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Effects of Fiber Type and Content on the Rutting Performance of Stone Matrix Asphalt

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Abstract: The purpose of this study is to evaluate the effect of fiber type and content on the rutting performance of stone matrix asphalt mixtures. In this research two types, cellulose fibers (made in Iran and Germany) and mineral fibers (rock wool) with various percentages (0.1-0.5%) of the total weight of the Stone Matrix Asphalt (SMA) mixture were used and after determining optimal bitumen content for each fiber percentage, we examined their effect on SMA bulk specific gravity, Void in Mineral Aggregate (VMA), void content, Marshall stability, Indirect Tensile Strength (ITS) and flow parameters. Also results of dynamic creep test were used as an indicator of rutting performance of SMA specimens. Results of the laboratory tests showed that variation of fiber type and content can lead to considerable changes in rutting performance of SMA. Specimens made with 3% cellulose-GER (made in Germany) has resulted to highest value of ITS and least permanent deformations. Also with considerations of potential rutting, optimum percentage for each fiber type has been concluded.

Key words: Cellulose fiber, mineral fiber, permanent deformation, indirect tensile strength, marshall stability

INTRODUCTION

Stone Matrix Asphalt (SMA) is hot mixture asphalt consisting of a coarse aggregate skeleton and a high binder content mortar. SMA was developed in Germany during the mid-1960s and it has been used in Europe for more than 20 years to provide better rutting resistance and to resist studied tire wear (Brown *et al.*, 1997). Because of its success in Europe, some states, through the cooperation of the Federal Highway Administration, constructed SMA pavements in the United States in 1991 (Brown *et al.*, 1997a; Schmiedlin, 1998). Since, that time the use of SMA in the US has increased significantly.

According to the SMA Technical Working Group, SMA is a gap graded aggregate-asphalt hot mixture that maximizes the asphalt cement content and coarse aggregate fraction. This provides a stable stone-on-stone skeleton that is held together by a rich mixture of asphalt cement, filler and establishing additive. SMA has also shown high resistance to plastic deformation under heavy traffic loads with high tyre pressures, as well as good low temperature properties (Brown, 1992; Brown *et al.*, 1996). A study conducted in Ontario, Canada, by the Ministry of Transportation on SMA pavement slabs trafficked with a wheel-tracking machine gave less rut depths in comparison to that occurring in a dense friction coarse (Brown *et al.*, 1997b). Coarse aggregate have the most important role in obtaining high rutting resistance of SMA and that's why regulations emphasize on type and quality of aggregate (Brown, 1992; Lynn *et al.*, 1999). Interlock between coarse aggregates, which constitute the skeleton of SMA, is an important factor of rutting performance of these mixtures. The interlock can be improved through better selection of fiber type and content, volume of bitumen or filler used and grading of aggregates. Fibers, used in SMA are divided into two major groups: mineral and organic fibers. Various fiber modifiers, such as cellulose fiber, polyester fiber and mineral fiber, have been widely used in stone matrix asphalt (Tayfur *et al.*, 2007; Sharma and Goyal, 2006). Many earlier research projects focus on the influence of fiber additives on the engineering properties of asphalt or asphalt mixture. (Chen and Kueiyi, 2005). Investigated cellulose, rock wool and polyester fiber on the engineering properties of asphalt and the test results indicated that good adhesion between fibers and bitumen enhances the load carrying ability of asphalt-fiber mastics (Shaopeng *et al.*, 2006). Using some cellulose fibers may make SMA more fatigue resistance (Muniandy and Bujang, 2006). Conducted Dynamic Shear Rheometer (DSR) test to study the rheological properties of asphalt with various fibers. Their results indicated that the rutting resistance property of asphalt with fibers could be improved to a large extent (Putman and Amirkhanian, 2004).

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SMA has less application than HMA in Iran. Mineral fibers are more used because there is not a proper cellulose fiber producer in Iran. In this study, two types, cellulose fibers (made in Iran and Germany) and mineral fibers (rock wool) with various percentages (0.1-0.5%) of the total weight of the mixture were used and after determining optimal bitumen content for each fiber percentage. Marshall Method is used in producing and designing SMA mixtures, which is the common method in Iran.

MATERIALS AND METHODS

In this study (Spring and Summer 2008), in order to examine type and percent of various fibers effect on resistance performance of SMA mixtures, specimens were made by 0.1 to 0.5% of mineral fibers and 2 types of cellulose fibers. Indirect tensile strength test was used as an indicator of strength and adherence against fatigue, temperature cracking and rutting. Also, specimens rutting were examined by dynamic creep test. Method of specimen making, used materials specification and test procedures are explained in the following.

