Evaluation of mineral fiber impact on Hot-Mix Asphalt performance

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ABSTRACT: This study presents characteristics and properties of alkaline mineral fiber-reinforced asphalt mixtures. It evaluates the effect of mineral fiber contents (0 %, 0.3 %, 0.5 %, 0.7 % and 0.9 %) and two kinds of asphalt binders (original asphalt AH-90 and 5 % SBS modified asphalt). Marshall test, dynamic stability, moisture susceptibility tests were conducted. The Marshall stability increased initially and then decreased with increasing the mineral fiber contents. The mechanical property (dynamic stability and tensile strength ratio) of fiber-reinforced asphalt mixtures increased with the increase of mineral fiber contents. Fiber contents had great influence on high temperature rutting resistance, while little influence on moisture susceptibility. Based on the performances and the economic factors, an optimum fiber content of 0.5 % was recommended for the alkaline mineral fiber used in this AC-16 mixture. The asphalt mixture modified by 5 % SBS had higher mechanical performances than the mixture modified by 0.5 % mineral fiber, especially for permanent deformation in high temperature. The research results would be of importance for material design of asphalt pavement according to traffic volume and loading distribution.

KEY WORDS: Alkaline mineral fiber, asphalt mixture, Marshall stability, dynamic stability, moisture susceptibility.

1 INTRODUCTION

Using fibers to improve the behavior of materials is not a new concept. Fibers are widely used as reinforcing agents in concrete [Song 2005, Yao 2003, Choi 2005, Alhozaimy 1996], however, the potential of fiber used as a construction material in cement concretes and lightweight structures was recognized in the early 1950s. As a reinforcement material, the principal function of the fiber is to provide additional tensile strength in the resulting composite. This could increase the amount of strain absorbed during the fatigue and fracture process of the mixture [Brown 1990]. The results obtained from field studies show that the addition of fiber will help produce more flexible mixtures that are also more resistant to cracking [Jiang 1993]. In recent years, a multitude of fibers and fiber materials are being introduced regularly in the market as new applications such as polyester fiber, asbestos fiber, glass fiber, polypropylene fiber, carbon fiber, cellulose fiber, etc. [Serfass 1996]. Polypropylene fibers are also used as a modifier in asphalt concrete in the United States. Ohio State Department of Transportation (ODOT) has published standards for using polypropylene fibers in high-performance asphalt concrete [ITEM 400HS. 1998]. The polypropylene fiber-reinforced asphalt mixture exhibits good resistance to rutting, prolongs fatigue life and decreases reflection cracking [Tapkin 2008]. The use of glass fiber shows that the addition of fiber improves properties of SMA mixtures by decreasing stability and increasing flow value as well as decreasing the voids in the mix. Addition of fiber also improves fatigue properties by increasing resistance to cracking and permanent deformation of bituminous mixtures [Abdelaziz 2005]. Carbon fiber has the potential to improve structural resistance to distress occurring in road pavement due to traffic loads. Further, addition of fiber improves fatigue life and permanent deformation of bituminous mixtures by improving mix stiffness [Jahromi 2008]. Three types of fibers, i.e., cellulose, mineral and polyester fibers, are mixed with bitumen to stabilize the mastic and reduce binder drainage. They are commonly used in stone matrix asphalt and porous asphalt in Europe, USA and other countries [Akbulut 2000, Cooley 2000, Stuart 1992, Nicholls 1997]. While these fibers have some advantages, they also exhibit some disadvantages. Asbestos was used but it was reported to be degradable and unsuitable as a long-term reinforcement [Bushing 1968] and a health hazard [Kietzman 1960, Marais 1979]. Cellulose fiber can not be recycled and polypropylene, polyester fibers are too expensive to be widely used.

Alkaline mineral fiber is a kind of inorganic fiber, which may offer excellent potential for binder modification due to lower moisture absorption, better flame spread and anti-aging. It can easily disperse into aggregates and exhibit higher ability to absorb asphalt. Beneficially, it can be recycled and has no health concerns. Therefore, the idea of modification of asphalt mixes with alkaline mineral fibers is further developed and tested in this paper. The objectives of this study are (1) to evaluate the effect of alkaline mineral fiber on asphalt mixture with different fiber contents and different asphalt binders; (2) to determine the optimum fiber content, (3) to contrast the effect of fiber-reinforced and 5 % SBS modified asphalt on HMA performance.

