalt fiber and polyester fiber are produced by machine, they are regularly cylindrical shaped fiber and their surface is smooth. The diameter of basalt fiber is about 5 μm, and the diameter of basalt fiber is about 20 μm. From the micro- structural characteristics of the fiber surface, the surface of brucite fiber and lignin fiber is rougher than that of basalt fiber and polyester fiber.

Fiber Asphalt Mixture Properties

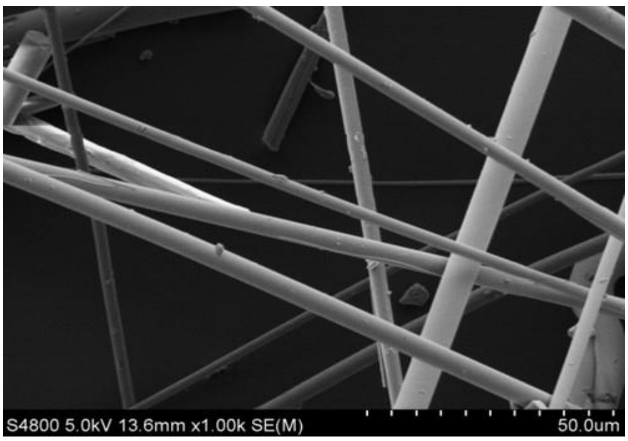
Marshall Index



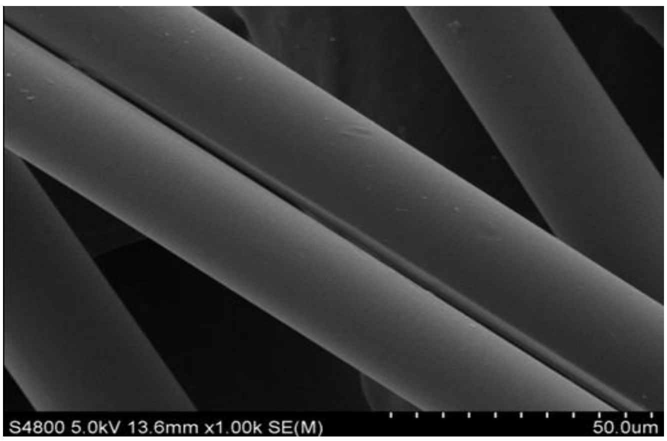
(a) Brucite fiber



(b) Lignin fiber



(c) Basalt fiber



(d) Polyester fiber

Fig. 1. SEM Microstructure of Fibers.

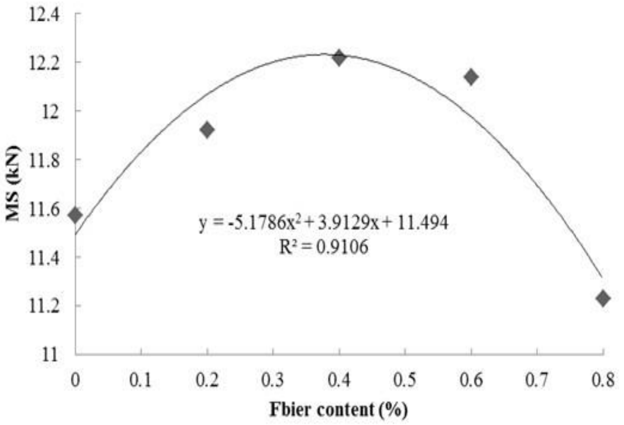


Fig. 2. Change in MS for Different Brucite Fiber Content

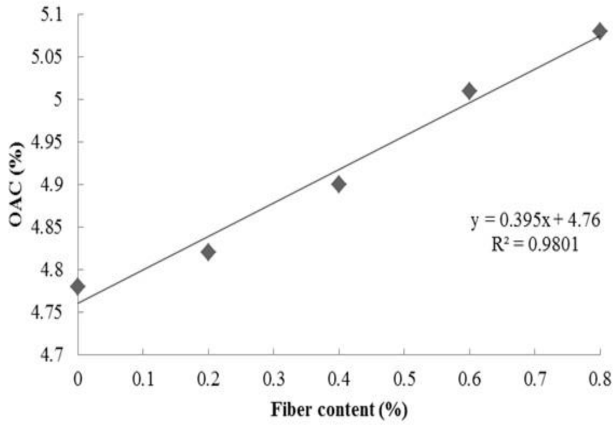


Fig. 3. Change in OAC for Different Brucite Fiber Content.

