International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Online International Journal Available at http://www.cibtech.org/jet.htm
2013 Vol. 3 (1) January-March, pp.1-10/Thanh and Feng

Research Article

INFLUENCE OF DIFFERENT FIBERS ON HIGH TEMPERATURE AND WATER STABILITY OF STONE MATRIX ASPHALT

Dang Van Thanh[1, 2] and [*]Cheng Pei Feng[1]
[1]*Civil Engineering College, Northeast Forestry University, Haerbin, PR China*
[2]*Vietnam Forestry University, Hanoi, Vietnam*
**Author for Correspondence*

ABSTRACT

Lignin fiber, basalt mineral fiber (abbreviated as mineral fiber) and polyester fiber are being used for Stone Matrix Asphalt (SMA) pavement in China. However, there is not sufficient information available for the selection of these three fibers with regard to different applications of SMA pavement. In order to investigate the effects of these three fibers, SMA-16 is used as an example in this study using these three different fibers. Based on the Marshall test, Residential stability test, Rutting test and Freeze–thaw cycle test of the mixtures, the influences of lignin fiber, mineral fiber and polyester fiber on high temperature and water stability of an SMA mixture were investigated. The results show that the fibers significantly improved the high temperature stability and water stability of the mixture. The influence of different fibers on high temperature and water stability of the SMA mixture are not very significant. Of the three SMA mixtures, each with different fibers, SMA mixtures with mineral fibers exhibit optimal high temperature and water stability.

Key Words: *Stone Matrix Asphalt (Sma), Asphalt Mixture, Fiber, High Temperature Stability, Water Stability*

INTRODUCTION

Stone Matrix Asphalt (SMA) is a type of gap-graded hot mixture asphalt, which relies on stone-on-stone contact to resist deformation. SMA is made up of asphalt, fiber stabilizer, mineral filler, and less fine aggregate consisting of mastic asphalt binder; this mixture fills in the gaps of the coarse aggregate skeleton gradation in the formation of SMA (Chiu and Lu, 2007; Brown and Manglorkar, 1993; Ibrahim, 2006; Moghadas *et al.*, 2010). SMA has a strong permanent deformation resistance capacity, is capable of resisting deformation in high temperatures, and can also significantly improve the water stability of the mixture. It also has positive performance features such as good phydroplaning resistance, anti-aging capability, and resistance to fissure in low temperature, consequently extending the life of the pavement (Ibrahim, 2006; Moghadas, 2010; Richardson, 1997; Brown *et al.*, 1997; Bellin, 1997; Cooley and Brown, 2003; Brown *et al.*, 1997; Scherocman, 1991; Karakus, 2011; yongjie *et al.*, 2009; Allen and Graham, 2004). In recent years, the application of SMA has been steadingly increasing. The charisteristics of the composition of SMA, mix optimization, and its road performance improvements have received considerable attention from the research community (Jinan and Fupu, 2003). At present, the fibers mainly used for SMA pavement applications in China are lignin fiber, mineral fiber and polyester fiber. There has been much research on the performance these three fiber SMA mixtures (Dang *et al.*, 2011; Wang and Xuefeng, 2010; Hongbin and peng, 2010; Liang, 2009; Naisheng *et al.*, 2009; Cao, 2011; Yinghua, 2008; Wang, 2010; Hou, 2009; NAPA, 1994) but none have performed a specific comparison of the performance of these three fibers with respect to the behaviour of the SMA mixture. In order to establish a basis for when to select these three fibers, this comparison needs to be conducted. Furthermore, asphalt mixture is a composite material and thus the use of different constituent materials leads to different properties of the SMA. The specific performance requirements also vary depending on the climate conditions in different regions. For these reasons, three types of SMA, each made from one of the three different fibers, namely lignin fiber, polyester fiber and mineral fiber were prepared. SMA-16 was used as an example, based on the Marshall test, Residential stability test, rutting test and Freeze–thaw cycle test of the mixtures, and the influences of lignin fiber, mineral fiber and polyester fiber on high temperature and water stability of SMA pavement are investigated in this paper.