2 MATERIALS

2.1 Asphalts

The asphalts employed in this experimental study were grade AH-90 (80-100 penetration) and 5% SBS modified asphalt binder. These materials, supplied by the China Petroleum Cooperation, are the usual asphalt grade used for asphalt pavements in China. The basic physical properties of asphalts were measured following the ASTM standard, and were presented in Table 1 and Table 2.

2.2 Fibers

Alkaline mineral fiber was supplied by a branch of Fiberand Corporation in China. The FIBERAND Mineral Road Fibers are processed fibers designed for exclusive use in hot mix asphalt systems, which are man-made vitreous silicate fibers formed by the spinning of a molten composition of furnace slag and other minerals. The basic properties of mineral fiber were presented in Table 3.

Table 1: Properties of the asphalt (AH-90)

Property	Test Value	Standard
Penetration at 25 ℃ , 1/10mm	82	ASTM D 5-73
Penetration Index	-0.8	
Ductility at 15 ℃ , cm	>100	ASTM D 113-79
Softening point, ℃	47	ASTM D 36-76
Specific gravity at 25 ℃ , kg/m^3	1.005	ASTM D 70-76
Flash point, ℃	260	ASTM D 92-78
Loss on heating, %	0.04	ASTM D 6-80

Table 2: Properties of 5%SBS modified asphalt (AH-90)

Property	Test Value	Standard
Penetration at 25 ℃, 1/10mm	63	ASTM D 5-73
Penetration Index	-0.4	
Ductility at 5 ℃, cm	55	ASTM D 113-79
Softening point, ℃	56.5	ASTM D 36-76
Flash point, ℃	260	ASTM D 92-78
Loss on heating, %	0.10	ASTM D 6-80

Table 3: Properties of Mineral Road Fiber

Properties	Typical properties	Value identification
Length(mm)	Maximum 6.35	-
Diameter(mm)	Average 0.00508	-
Tensile strength(MPa)	620.69	CAE Tensile & MOE Test
Specific gravity(g/cm^3)	2.70	TBD
Moisture - (%)	< 0.5	70.30.002
Loss on Ignition - (%)	< 0.5	70.30.002
Non-Fibrous Material - (%)	< 35.0	ASTM C-612

2.3 Aggregate and Gradation

The aggregates used were typical crushed limestone supplied by Jilin rock quarry in China. The gradation of the aggregates was chosen according to the dense packing criteria and the Technical Specifications for Construction of Highway Asphalt Pavements in China [JTG F40 2004]. Figure 1 showed the gradation of the mixture including the restricted zone and control points.