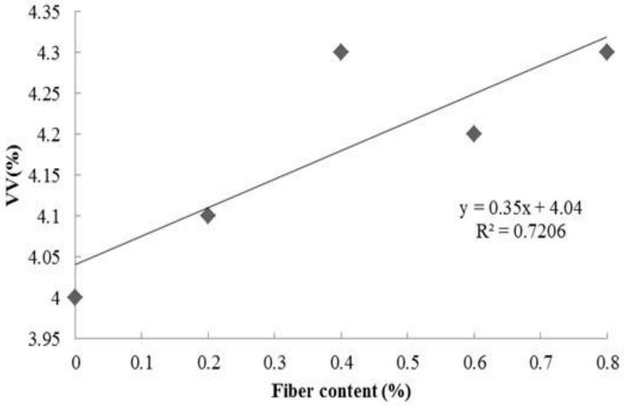


Fig. 4. Change in VV for Different Brucite Fiber Content.

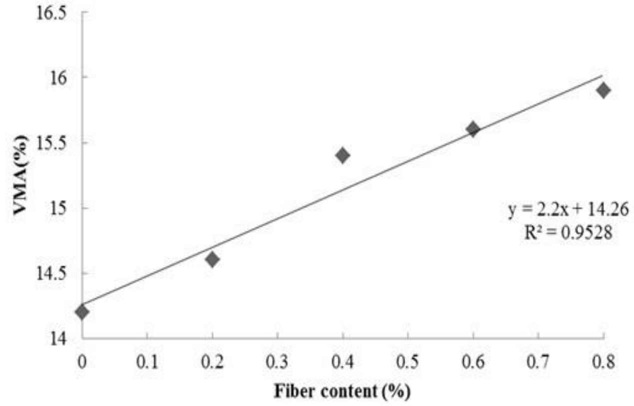


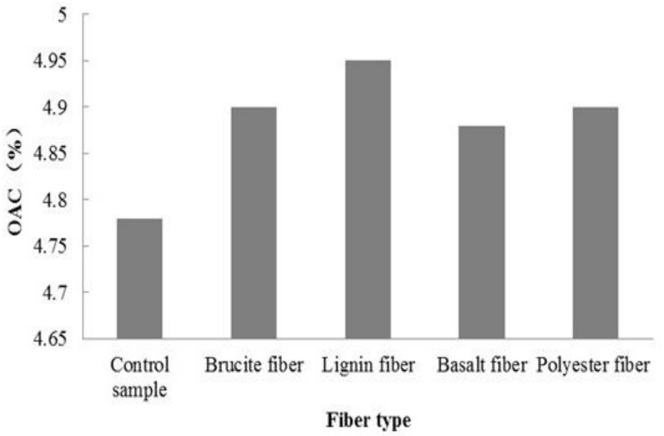
Fig. 5. Change in VMA for Different Brucite Fiber Content.

The physical and mechanical characteristics obtained for the mixtures with different brucite fiber content are given in Figs. 2-5. Fig. 2 shows an initial increase in stability values once the fiber content increased in the mixture, but it also decreases with higher fiber contents. Maximum Marshall Stability values are obtained when 0.40% brucite fiber is added. Due to brucite fiber absorbing asphalt, from Fig. 3, we can find that the optimal asphalt content increases from 4.78% to 5.08% when the fiber content increases from 0% to 0.8%. The main reason for this is because the fibers are absorbed and assimilated into asphalt, so the asphalt content of mixture increased. Fig. 4 shows that the value of VV increased with the increase of the brucite fiber content. This growth probably occurred due to the increase in surface area for the fibers. Fig. 5 reveals that for all mixtures, as the amount of brucite fiber increases, the VMA will also increase.

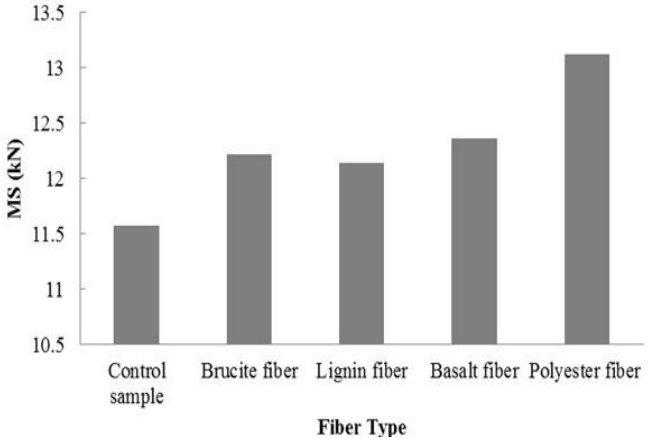
The physical and mechanical characteristics obtained for four kinds of fiber mixtures are given in Fig. 6. Fig. 6(a) shows that the OAC of brucite fiber asphalt mixture is slightly lower than that of lignin fiber asphalt mixture, and it is slight higher than that of basalt fiber asphalt mixture and polyester fiber asphalt mixture. Dosage of lignin fiber is lower than that of brucite fiber. However, the OAC of lignin fiber asphalt mixture is higher than that of the brucite fiber mixture. The reason is that the various fiber asphalt absorption levels are not the same. The asphalt absorption of the lignin fiber is much higher than that of brucite fiber. Fig. 6(b) shows that with the addition of brucite fiber, lignin fiber, basalt fiber, and polyester fiber, the MS of asphalt mixture has increased by 6.14%, 4.93%, 2.09%, and 13.40%, respectively. Because of its much higher tensile strength, the MS of the brucite fiber asphalt mixture is higher than that of lignin fiber. It is lower than that of basalt fiber and polyester fiber. From Fig. 6(c) and (d), it can be seen that all four fiber mixtures have similar VV and VMA at respective optimum asphalt contents. This finding is also supported by the results of Alvaro García [14]. They have shown that a higher volume of fibers in the mixture may increase the air void content of asphalt mixture. China standards require VV ranging from 3.0 to 5.0%. All the mixtures followed the standard requirements. VMA is another important parameter of the Marshall Test.