MATERIALS AND METHODS

Materials

The asphalt was used styrene butadiene styrene (SBS) polymer modified asphalt, made in China with a penetration of 67 (0.1 mm at 25oC, 100 g and 5s), ductility of 95.2 cm (at 5oC) and softening point of 76.5oC.

The aggregate used was crushed basalt mineral, with an apparent specific gravity of 2.84 g/cm3 and a maximum nominal size of 16 mm. Mineral filler used was limestone type, with a specific gravity of 2.78g/cm3, with 87.7% by mass smaller than 0.075 mm. The aggregate gradation and mineral filler are shown in Table 1.

Table 1: Grading of mineral aggregate (%)

Sieve size (mm)	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Crushed stone (10-20mm)	100	88.9	29.0	0.7	0.1	0					
Crushed stone (5-10mm)			100	98.8	0.2	0.1	0				
Crushed stone (3-5mm)				100	70.5	0.2	0				
Fine aggregate (< 3mm)					100	90.3	63.0	35.9	21.9	11.2	5.7
Mineral filler									100	96.6	87.7

Three types of Chinese-grown fibers are used: lignin fiber, mineral fiber and polyester fiber. Figure 1 shows photographs of these three fibers, and their relevant properties are listed in Table 2.

Lignin fiber Mineral fiber Polyester fiber

Figure 1: The photographs of the three fibers

Table 2: Properties of the three fibers

Index	Color	Length (mm)	Diamete (µm)	Density (g/m^3)	Tensile Strength (MPa)	pH Value
Lignin fiber	Gray and white	< 5	46	1.6	-	7.5±1
Mineral fiber	Gray	6	15	2.463	3000-4840	-
Polyester fiber	white	< 6	14-50	1.36	> 500	-

Test Program

First, in accordance with China's "Asphalt pavement construction specifications" (JTG F40-2004) and sieve test results, SMA-16 mineral aggregate gradation was made to conform to Chinese standard requirements for SMA-16. Based on published results shown in (Dang *et al.*, 2011; Wang and Xuefeng, 2010; Hongbin and peng, 2010; Liang, 2009; Naisheng *et al.*, 2009; Cao, 2011; Yinghua, 2008; Wang, 2010; Hou, 2009; NAPA, 1994) corresponding SMA mixtures were made from each of the three fibers, selecting three asphalt-aggregate ratios and three fiber-aggregate ratios. Then, according to Chinese regulations and norms (JTJ 052-2000) a Marshall test was conducted to determine the optimum asphalt-aggregate ratios of the three different fibers SMA-16. Finally, a Residual stability test, rutting test and Freeze–thaw cycle tests were used to study the three different fiber mixtures. The effects of the different fibers on the high temperature and water stability of the SMA were then analysed through these test results. Based on this study, a selection basis and usage of these three fibers in SMA pavement application will be proposed.

Mix Selection

In accordance with Chinese Standard (JTG F40-2004) and sieving test results, SMA-16 mineral aggregate gradation requirements and design are shown in Table 3. The mixture asphalt-aggregate ratios and fiber-aggregate ratios are presented in Table 4.

Table 3: Grading of mineral aggregate for SMA-16 (%)

Sieve Size (mm)	**19**	**16**	**13.2**	**9.5**	**4.75**	**2.36**	**1.18**	**0.6**	**0.3**	**0.15**	**0.075**
Designed	100	95.1	81.9	53.7	25.3	18.4	16.2	14.0	12.1	10.8	9.4
Requirement (JTG F40-2004)	100	90-100	65-85	45-65	20-32	15-24	14-22	12-18	10-15	9-14	8-12

Table 4: Preliminary selection of asphalt-aggregate ratio and fiber-aggregate ratio

	Lignin fiber	**Mineral fiber**	**Polyester fiber**	**Without fiber**
Asphalt-aggregate ratio (%)	6.2	6.0	6.0	5.8
Fiber-aggregate Ratio (%)	0.31	0.4	0.25	0

In Table 4, the asphalt-aggregate ratio is the percentage of asphalt to mineral aggregate (coarse aggregate, fine aggregate and mineral filler). Similarly, fiber-aggregate ratio is the percentage of fibers to mineral aggregate.