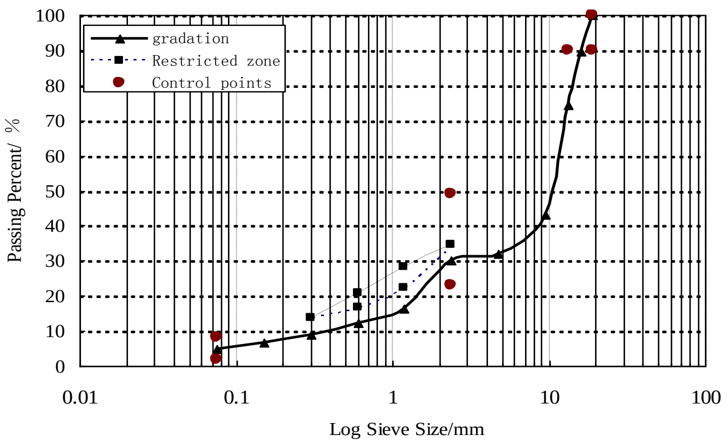


Figure 1: Aggregate gradation

3 SPECIMEN PREPARATION AND TEST METHODS

3.1 Specimen Preparation

Fiber asphalt mixtures were separately prepared by graded aggregates and AH-90 grade original asphalt and 5 % SBS modified asphalt with different mineral fiber contents. In order to study the influence of fiber content on the mechanical properties of asphalt mixture, five different fiber contents (by weight of mixture): 0 %, 0.3 %, 0.5 %, 0.7 %, and 0.9 % were used for the alkaline mineral fiber. The optimum asphalt contents (OAC) for the fiber mixtures were determined following Marshall design method. The optimum asphalt contents for the original asphalt mixture were 4.3 %, 4.4 %, 4.5 %, 4.6 % and 4.7 % by weight corresponding to fiber content of 0 %, 0.3 %, 0.5 %, 0.7 %, and 0.9 %, respectively. While the modified asphalt mixtures were found to have the optimum asphalt content of 4.7 %, 4.8 %, 4.9 %, 5.0 %, and 5.1 % respectively. Specimens were prepared using a Marshall Compactor machine. The compaction blows were 75 for the top and bottom specimens in accordance with the standard specified for traffic-congested roads. Mixing and compaction temperatures were designated at 160 ℃ and 140 ℃ for original asphalt mixture and 175 ℃ and 160 ℃ for modified asphalt mixture, respectively.

3.2 Test Methods

3.2.1. Marshall Stability Test

The Marshall stability is measured following the specification [JTG F40 2004], which is also detailed in many other literatures [Roberts 1996]. In the test a compressive loading is applied on the specimen at a rate of 50.8 mm/min until it was broken. The maximum loading at material failure is called Marshall stability (MS), and the associated plastic flow (deformation) of specimen is called flow value (FL).

3.2.2 Dynamic Stability

Dynamic stability is used to evaluate the high-temperature performance (rutting resistance) of asphalt mixture following the specification [JTG F40 2004]. A mixture slab is prepared and placed in a steel frame, and then cured in a temperature chamber at 60 ℃ (simulating the high temperature in summer weather) for more than 5 hours to achieve a uniform temperature, but less than 24 hour to minimize the aging effect of high temperature. Then a wheel with a tire contact pressure of 0.7 ± 0.05 MPa is applied on the slab specimen, running within a distance of 23 cm ± l cm at a speed of 42 cycle/min along one direction. The dynamic stability (cycle/mm) is determined as follows:

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

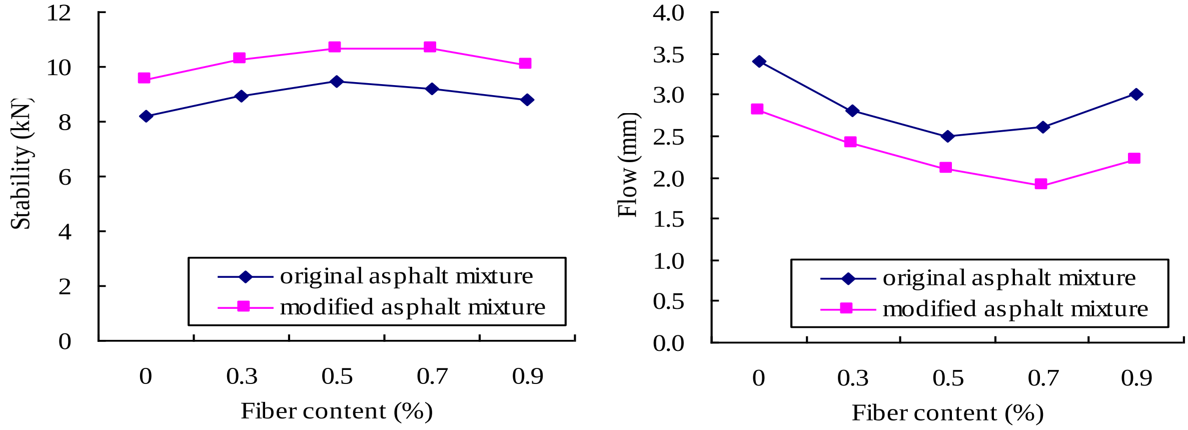
Where d_{60} is the rutting depth (mm) at 60 min, d_{45} is the rutting depth at 45 min, 42 is the speed (cycle/min), and 15 is the time difference (min). A higher DS represents a higher rutting resistance of asphalt mixture.