High Temperature Stability

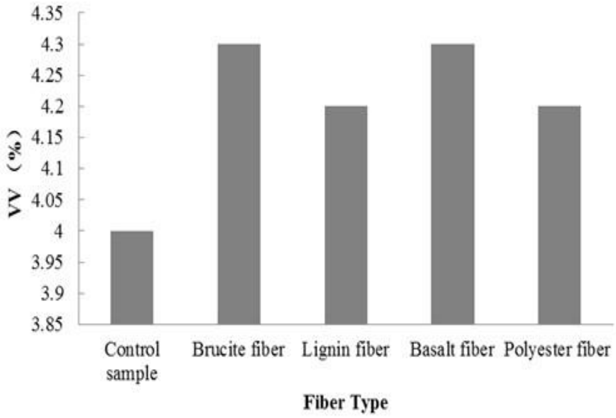
Fig. 7 presents the high temperature stability of mixtures with different brucite fiber contents. From Fig. 7, it can be seen that the maximum dynamic stability value is obtained from 0.40% brucite fiber addition. Compared with the asphalt mixtrue without fiber, the value of the dynamic stability of brucite fiber asphalt mixture is increased by 53.8%. This indicates that the brucite fiber portion has a great influence on a mixture's dynamic stability. In the asphalt mixture, asphalt and fiber have a good absorption and adhesion ability. Brucite fibers absorb and stabilize free asphalt, so asphalt



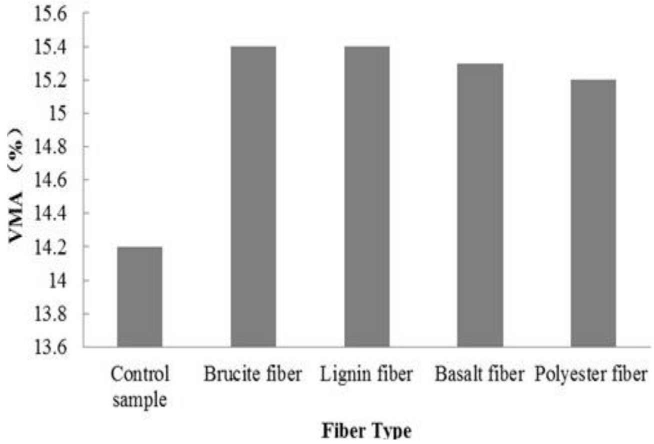
(a) OAC



(b) MS



(c) VV



(d) VMA

Fig. 6. Marshall Test Results of Four Kinds of Fiber Asphalt Mixtures.

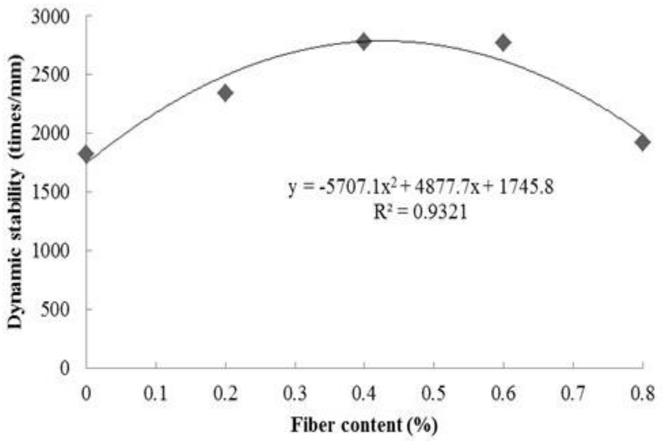


Fig. 7. Change in Dynamic Stability for Different Brucite Fiber Content.