Marshall Test

For the Marshall test (JTJ 052-2000) specimens were manufactured following Marshall Standard. Four replicates of the specimens for each group (101.6 mm in diameter and 63.5 ± 1.3 mm in height) were produced with 75 blows compacting energy per side. The test measures include determining the specimen Bulk specific gravity (MD), Marshall stability (MS- Marshall stability at 60oC, 30 min water immersion) and Marshall flow value (FL) and calculating the Air void (VV), Voids in mineral aggregate (VMA) and Voids filled asphalt (VFA).

High Temperature Stability Test

A rutting test was used to evaluate the high temperature stability of the SMA. The rutting test was utilized to measure rutting resistance of the specimens. The 300mm long, 300mm wide and 50mm thick square slab specimen was immersed in a dry atmosphere at 60 ± 0.5oC for six hours. Subsequently, a wheel pressure of 0.7MPa ± 0.05MPa was applied onto the specimen. The traveling distance of the wheel was 230 ± 10mm. The traveling speed of the wheel was 42 ± 1cycles/min. The wheel was loaded to test for 60 minutes. The Dynamic stability was determined as follows (JTJ 052-2000):

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

Where DS is the Dynamic stability (cycle/mm); d60 and d45 is the rutting depth (mm) at 60 min and 45 min; 42 is the speed (cycle/min) and 15 is the time difference (min).

Water Stability Test

Residual stability test: A residual stability test was used to evaluate the water stability of the SMA. Two groups of duplicate specimens (three specimens for each group, 101.6mm in diameter and 63.5 ± 1.3mm in height) were prepared. The first group was submerged in water at 60oC for 30min, while the second group of the specimens was submerged in water at 60oC for 48h. Consequently, the residual stability (retained stability) was determined as follows [26]:

$$MS_0 = \frac{MS_1}{MS} \times 100 \tag{2}$$

Where MS1 is Marshall Stability at 60oC after 48h water immersion (KN); MS is Marshall Stability at 60oC, 30min water immersion (KN) and MS0 is residual stability at 60oC, after 48h water immersion (%). Freeze–thaw cycle test: A residual stability test method is simple to use but is not capable of reflecting the actual water damage situation of asphalt mixtures in a water damage situation. In order to evaluate water stability of the asphalt mixture from multiple perspectives, a freeze–thaw cycle test was used in this study. This test also uses two groups of Marshall standard specimens, each group consisting of four specimens. The first group was kept at room temperature. The second group was placed in a water-saturated vacuum device and maintained for 15min at a pressure of 98.3 ~ 98.7kPa (730 ~ 740mmHg) in a vacuum condition. Then, the valve was opened and the specimens were kept under water at atmospheric pressure for 30 min. After that, the specimens were taken out and put into a plastic bag with 10ml of water added. The bag was then fasten, put into a freezer with temperature at -180C, and kept for 16h. Next, these specimens were taken out of the bag and immediately placed into a 600C warm water bath for 24h. Afterwards, both of the first group and second groups were placed in 250C water bath for 2h and then brought to test. Test loading rate was 50 ± 5mm/min. The split indirect tensile strength ratio before and after freezing and thawing (abbreviated: tensile strength ratio) was calculated using Equation 3 (JTJ 052-2000).

$$TSR = \frac{R_{T2}}{R_{T1}} \times 100 \tag{3}$$

TSR is the split indirect tensile strength ratio before and after freeze–thaw (%); RT1 is the split indirect tensile strength of the fresh specimen (MPa); RT2 is the split indirect tensile strength of the frozen–thawed specimen (MPa).