3.2.3 Moisture Susceptibility Test

The AASHTO T-283 test is used to evaluate the moisture susceptibility of the fiber reinforced asphalt mixtures. The air voids of the specimens are controlled at 7 ± 1 %. Two groups of duplicate specimens (five samples for each group) are prepared. One group of samples for freeze-thaw are subjected to vacuum, and then frozen at -18 ℃ for 16 hours, followed by 24 hours at 60 ℃ in water. After this water conditioning, the two groups of specimens are placed at the same time in 25 ℃ water for no less than 2 hours. Their indirect tensile strengths are measured. Consequently, the tensile strength ratio (TSR) is determined as follows:

$$TSR = \frac{S_2}{S_1} \tag{2}$$

Where S_2 is the average tensile strength of conditioned subset, and S_1 is the average tensile strength of dry subset. TSR is used to evaluate the moisture susceptibility of asphalt mixture, and a higher TSR value indicates higher moisture susceptibility (lower moisture damage resistance).



a. Stability and fiber content b. Flow and fiber content

Figure 2: Marshall test result of mixtures

4 TEST RESULTS AND DISCUSSION

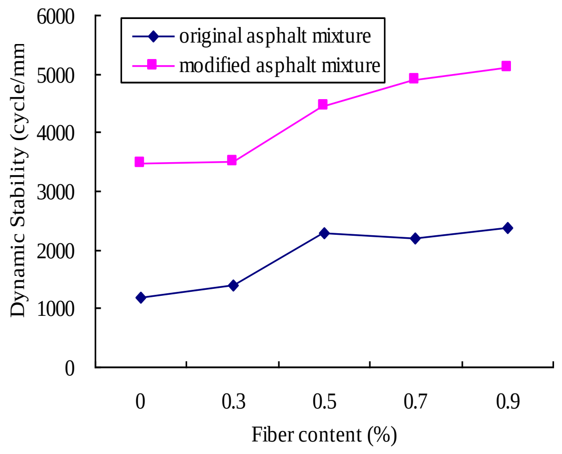
4.1 Marshall Stability and Flow Values

Figure 1a showed an initial increase in stability values once the fiber content in the mixture, but it also decreased with higher fiber contents for original asphalt and modified asphalt mixtures. There existed the optimum percentage of alkaline mineral fiber content (0.5 %) for Marshall Stability. A large amount of fiber in the mixture may produce lower contact points between aggregates, hence resulting in lower stability. Figure 1b showed that an increase in fiber content decreased the flow value. When the fiber content was more than 0.5%, the flow values started to increase. From Figure 2, the optimum fiber content for original asphalt mixture was 0.5 %, while was 0.5 % — 0.7 % for modified asphalt mixture.

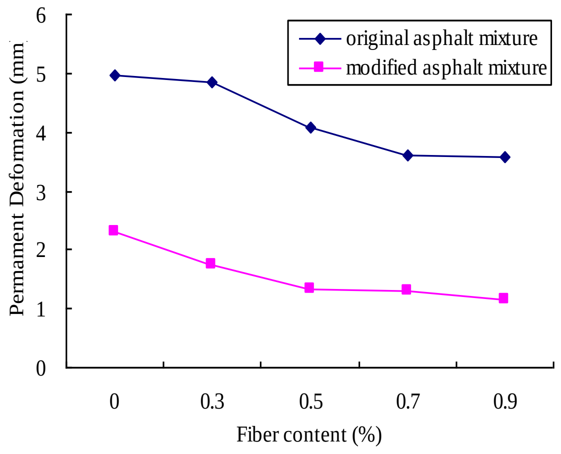
4.2 Dynamic Stability

Figure 3a and 3b separately showed an increase in the dynamic stability and a decrease in the permanent deformation with the increasing fiber content. The test results showed that the dynamic stability increased 91.5 % when fiber content increased from 0 % to 0.5 % for original asphalt mixture and increased 28.0 % for modified asphalt mixture. This result could be attributed to fiber's adhesion and networking effects. The spatial networking effect was regarded as the primary factors contributing to fiber's reinforcement [Chen 2005]. Generally, a fiber with higher length/diameter ratio posed higher networking effect [Fu 2000]. The mineral fiber had the higher length/diameter ratio, equal to 1250 in this test. The test results were observed in the laboratory as well as in the field. The addition of fibers into asphalt mixtures enhanced the pavement resistance to rutting at high temperatures.