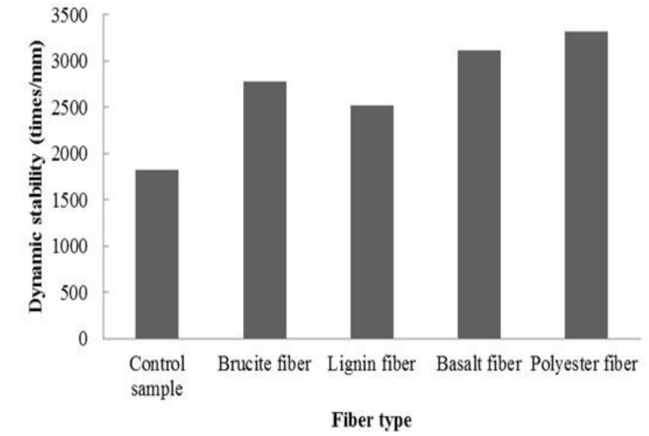
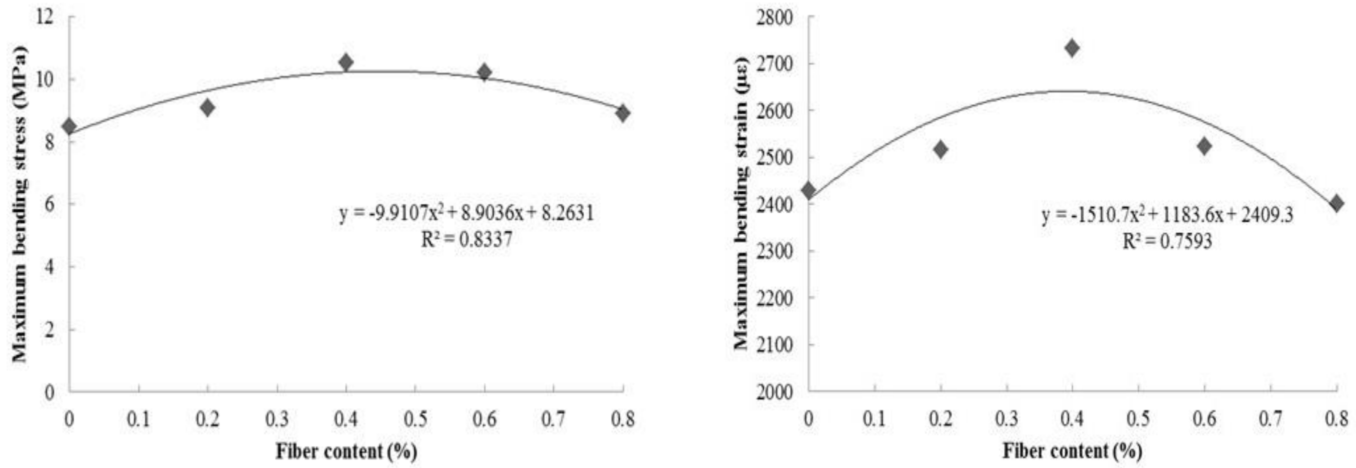


Fig. 8. Dynamic Stability of Different Fiber Mixtures.

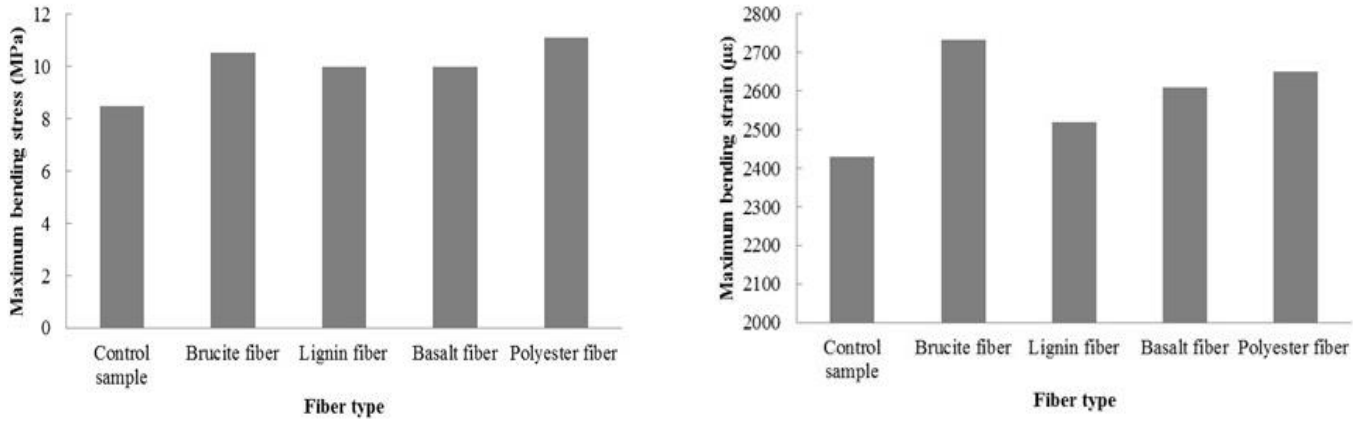
viscosity and cohesive strength increase. In addition, the fiber has "connection", a "bridge" role that crisscrosses to the external envelope in the aggregate and thus forms an effective fiber frame structure. This frame structure establishes the integrity within the asphalt mixture and consequently enhances rutting resistance and shear capacity [15]. After 0.40% fiber content, it shows a decrease. The main reason is that if the fiber content is too high, part of the fibers cannot absorb asphalt, so they are in the mixture as loose bodies. These loose fibers not only do not contribute anything to the mixture but also take a certain mixture volume, which adversely affects road performance [16].