Lime stone aggregates used in this research were chosen from Asb-cheran mine from north-east of Tehran. Results of tests conducted on this aggregate type were in acceptable limits. Table 1 shows specifications related to the aggregate used in SMA construction. To make specimens, AC 60-70 produced by Tehran refinery was used as common bitumen in Iran. Standard laboratory test results for asphalt cement are shown in Table 2.

Rock wool mineral fibers were provided from Iran Rock Wool Company, moreover two types of cellulose fibers made in Germany and Iran were used. In order to examine effect of fiber content on SMA properties, laboratory specimens with optimal binder content and various percents of these fibers (0.1 to 0.5%) were made.

Table 1: Properties of coarse and fine lime stone aggregate

Properties	Test method	Value
Coarse aggregate		
L.A. abrasion (%)	ASTM C-131	13
Soundness in $NaSO_4$ (%)	ASTM C-88	4.8
Water absorption	ASTM C-127	0.9
Flat and elongated (%)	ASTM D-4791	
3 to 1		4.8
5 to 1		0.5
Crushed content (%)		
One face		100
Two faces		100
Bulk specific gravity (g cm^{-3})	ASTM C-127	2.671
Fine aggregate		
Plasticity index		Non-plastic
Bulk specific gravity	ASTM C-128	2.669

Table 2: The result of test performed on asphalt cement (AC 60-70)

Test	Method	Unit	Value
Specific gravity (25°C)	ASTM D-70	g cm^{-3}	1.01
Flash point (Cleveland)	ASTM D-92	°C	301
Penetration (25°C)	ASTM D-5	0.1 mm	62
Ductility (25°C)	ASTM D-113	cm	100+
Heating loss (163°C)	ASTM D-1754	%	0.02
Heating loss pen/original pen		%	65
Softening point	ASTM D-36	°C	48.9
Penetration index (PI)			-1.05
Penetration viscosity No. (PVI)			-0.50

Table 3: Aggregate gradation in this study and limits

Sieve size (mm)	Passing (%)	Specification limits
12.5	95	90-100
9.5	65	50-80
4.75	28	20-35
2.36	20	16-24
0.075	10	8-12

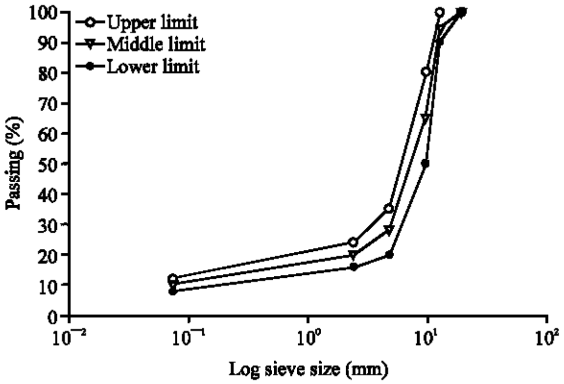

Fig. 1: Aggregate distribution

Results of Marshall stability, ITS and Dynamic creep test have been conducted to identify SMA resistance properties. Aggregate grading of SMA specimens is according to Table 3 and Fig. 1.

RESULTS AND DISCUSSION

Marshall design results: Specimens were done by Marshall Method with 5.5-7.5% of bitumen weight. in order to determine optimal bituminous percent. Six identical specimens were produced for all alternatives. Compacting energy was applied as 50 blows. The results of Marshall test are presented in Table 4 and Fig. 2. Minimum VMA of 17% and void content of 3-4% was considered to obtain optimum binder content (Brown, 1992).

According to Table 4, specimens with mineral fibers resulted to lower VMA and optimum binder content than cellulose fibers. Increase in fiber content in all cases lead to an increase in optimum binder content.

Highest optimal binder content was related to specimens made with 0.5% Iranian fibers and lowest value

Table 4: Summary of marshall design results

Type of fiber	Fiber (%)	AC (%)	G_{mb} (g cm^{-3})	Void content (%)	VMA (%)	Stability (kg)	VFA (%)
Cellulose-GER	0.1	6.0	2.348	4.3	17.1	1021	74.8
	0.2	6.3	2.357	3.7	17.1	1063	78.4
	0.3	6.8	2.366	3.5	17.3	1129	80.0
	0.4	7.0	2.361	3.1	17.6	1088	82.4
	0.5	7.2	2.349	3.0	18.2	1083	83.5
Cellulose-IRI	0.1	6.1	2.341	4.4	17.5	854	74.8
	0.2	6.4	2.347	4.1	17.6	936	76.7
	0.3	6.9	2.351	3.9	17.9	1066	78.2
	0.4	7.1	2.357	3.6	17.7	1077	79.6
	0.5	7.3	2.348	3.1	18.3	1051	83.0
Mineral	0.1	5.9	2.343	4.1	17.2	995	75.6
	0.2	6.2	2.351	3.9	17.2	1015	77.3
	0.3	6.4	2.357	3.7	17.2	1083	78.5
	0.4	6.6	2.369	3.4	17.0	1141	80.0
	0.5	6.8	2.360	3.0	17.5	1116	82.9