RESULTS AND DISCUSSION

Test Results

Marshall Test Results

The Marshall Test results of different fiber SMA-16 are shown in Table 5 and in Figures 2 to 4.

Table 5: The Marshall test results of different fiber SMA-16.

Fiber Type	Optimum of Asphalt-Aggregate Ratio (%)	MD (g/cm^3)	MS (kN)	FL (mm)	VV (%)	VMA (%)	VFA (%)
Without fiber	5.8	2.454	7.23	3.37	4.46	17.27	74.19
Lignin fiber	6.1	2.442	10.39	3.95	4.45	18.21	74.97
Mineral fiber	5.9	2.449	9.08	3.44	4.49	17.79	74.24
Polyester fiber	6.0	2.443	8.43	4.31	4.41	17.19	74.86
Requirement (JTG F40-2004)			≥ 6	2～5	3～4.5	≥16.5	70～85

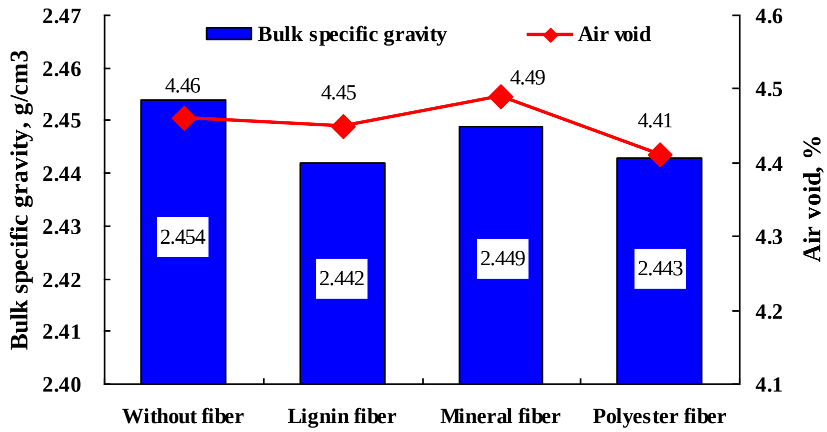

Figure 2: Comparison of bulk specific gravity and air void of mixture

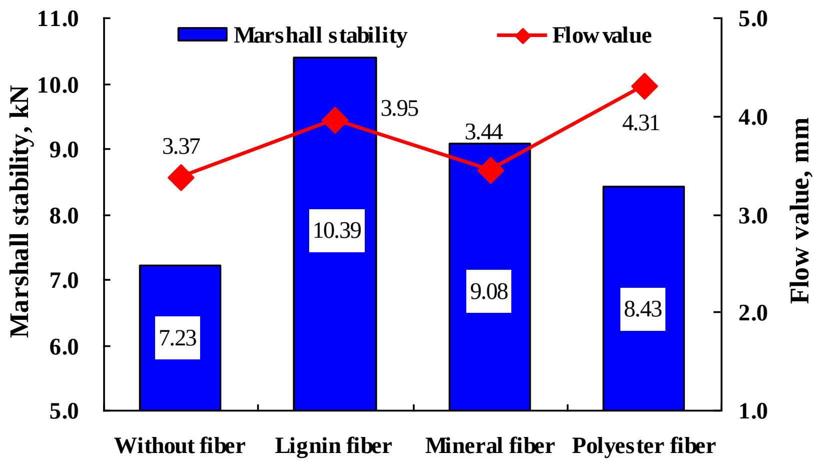

Figure 3: Comparison of Marshall Stability and flow value of mixture