Fig. 8 shows that dynamic stability of brucite fiber asphalt concrete is higher than that of lignin fiber asphalt mixture, and its reinforcing effect is lower than the basalt fiber and polyester fiber.



(a) Maximum Bending Stress (b) Maximum Bending Strain

Fig. 9. Low Temperature Bending Test Results of Brucite Fiber Mixtures.



(a) Maximum Bbending Stress (b) Maximum Bending Strain

Fig. 10. Low Temperature Bending Test Results of Different Fiber Mixtures.

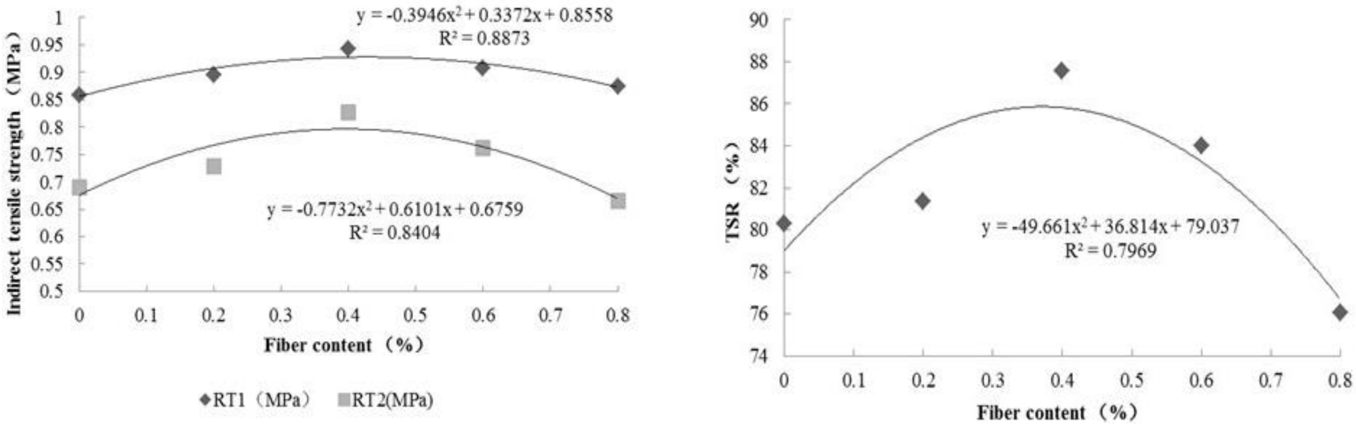
Compared with the lignin fiber asphalt concrete, the value of the dynamic stability is increased by 10.5%. Mechanical properties of fiber are the main factors to affect the performance of asphalt mixture in high temperature [17]. Because brucite fiber has better mechanical properties than lignin fiber, rutting resistance and shear capacity of the mixture prepared with brucite fiber can be more enhanced.

Low Temperature Properties

Fig. 9 shows low temperature properties of mixtures with different brucite fiber content. As seen from Fig. 9, the change trend of the results of the low temperature bending test is similar to that of the high temperature stability test. The best low temperature properties of asphalt mixture are obtained for 0.40% brucite fiber addition.When fiber content reaches 0.8%, the maximum bending strain of the fiber reinforced specimens is lower than that of the specimens without fiber. From Fig. 9, it can be seen that low temperature properties of asphalt concrete at low temperature can be improved greatly with the proper addition of brucite fiber. The reason may be that the brucite fiber contributes to flexibility at low temperature. The interlacing of the fiber vertically and horizontally improves the elasticity, which helps to reduce the propagation of cracks [18].