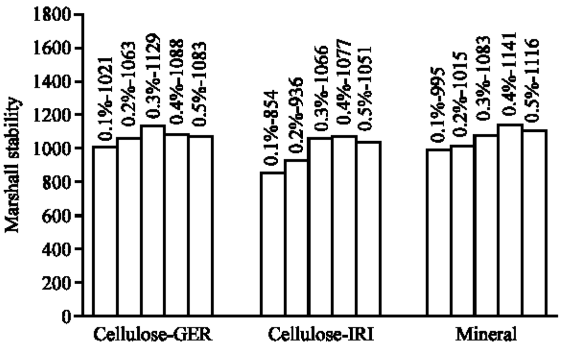

Fig. 2: Marshall stability for stone matrix asphalt mixtures

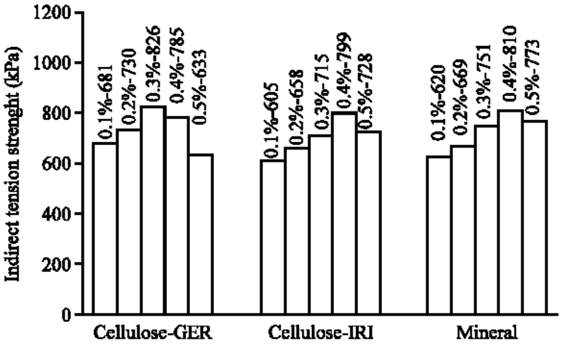

Fig. 3: Indirect tension strength of the mixtures

was from specimens with 0.1% mineral fibers. Highest Marshall stability achieved by specimens with 0.4% mineral fibers. In contrast, cellulose-IRI as an additive was found to have the lowest effect on Marshall stability of specimens. Using 0.4% of Iranian cellulose fibers caused increase of Marshall stability.

Indirect tensile strength test: The indirect tensile strength test is used to determine the tensile properties of the asphalt concrete which can be further related to the cracking properties of the pavement. Low temperature cracking, fatigue and rutting are three major distress mechanisms. Numerous researches have been conducted relating the tensile strength of asphalt mixtures to the performance of asphalt pavements (Anderson *et al*., 2001; Zhang *et al*., 2001). A higher tensile strength corresponds to a stronger low temperature cracking resistance (Huang *et al*., 2003). This test is summarized in applying compressive loads along a diametrical plane through two opposite loading strips. This type of loading produces a relatively uniform tensile stress which acts perpendicular to the applied load plane and the specimen usually fails by splitting along the loaded plane. The test is simple and Marshall Specimens may be used. This test was done according to ASTM-D6931 and indirect tensile strength values were calculated from Eq. 1.

$$S_t = 2p_{max}/\pi td \qquad (1)$$

Where:

S_t = Indirect tensile strength (Pa)
p_{max} = Total applied vertical load at failure (N)
t = Height of specimen (mm)
d = Diameter of specimen (mm)

Using proper fiber type and content has important effect on tensile strength of SMA asphalt mixture. This can enhance aggregate interlock and mortar adhesion. Variations of indirect tensile strengths of the mixtures were illustrated in Fig. 3.

The best results from ITS test were achieved by cellulose-GER specimens with 0.3% of total weight. 0.1% addition of cellulose-IRI fiber had the least effect on ITS test results between these fiber types. Variation in fiber content cause different ITS results. When cellulose-IRI or mineral fiber is added, 0.4% fiber addition results in better ITS outcome.