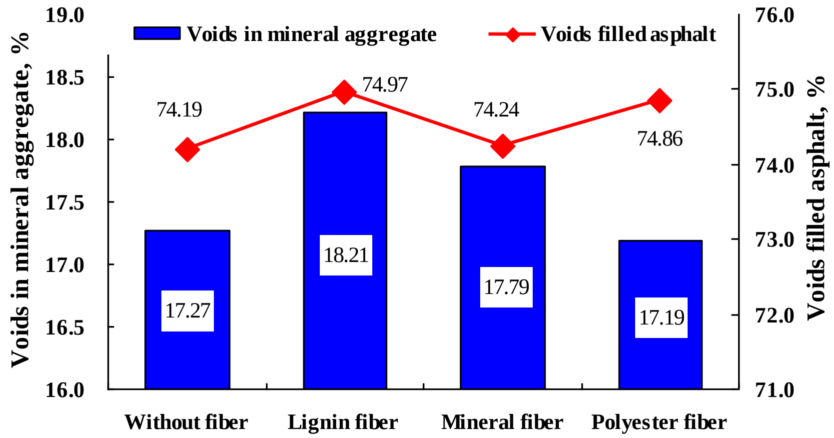

Figure 4: Comparison of voids in mineral aggregate and voids filled asphalt of mixture

High Temperature Stability Test Results
The Rutting test results of different fiber mixture are shown in Table 6 and in Figures 5.

Table 6: The Rutting test results of different fiber SMA-16

Fiber Type	d_{45} (mm)	d_{60} (mm)	DS (Cycle/Min)
Without fiber	2.931	3.121	3324
Lignin fiber	1.900	1.993	6828
Mineral fiber	1.899	1.990	6956
Polyester fiber	1.925	2.018	6858
Requirement (JTG F40-2004)			≥ 3000

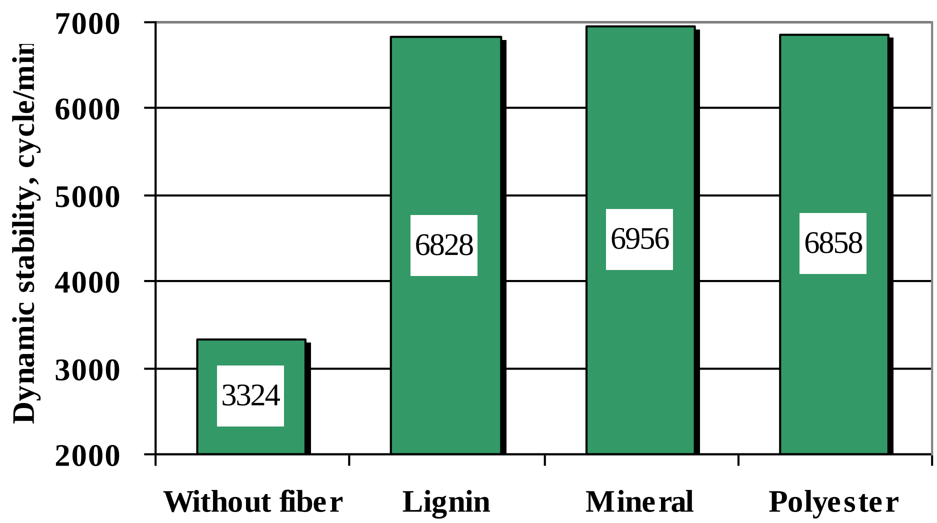

Figure 5: Comparison of dynamic stability of different fiber mixtures

Water Stability Test Results

Results of Residential stability test and Freeze–thaw cycling test are shown in Table 7 and in Figures 6 to 7.