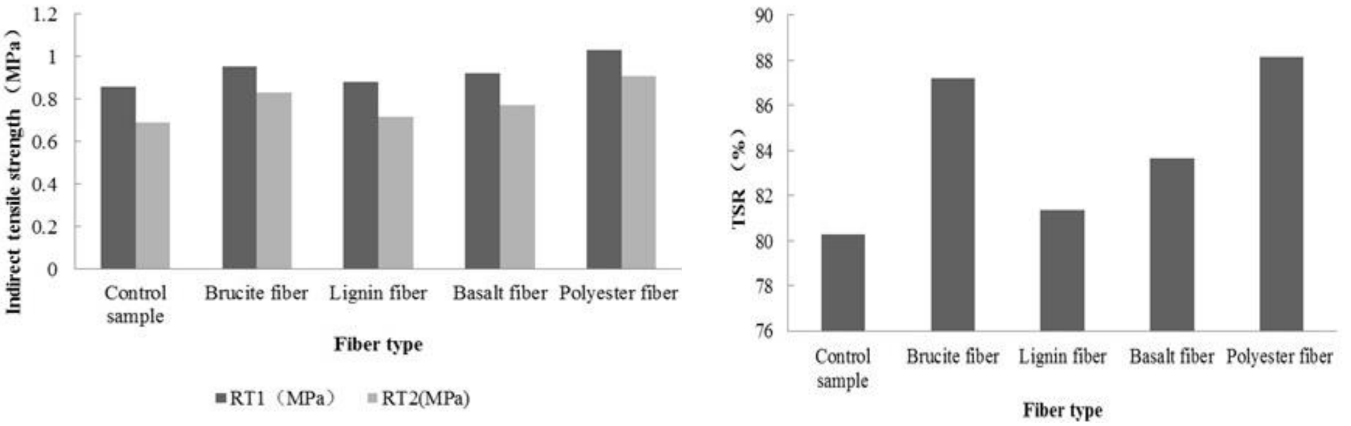
Fig. 10 shows that the maximum bending strength of brucite fiber asphalt mixture is lower than that of polyester fiber asphalt mixture, and it is higher than that of the lignin fiber and basalt fiber aspalt mixtures. Brucite fiber asphalt mixture has the highest bending strain. It implies that brucite fiber asphalt mixture has better anti-crack ability at low temperature. The main reason is that brucite fiber has better absorption and adhesion of asphalt. It is difficult to pull out brucite fiber from the mixture. Moreover, brucite fiber is formed by a number of single fibers, which have diameters in nanometer level (Fig. 1). After stirred with aggregate in the mixer, some brucite fiber bundles will be dispersed in nanometer level. Dang Van Thanh has shown that short fibers are very effective in blocking crack propagation [19]. Fibers in the asphalt matrix are randomly distributed in three-dimensional space. Due to its smaller cross-section, brucite fibers appear in large quantities, even with a small fiber content, which can form a cross-link network within the mixture .

Water Sensitivity



(a) Residual Strength (b) TSR

Fig. 11. Change in Residual Strength and TSR for Different Brucite Fiber Content.



(a) Residual Strength (b) TSR

Fig. 12. Water Sensitivity of Different Fiber Mixtures.

Fig. 11 shows water sensitivity of mixtures with different brucite fiber content. Fig. 11 shows that the residual strength and the TSR value both increase when brucite fiber is added to the asphalt, which suggests that brucite fiber could help to protect the asphalt mixture from water damage. Maximum residual strength and TSR are obtained from 0.40% brucite fiber addition. After this value, residual strength and TSR decrease. Compared with the asphalt concrete without fiber, the value of the residual strength and TSR of 0.4% brucite fiber asphalt mixture is increased by 19.7% and 9%, respectively. Due to the absorption of the asphalt by the fiber, the free asphalt content is reduced and the adhesive strength is enhanced [20]. This is the reason why the asphalt mixture's brucite fiber exhibited higher values for residual stability and TSR, and why the resistance to water damage is improved. It is concluded that the addition of fiber improves the water sensibility of asphalt mixes by increasing the adhesive strength between the asphalt and mineral aggregate to resist the ingress of water. However, when fiber content is 0.8%, the value of TSR of the brucite fiber-reinforced specimens is lower than that of the asphalt mixture without fiber.

Fig. 12 illustrates the residual strength and the TSR value of four kinds of fiber mixtures and the control sample. As seen in Fig. 9, brucite fiber asphalt mixture has better moisture damage resistance than the control sample, lignin fiber, and basalt fiber asphalt mixture; it is also similar to polyester fiber asphalt mixture, which may be attributed to the water absorption of fibers. Water absorption will lead to swelling of the fiber, which can break the bond between asphalt and fiber and ingress of additional water [13]. Lignin fiber absorbs more water than other fibers (Table 5). This is one of main reasons why the lignin fiber asphalt mixture exhibited the lower value of TSR than the other fiber asphalt mixture.