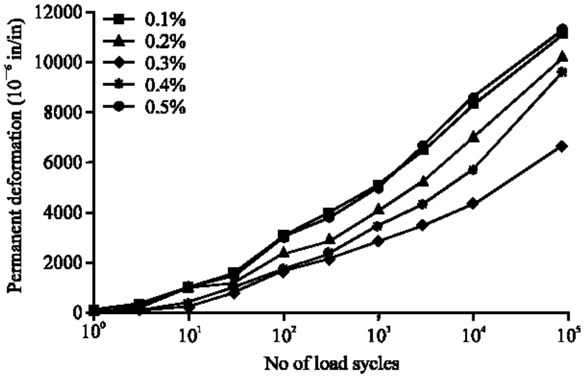

Fig. 4: Permanent deformation versus number of load cycles, cellulose-GER fibers

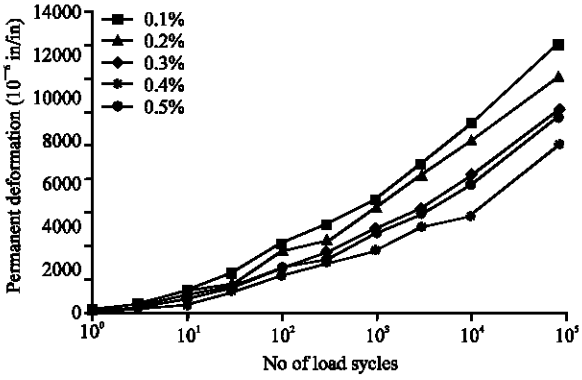

Fig. 6: Permanent deformation versus number of load cycles, mineral fibers

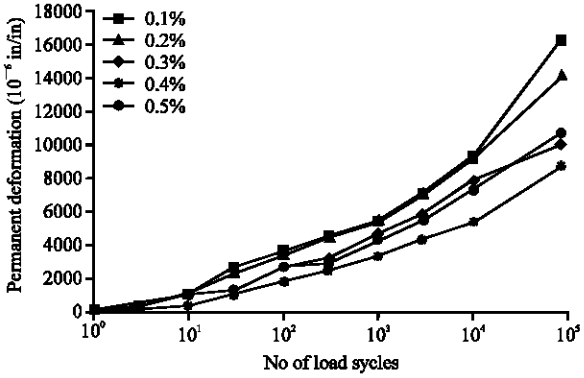

Fig. 5: Permanent deformation versus number of load cycles, cellulose-IRI fibers

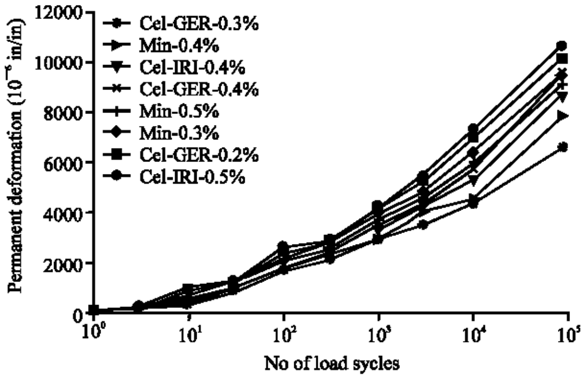

Fig. 7: Permanent deformation versus number of load cycles, best results

Dynamic creep test: There are various methods for determining asphalt mixture rutting. Using parameters like dynamic modulus, flow time resulted of static creep test, flow number resulted of dynamic creep test and cumulative strains in proportion to number of load cycles are of these methods.

Strength of the asphalt mixture up to the plastic deformation may be determined with the repeated creep test. The equipment is the same as the static creep test but repeated load are carried out differently.

Accumulated stains in asphalt mixtures can be divided to preliminary, secondary and ultimate phases. These strains show a high speedy rise in the preliminary phase and then rate of increase in deformation drops in secondary phase. In the ultimate phase, once the numbers of loading cycles have been added, permanent deformation and accumulated strains rise much speedily (Biligiri *et al*., 2007). It can be said that it yields a rutting condition.

This study tested the specimens produced with different fibers by means of Universal Testing Machine (UTM). Tests have been conducted to determine permanent deformation of SMA. Experiments were done at 45°C test temperatures during 1000 ms pulse period. 1100 N (138 kPa) average load was put into practice during the test process. Deformation values were measured by a linear variable transformer (LVDT). Tests were carried out for all mixtures at the dosage of optimal bitumen. Load and permanent deformations were recorded at 24 h.

Permanent deformations of SMA specimens at different number of cycles loads is shown in Fig. 4-6. Furthermore, in Fig. 7, some specimens with lower permanent deformations has been shown.

Permanent deformation was highly affected by variation in fiber content and type. Dynamic creep test, like ITS test, express that best results when 0.3% of cellulose-GER or 0.4% of mineral or cellulose-IRI is employed. It can be concluded that these specimens demonstrate higher rutting resistance. Specimens with lowest percentage (0.1%) of mineral fiber or cellulose-IRI lead to highest permanent deformations

CONCLUSION

- Results show that SMA specimens with mineral fibers have less optimal binder content and VMA than cellulose fibers
- SMA samples made by 0.3% cellulose-GER fibers has provided more indirect tensile strength than other samples. Also, using 0.4% of Iranian cellulose and mineral fibers significantly affects indirect tensile strength of specimens
- Marshall Test results, alone cannot be used as a proper standard for determining SMA samples rutting. Marshall Stability test demonstrated at better performance of specimens with mineral fibers, but ITS and dynamic creep test challenge this result
- Considering results of dynamic creep and ITS test, using German cellulose fibers and mineral fibers has more positive effects on SMA than all other fibers. Also, SMA samples made by 0.4% of Iranian cellulose fibers had proper tensile strength and rutting
- Optimal fiber content can differ considering fibers type and quality. In order to determine optimum fiber content in each specific case, it's necessary to organize related test. In this study, optimum fiber content for cellulose-GER was found to be 0.3% and mineral or cellulose-IRI was 0.4% of total weight of the mixture

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