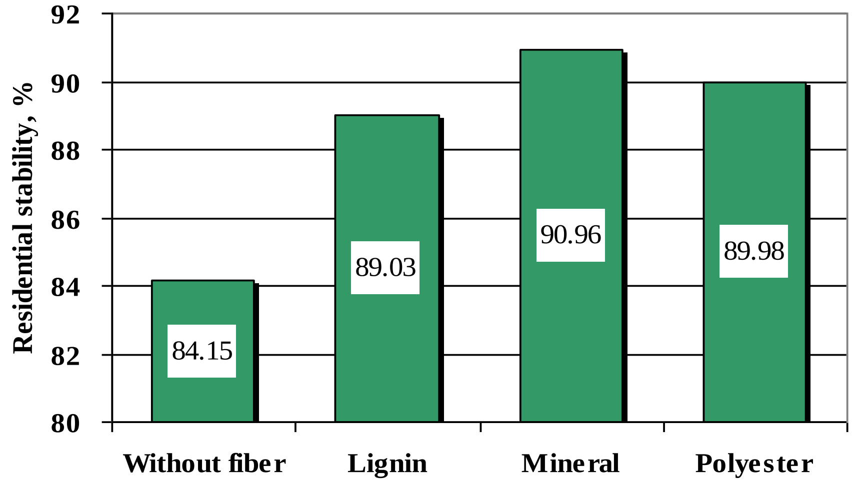

Figure 6: Comparison of residential stability of different fiber mixtures

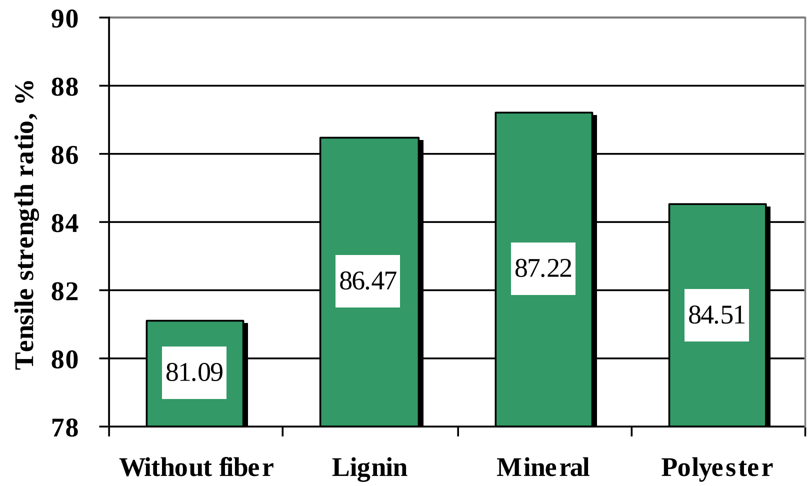

Figure 7: Comparison of tensile strength ratio of different fiber mixtures

Table 7: The water stability test results of different fiber SMA-16 mixtures

Fiber Type	R_{T1} (MPa)	R_{T2} (MPa)	TSR (%)	MS (%)	MS_1 (%)	MS_0 (%)
Without fiber	0.573	0.463	81.09	7.23	6.09	84.15
Lignin fiber	0.627	0.542	86.47	10.39	9.25	89.03
Mineral fiber	0.651	0.568	87.22	9.08	8.26	90.96
Polyester fiber	0.660	0.557	84.51	8.43	7.59	89.98
Requirement (JTG F40-2004)			≥ 80			≥ 80

Research Article

From Table 5 and Figure 2 to 4 it can be seen that when the air voids of SMA are maintained at 3 to 4.5%, the bulk specific gravity of SMA made from the three types of fiber decreases when compared to the mixture without fiber. The bulk specific gravity of lignin fiber mixture decreased most, but this decrease is less significant in a mineral fiber mixture. This is because the fibers take up some space in the mixtures; the density of the mineral fibers is high, with the mineral aggregate density not much lower. Therefore, the mineral fiber mixture density decreased less; the density of lignin fiber and polyester fiber is much smaller than the density of mineral aggregate, so it caused a greater reduction in the bulk specific gravity of the mixture. Furthermore, adding fibers into the mixture causes the optimum asphalt-aggregate ratio to increase. The optimum asphalt-aggregate ratio for the lignin fiber mixture was the highest at 6.1% and was lowest for the mineral fiber mixture at 5.9%. The main reason for this is because the fibers absorbed and assimilated asphalt, so the asphalt content of mixture increased; but the various fiber oil absorption are not the same, the oil absorption of the lignin fiber is highest, polyester fiber is second and mineral fiber is the lowest.