From Figure 3a, the mineral fiber at 0.5 % concentration showed a significant increase in the dynamic stability (from 1201 to 2300 cycle/mm for original asphalt mixture and from 3480 to 4455 cycle/mm for 5 % SBS modified asphalt mixture). Thus, concentrations at 0.5 % mineral fibers are found to be the desirable content.



a. Dynamic stability and fiber content



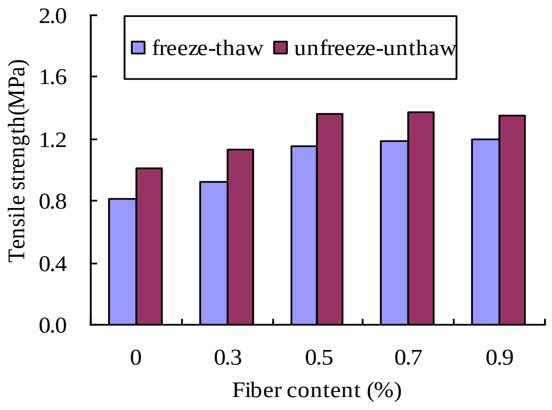
b. Permanent deformation and fiber content

Figure 3: Wheel track test results of mixtures

4.3 Moisture Susceptibility

An addition of mineral fibers resulted in an increase of tensile strength ratio in the mixture regardless of fiber contents and asphalt binders (Figure 5). The addition of mineral fibers effectively enhanced the ultimate strength (Figure 4). From Figure 4, the addition of fibers caused an increase in tensile strength, no matter what the asphalt type (Figure 4 just showed the result of original asphalt mixture). This improvement in tensile strength implied that there was good cohesion between asphalt and fibers, providing enough adhesion between the aggregate and mastic. As a result, the tensile strength of the overall system increased. It appeared that the mechanical bonding between fibers and asphalt binders played an important role in increasing the tensile strength of asphalt mixtures. This result further approved that the mixture with mineral fiber would result in higher performance of moisture susceptibility.

The freeze-thaw condition has little effect on the fiber-reinforced asphalt mixtures, no matter what asphalt binder and fiber content. The test results showed that the TSR increased 10.8% for fiber content from 0% to 0.9% for original asphalt mixture, while 5% SBS modified asphalt mixture increased only 9.3%. The Figure 5 showed that the TSR value increased with the increase of fiber content up to 0.5% and remained constant when the fiber content increased above 0.5% for modified asphalt mixture.



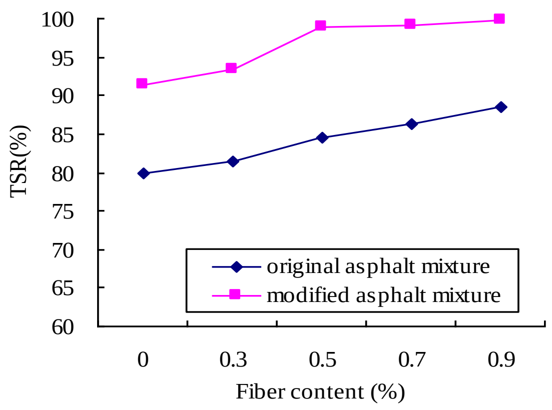


Figure 4: Tensile strength and fiber content   Figure 5: Tensile strength ratio and fiber content

4.4 Determine the Optimum Fiber Content

In this research, the laboratory performance tests including the Marshall stability, high-temperature performance (i.e., dynamic stability), and moisture susceptibility were recommended to determine the optimum fiber content. Based on the performance test results discussed previously and considering the economic factors, an optimum fiber content of 0.5 % was recommended for the alkaline mineral fiber used in this AC-16 mixture.

