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LABORATORY INVESTIGATION OF THE PROPERTIES OF STONE MATRIX ASPHALT MIXTURES MODIFIED WITH RGP–SBS

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The objective of this study is to evaluate the advantages of adding recycled glass powder (RGP) and styrene butadiene styrene (SBS) polymer to the base bitumen with the penetration grade of 60/70 and to modify stone matrix asphalt (SMA) in flexible pavement. Initial studies were conducted for determining the physical properties of bitumen and modifiers. Seven different combinations were provided by mixing different amounts of SBS and RGP with base bitumen. Then, asphalt mixture performance tests including Marshall Stability, indirect tensile strength and resilient modulus were performed on the modified and control asphalt samples. The results of the evaluation showed that SMA mixtures modified by 3.5% RGP and 1.5% SBS presented the best results in the experiments conducted in this research and also considerably increased mechanical and physical properties of asphalt and bitumen.

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1. Introduction

Traditional bitumen materials have been successfully used in most of highways and airports for years. In recent years, increase in the traffic loads in terms of number and weight of heavier trucks and vehicles with higher tire pressure have increased damage to pavements. To construct more stable pavements, materials with better properties are required. Polymer modification is one of the ways for overcoming the weakness of bitumen and, as a result, improving the performance of asphalt mixtures. Different polymer materials like polyethylene, ethylene vinyl acetate (EVA), polypropylene, etc. have been evaluated as modifiers in order to improve bitumen performance [1]. SBS is in the group of elastomers, which improves the elastic properties of bitumen and is probably the best polymer for modifying bitumen. Although bitumen flexibility increases in low temperatures, some researchers have referred to the decrease of resistance and endurance against penetration at higher temperatures [2].

Additionally, it seems that modifying asphalt mixtures by polymers has the maximum potential for the successful application in designing flexible pavements. These advantages include increasing the pavement's useful lifetime or decreasing the thickness of base or asphalt concrete layer [3, 4].

Awanti et al. (2008) found that (a) the Marshall flow and stability values of polymer asphalt were more than those of the traditional asphalt, (b) indirect tensile strength of polymer asphalt was more than that of traditional asphalt at different temperatures and (c) the sensitivity of polymer asphalt against moisture is lower than that of traditional asphalt [5].

Xiao et al. (2007) found that modifying bitumen by SBS led to the resistance improvement against initial cracking although it does not affect the aging of asphalt mixture [6].

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Nowadays, environmental issues and material recycling considerations have become part of daily life. Therefore, using useless broken glass is an appropriate option for improving asphalt performance. Although improvement in asphalt performance has been obtained by polymer modification, studies with regard to decreasing SMA problems using SBS and RGP seem to be attractive. The authors of this research have not observed any information regard to the effect of simultaneous combination of SBS and RGP on SMA properties.

1-1 Objectives

The objectives of this research include:

1. Determining and comparing the physical properties of unmodified and modified bitumen,
2. Determining the compatibility of base bitumen with SBS and RGP,
3. Determining Marshall characteristics of modified and unmodified SMA mixtures,
4. Determining indirect tensile strength of modified and unmodified SMA mixtures,
5. Evaluating and comparing sensitivity of modified and unmodified SMA mixtures against moisture,
6. Determining compression strength of modified and unmodified SMA mixtures, and
7. Determining resilient modulus of modified and unmodified SMA mixtures.

Laboratory studies were conducted on the bitumen modified by SBS and RGP in order to evaluate engineering properties like penetration, softening point, flash point, ductility, specific gravity and percentage of loss on heating. Performance tests such as Marshall strength, indirect tensile strength, tensile strength ratio, compression strength and resilient modulus were done to examine engineering properties of SMA mixtures modified by SBS and RGP and control mixtures.

SBS polymer was selected for this research for the following reasons: this polymer was appropriate for the climate of Iran; only a small percentage of it was required for bitumen modification (about 5 to 6 percent by weight) and it had medium costs. According to the studies conducted by Awanti et al. (2008), 5% SBS was used for the combination with base bitumen [5].

2. The Experimental Program

For investigating the properties of SMA modified by SBS and RGP, an extensive experimental study was conducted. Fig. 1 demonstrates the experimental design of this study. In the present study, a total of seven modified binders were evaluated by a randomized complete block experimental design. A total of 192 Marshall Specimens (50 blows/side) were constructed and tested. All the replicates were randomly applied in order to ensure the fairness of testing.

2.1. Material Properties

The used aggregate was river-type granular soil excavated from a huge mine located in EkhtiarAbbad Kerman site, south-east of Iran. In 1994, the SMA Technical Working Group (TWG) of Federal Highway Administration (FHWA) developed Model Material and Construction Guidelines for SMA [7]. The specifications of the guideline recommended a maximum L.A. Abrasion loss of 30 percent. A single gradation was also specified which corresponded with the European 16 mm SMA with 100 percent passing the 19.0 mm sieve and 85 to 95 percent passing the 12.5 mm sieve (Fig. 2). The value of the sand equivalent of the tested soil was determined according to ASTM D 2419 - 02 [8] which was76%. ASTM Test Method for Specific Gravity of Soils (D 854 - 02) was used to find the specific gravity of the tested soil which was 2.827 at the temperature of 20°C [9]. The values of water absorption ratio, abrasion loss and frost action of the tested soil were determined according to ASTM C-127, ASTM DC-131 and ASTM C-88 which were 1.7%, 14.2% and 0.72%, respectively. The above-mentioned information is summarized in Table (1). The applied filler was calcium carbonate ($CaCO_3$) which came from an asphalt plant. Calcium carbonate was constructed for passing through an ASTM #200 sieve and had a specific gravity of 2.724.