From the test results it can be seen that, with a variety of fibers added, all of Marshall Stability, Dynamic stability, Residual stability and Tensile strength ratio of mixture increased. Compared to a mixture without fiber, lignin fiber SMA had an increase of 43.71% in Marshall Stability, 105.42% in Dynamic stability, 5.8% in Residual stability and 6.63% in Tensile strength ratio. Mineral fiber SMA had an increase of 25.59% in Marshall Stability, 109.27% in Dynamic stability, 8.09% in Residual stability and 7.56% in Tensile strength ratio. Polyester fiber SMA had an increase of 16.6% in Marshall Stability, 106.32% in Dynamic stability, 6.93% in Residual stability and 4.22% in Tensile strength ratio.

This was mainly because, of the complex interactions between the fibers and between the fibers and the surrounding asphalt and mineral aggregate due to fiber discontinuity. These interactions can significantly impact on toughness and destructive process of the SMA. In the SMA mixture, asphalt and fiber have a good adhesion; fibers absorb and stabilize free asphalt, so the asphalt viscosity and cohesive strength increased; this leads to a reduction of the temperature sensitivity of asphalt.

The interface between the fiber and the asphalt is a thick layer, which is composed of one or a few molecular layers. Its structure and performance plays an important role in enhancing the physical and mechanical properties of the SMA. The acidic resin component of the asphalt is a surface-active substance, which soaks, absorbs and chemically bonds to the surface of fibers making single molecules of the asphalt arrange on the fiber surface and form a solid cohesive "structural asphalt" thin film. Structural asphalt is larger than the free asphalt outside the thin film, and has good heat resistance.

Meanwhile, fiber diameter is extremely small, and the fiber and asphalt structure of around it together cover the aggregate surface, so the both the asphalt film thickness and its properties are changed. Thick asphalt film slows down the aging speed of the asphalt, which can maintain its long visco-elasticity, reduce the temperature sensitivity of asphalt, improve the performance of the asphalt mixture and ultimately extend the road performance. Furthermore, short fibers in the asphalt matrix are randomly distributed in three-dimensional space, due to a very small cross-section, short fibers appear in large quantities even with a small fiber content, which can form a cross-link network within the mixture. This effect of short fibers is very effective in blocking crack propagation.

From the above analyses it can be seen that, although different fibers SMA mixture have different performance indexes, they all meet the specification requirements. The performance indicators of mineral fiber SMA are higher than those of the other two fiber mixtures except for Marshall Stability. The performance of lignin fiber SMA mixture is not much different from those of mineral fiber and polyester fiber mixtures. This shows that when correct mixture proportions are selected, high temperature and water stability of lignin fiber, mineral fiber and polyester fiber SMA are all preferable. The selection of fiber types should be in accordance with regional conditions, construction conditions, magnitude of the impact on the environment and economic comparisons. Compared with the other two fibers, high temperature and water stability of mineral fiber SMA are optimal, while lignin fiber and polyester fiber mixtures are the same.

CONCLUSION

By analyses of Marshall Test, Residual stability test, Freeze–thaw cycle test and the Rutting test results of lignin fiber, mineral fiber and polyester fiber modified asphalt SMA, the following results have been obtained:

Fibers significantly improve the high temperature and water stability of SMA. The three types of SMA mixtures used include lignin fiber, mineral fiber and polyester fiber all of which exhibit good performance of high temperature and water stability.

When the optimal mixture proportion is selected, high temperature and water stability of mineral fiber SMA are better than that of lignin fiber and polyester fiber SMA.

Apart from the requirements of SMA performance, the selection of fiber types should be based on regional conditions, construction conditions, degree of impact on the environment and economic comparison.

REFRENCES

Askeri Karakus (2011). Investigating on possible use of Diyarbakir basalt waste in Stone Mastic Asphalt. *Journal of Construction and Building Materials* 1-6.

Bellin P (1997). Development, principles and long-term performance of stone mastic asphalt in Germany. In: Symposium on stone mastic asphalt and thin surfacings. SCI Lecture Papers Series, London: *Society of Chemical Industry*.