Fatigue Property

Fatigue test results for four kinds of fiber asphalt mixture are shown in Figs. 13 and 14. Fig. 13 shows that maximum bending stress of all mixtures are improved greatly by addition of fiber. The maximum bending stress of brucite fiber asphalt mixture is lower than that of polyester fiber asphalt mixture and basalt fiber asphalt mixture, and it is higher than that of the other fiber aspalt mixtures. From Fig. 14, it can be seen that the fatigue property of asphalt mixtures can be improved by fibers. The number of cycles to failure for asphalt mixture reinforced by fiber can be increased at all stress ratios tested. It is obvious that the fatigue property of asphalt mixture is enhanced dramatically at lower stress ratios, but this improvement is poor at higher stress ratios. When the stress ratio is lower than 0.5, the effect is obvious. Polyester fiber, asphalt fiber, brucite fiber, and lignin fiber improve fatigue life of asphalt

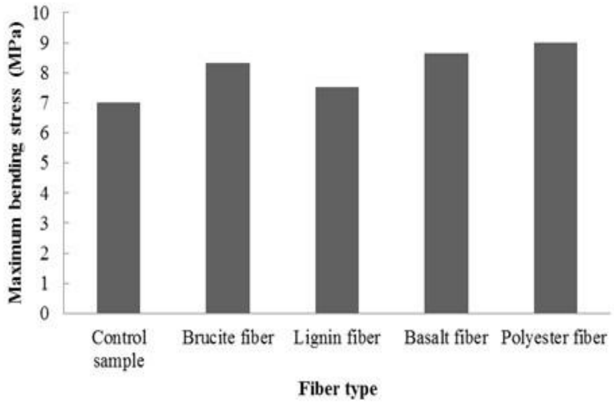


Fig. 13. Maximum Bending Stress of Fiber Asphalt Mixtures.

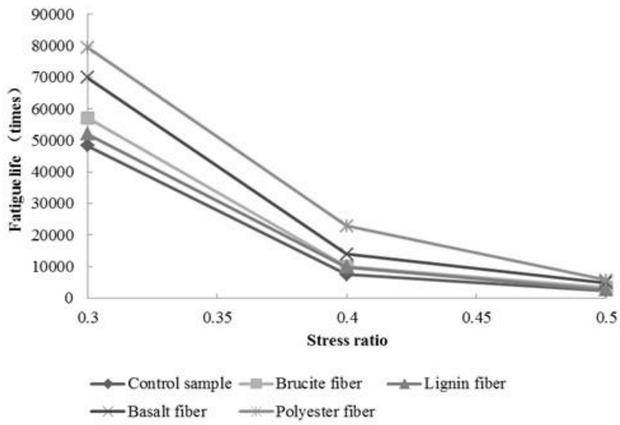


Fig. 14. Fatigue Life of Different Fiber Asphalt Mixtures.

mixture. Compared to the control sample, it is increased by 64.67%, 44.70%, 18.32%, and 7.88% in 0.3 stress ratio, respectively, which reveals that the fatigue property of asphalt mixtures can be improved by fibers. When the asphalt mixture is suffering from fatigue stress, lots of micro-cracks appear. However, fiber can prevent the development of micro-cracks [21]. Meanwhile, Addition of fiber improves fatigue life by increasing the resistance to permanent deformation of asphalt mixture [22]. So, the destruction time of the concrete is extended and service life of the asphalt mixture is increased by addition of fibers. In this test, Brucite fiber asphalt mixture is found to have better fatigue resistance than the control sample and lignin fiber asphalt mixture. Due to its high tensile strength and length/diameter ratio, brucite fiber can absorb more strain energy during the fatigue and fracture process of the mixture than lignin fiber.

Conclusion

(1) Brucite fiber has a good state of preservation in moist storage environment, and its thermo-stability is better than lignin fiber. The brucite fiber has greater asphalt absorption and adhesion function than the basalt fiber and polyester fiber.

(2) The brucite fiber content of 0.4% by weight of the total mixture resulted in highest performance in terms of high temperature stability, low temperature properties, water sensitivity, and fatigue, as compared to the control sample; however these properties degrade when the fiber content exceeds 0.4%.

(3) Compared with the other ordinary fibers asphalt mixture, brucite fiber asphalt mixture also has excellent high temperature stability, water sensitivity, and fatigue property, especially low temperature properties.

(4) According to the above results, addition of brucite fiber is feasible to improve major performance properties of asphalt mixture. This finding has quite important practical implications for the design of high performance asphalt pavements.

However, funding and lab conditions limited experiments. Further research can be processed, including the performance of brucite fiber modified asphalt as analyzed with PG appraisal system through DSR, BBR, and Brookfield revolving viscosity tests.

Acknowledgements

The authors wish to thank the financial support from the National Natural Science Foundation of China (No. 51308062), China Postdoctoral Science Foundation (No. 2013M540726), and the National Key Technology R&D Program (No.2011BAE27B04).