4.5 Performance Contrast between Fiber-reinforced and 5 % SBS Modified Asphalt Mixture

Table 4, Figure 6 showed that the asphalt mixtures, modified by 0.5 % mineral fiber or 5 % SBS modified asphalt, both exhibited some degree improvement in mechanical performance. The high-temperature rutting resistance of the modified asphalt mixtures had been improved greatly by using any of the two modified methods (i.e., improved 91.5 % and 189.8 % with 0.5 % fiber content and 5 % SBS modified asphalt in DS, separately). The moisture susceptibility improved 5.9 % and 14.3 % for mixtures with the content of 0.5 % fiber and 5 % SBS, separately. From the results in Table 4, it could be concluded that the asphalt mixture modified by 5 % SBS had higher mechanical performances that the mixture modified by 5 % mineral fiber, especially in high temperature performance. Therefore, the asphalt mixtures were ranked by the mechanical performance from high to low as follows: 5 % SBS modified asphalt + 0.5 % mineral fiber, 5 % SBS modified asphalt+ 0 % mineral fiber and original asphalt + 0.5 % mineral fiber (Figure 6). It also indicated that different grades of asphalt mixtures could be modified according to the traffic volumes of the highways to which they are applied.

Table 4: Performance contrast of the asphalt mixtures modified by different methods

Asphalt mixture		MS	Improved	DS	Improved	TSR	Improved
Asphalt	Fiber (%)	(kN)	(%)	(cycles/mm)	(%)	(%)	(%)
Original AH-90	0	8.23	0	1201	0	79.9	0
Original AH-90	0.5	9.45	14.8	2300	91.5	84.6	5.9
5%SBS modified	0	9.55	16.0	3480	189.8	91.3	14.3
5%SBS modified	0.5	10.68	29.8	4455	270.9	98.9	23.8

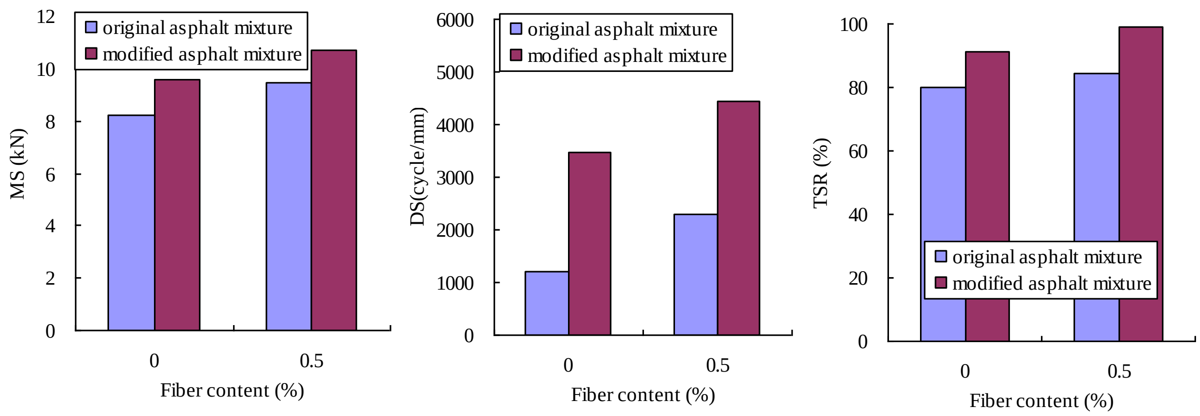


Figure 6: Performance contrast of different modified asphalt mixture

5 CONCLUSIONS

This paper mainly studied the behavior and mechanical properties of asphalt mixtures with different alkaline mineral fiber contents and two kinds of asphalt binder. On the basis of determining the optimum mineral fiber content, the mechanical properties of asphalt mixtures were measured and evaluated through laboratory tests. The following conclusions were drawn based on the test results:

- The Marshall stability increased initially and then decreased with increasing fiber content for original asphalt and modified asphalt mixtures. There existed the optimum percentage of alkaline mineral fiber content (0.5 %) for Marshall Stability.

- The mechanical property of (DS and TSR) of fiber-reinforced asphalt mixtures increased with the increase of mineral fiber contents. Fiber contents had great influence on high temperature rutting resistance, while little influence on moisture susceptibility.
- There existed the optimum alkaline mineral fiber content (0.5 %) for original and modified asphalt mixtures. Based on the performances and the economic factors, an optimum fiber content of 0.5 % was recommended for the alkaline mineral fiber used in this AC-16 mixture.
- The asphalt mixture modified by 5 % SBS had higher mechanical performances than the mixture modified by 0.5 % mineral fiber, especially for permanent deformation in high temperature. The research results would be of vital importance for material design of asphalt pavement according to traffic volume and loading distribution.

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