Brown E and Manglorkar H (1993). Evaluation of laboratory properties of SMA mixtures. National asphalt paving association research and education foundation. *National Center for Asphalt Technology* 1993.

Brown ER, Rajib B Mallick, John E Haddock and John Bukowski (1997). Performance of stone matrix asphalt (SMA) mixtures in the United States. *Proceedings of the Association of Asphalt Paving Technologists* **66**.

Brown ER, Mallick RB, Haddock JE and Bukowski J (1997). Performance of stone matrix asphalt (SMA) mixtures in the United States. National Center for Asphalt Technology, NCAT Report No.97-1, Auburn University, Alabama.

Cao Rui (2011). SMA-13 asphalt mix design method. *Asphalt Technology* **3**(4) 242-244.

Chui-Te Chiu and Li-Cheng Lu (2007). A laboratory study on stone matrix asphalt using ground tire rubber. *Journal of Construction and Building Materials* **21** 1027-1033.

Cooley Jr Allen and Hurley Graham C (2004). Potential of using stone matrix asphalt (SMA) in Mississippi. USA National Center for Asphalt Technology Publication.

Cooley LA and Brown ER (2003). Potential of using stone matrix asphalt (SMA) for thin overlays. National Center for Asphalt Technology, NCAT Report No. 03-01, Auburn University, Alabama.

Dang Van Thanh, Cheng Pei Feng and Liu Hai Long (2011). Analysis of High Temperature Stability and Water Stability of SMA Mixture using Orthogonal Experiments. *International Journal of Civil and Structural Engineering* **2** 28-31.

Hongbin Lai and Peng He (2010). SMA Stone Mastic Asphalt Pavement Mixture Design. *Journal of Communications Standardization* **232** 115-117.

Hou Lin (2009). SMA Mixture Design and Applicatio. *Journal Highways and Transportation in Inner Mongolia* (224) 49-52.

Ibrahim M Asi (2006). Laboratory comparison study for the use of stone matrix asphalt in hot weather climates. *Journal of Construction and Building Materials* **20** 982-989.

Jinan Chen and Fupu Li (2003). SMA pavement design and paving. Beijing: *Chinese Communications Press*.

JTJ 052 (2000). Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering. Chinese Standard.

JTG F40 (2004). Asphalt pavement construction technology specifications. Chinese Standard.

Liang Juan (2009). SMA Asphalt Mixture Design. *Asphalt Technology* **13** 192-194.
Moghadas Nejad F, Aflaki E, Mohammadi MA (2010). Fatigue behavior of SMA and HMA mixtures. *Journal of Construction and Building Materials* **24** 1158-1165.
Naisheng Guo, Xueyuan Wang and Zhao Yinghua (2009). Granite SMA Mixture mix design. *Journal of Building Materials* **12**(2)197-200.
National Asphalt Pavement Association (1994). Guidelines for materials. Production and placement of stone matrix asphalt (SMA). *Technical Working Group (TWG)* 118.
Richardson JTG (1997). Stone mastic asphalt in the UK. Symposium on stone mastic asphalt and thin surfacing.
Scherocman JA (1991). SMA reduces rutting. *Better Roads* **61**(11).
Wang Jian Ya (2010). Study on selection of materials for SMA pavement. *Journal of Highway Construction and Maintenance* **224** 175-178.
Wang Jun and Lu Xuefeng (2010). SMA improved petroleum pavement materials test Research. *Journal of East Chinese Highway* **185**(5) 43-46.
Yinghua Zhao, Lidong Zhao, Yingfan Fan and Naisheng Guo (2008). Polyester fiber on high temperature and water stability of modified asphal mixture. *Journal of Building Materials* **5**(11) 550-554.
Yongjie Xue, Haobo Hou, Shujing Zhu and Jin Zha J (2009). Utilization of municipal solid waste incineration ash in stone mastic asphalt mixture: pavement performance and environmental impact. *Journal of Construction and Building Material* **23** 989-996.