Reference

1. King, G. (1999). Additives in Asphalt. *Journal of the Association of Asphalt Paving Technologists*, 68, pp. 32–69.
2. Chen, H., Xu, Q., Chen, H., Zhang, Z. (2009). Evaluation and Design of Fiber Reinforced Asphalt Mixture**.** *Materials and Design*, 30, pp. 2595-603.
3. Chen, H., Li, N., Hu, C., Zhang, Z. (2004). Mechanical Performance of Fibers-reinforced Asphalt Mixture. *Journal of Chang'an University (Natural Science Edition)*, 24(2), pp. 1-5 (in Chinese).
4. Chen, Y. and Li, Z. (2012). Study of Road Property of Basalt Fiber Asphalt Concrete. *Applied Mechanics and Material*, 328, pp. 22–25.
5. Hassan, H.F., Oraimi, S.A., and Taha, R. (2005). Evaluation of Open-graded Friction Course Mixtures Containing Cellulose Fibers and Styrene Butadiene Rubber Polymer. *Journal of Materials in Civil Engineering*, 17, pp. 416–22.
6. Tapkın, S. (2008). The Effect of Polypropylene Fibers on Asphalt Performance. *Building and Environment*, 43, pp. 1065-1071.
7. Chen, J.S. and Lin, K.Y. (2005). Mechanism and Behavior of Bitumen Strength Reinforcement Using Fibers. *Journal of Materials Science*, 40, pp. 87–95.
8. Serin, S., Morova, N., Saltan, M., and Terzi, S. (2012). Investigation of Usability of Steel Fibers in Asphalt Concrete Mixtures. *Construction and Building Materials*, 36, pp. 238–44.
9. Dong, F.P., Wan, K., Zhou, J., and Liu, S. (1997). Environmental Safety Investigation on Fibrous Brucite. *Bulletin of Mineralogy, Petrology and Geochemistry*, 16(1), pp. 43–46.
10. Zheng, R. and Wei, K. (1998). Utilization and Development of the Brucite Resources in China. *China Mines Industry*, 7(2),

pp. 21– 23 (in Chinese).
11. Liu, K. and Zhou, J. (2003). Experimental Study of Brucite Fiber/cement Matrix Composite, *China Concrete Cememt Production,* 3, pp. 32– 35 (in Chinese).
12. Liu, K., Cheng, H., and Zhou, J. (2004). Investigation of Brucite Fiber Reinforced Concrete, *Cement and Concrete Research*, 34(11), pp. 1981-1986.
13. Chen, H. and Xu, Q. (2010). Experimental Study of Fibers in Stabilizing and Reinforcing Asphalt Binder, *Fuel*, 89, pp. 1616-1622.
14. García, A., Norambuena-Contrerasb, J., Partl, M.N. (2013). Experimental Evaluation of Dense Asphalt Concrete Properties for Induction Heating Purposes, *Construction and Building Materials*, 46, pp. 48-54.
15. Dang, V., Cheng, P., and Liu, H. (2011). Analysis of High Temperature Stability and Water Stability of SMA Mixture using Orthogonal Experiments. *International Journal of Civil and Structural Engineering*, 2(2), pp. 635-647.
16. Karakus, A. (2011). Investigating on Possible Use of Diyarbakir Basalt Waste in Stone Mastic Asphalt, *Construction and Building Materials*, 25(8), pp. 1–6.
17. Serfass, J.P. and Samanos, J. (1996). Fiber-Modified Asphalt Concrete Characteristics, Applications and Behavior. *Journal of the Association of Asphalt Paving Technologists*, 65, pp. 193-230.
18. McDaniel, R.S. (2001). *Asphalt Additives to Control Rutting and Cracking.* PhD Thesis, Purdue University, West Lafayette, Indiana, USA.
19. Dang, V. and Cheng, P. (2013). Influence of Different Fibers on High Temperature and Water Stability of Stone Maxtrix Asphalt.. *International Journal of Applied Engineering and Technology*, 3(1), pp. 1-10.
20. Wu, S., Ye, Q., and Li, N. (2008). Investigation of Rheological and Fatigue Properties of Asphalt Mixtures Containing Polyester Fibers. *Construction and Building Materials*, 22, pp. 2111–2115.
21. Lee, S.J., Rust, J.P., Hamouda, H., Kim, Y.R., and Borden, R.H. (2005). Fatigue Cracking Resistance of Fiber–reinforced Asphalt Concrete. *Textile Research Journal*, 75, pp. 123–128.
22. Abdelaziz, M., Mohamed, R., and Yati, H. (2005). Fatigue and Deformation Properties of Glass Fiber Reinforced Bituminous Mixes. *Journal of the Eastern Asia Society for Transportation Studies,* 6, pp. 997- 1007.