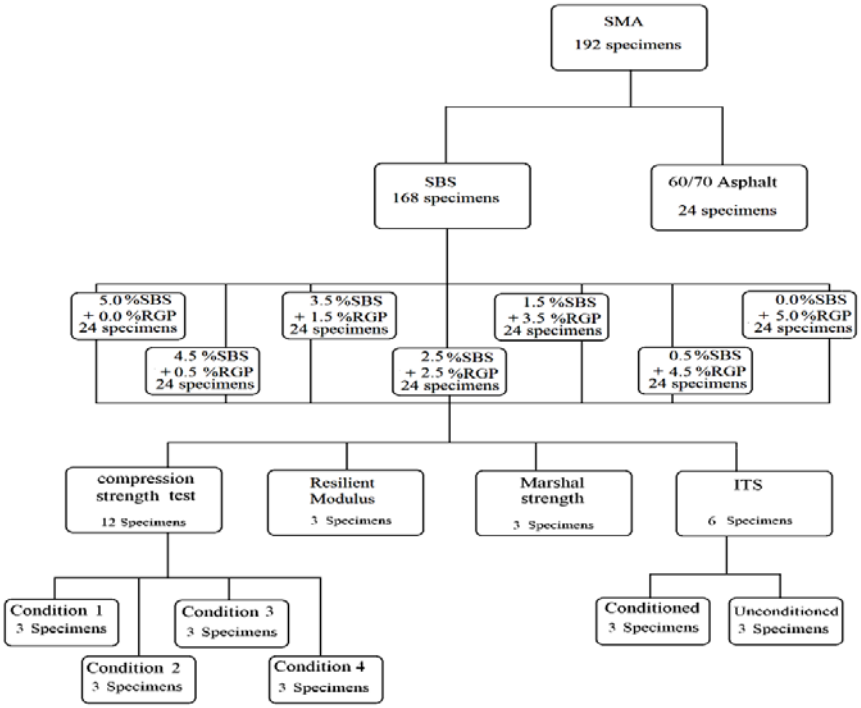

Fig. 1 Flowchart of experimental design.

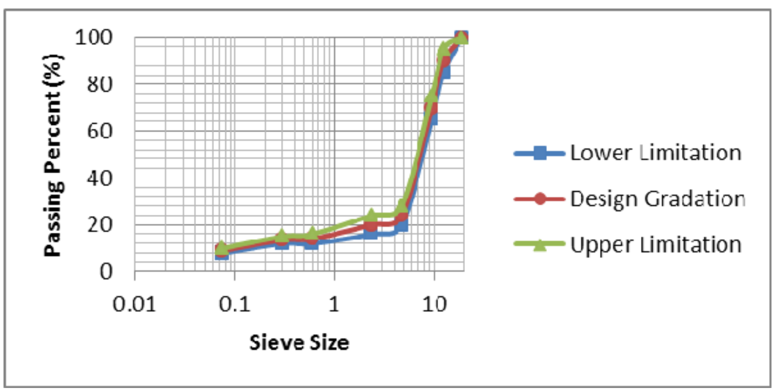

Fig. 2. Envelope of SMA gradation and design gradation.

Table 1. The tested aggregate properties.

Sand Equivalent (%)	Specific Gravity	Water absorption ratio (%)	Abrasion loss (%)	Frost action (%)
76	2.827	1.7	14.2	0.72

In this research, a kind of asphalt binder with the normal paving of 60/70-penetration grade was used for producing all test specimens which was taken from the Isfahan Mineral Oil Refinery. This used asphalt binder properties are summarized in Table (2).

Table (2): The used bitumen properties.

Property	Test method	Quantity
Penetration at 25 ^oC, 100g, 5 s (deci-millimetre, d-mm)	ASTM D-5	65
Softening Point, ring and ball (^oC)	ASTM D36	50
Flash Point, Cleveland open cup (^oC)	ASTM D-92	292
Ductility at 25 ^oC at 5 cm/min (cm)	ASTM D-113	165.4
Specific gravity at 25 ^oC (gr/cm^3)	ASTM D-70	1.017
Loss on heating, wt (%)	ASTM D-6	0.05

The recycled glass was crushed and groundusing a jaw crusher and a ball mill, respectively, for 10 min in order to obtain RGP, which was made for passing through an ASTM #200 sieve and had the specific gravity of 2.47. The RGP particle size distribution was determined by a laser particle analyzer and is given in Table (3).

Table (3) Particle size distribution of RGP.

Size, nm	Percent Passing
4587	100
3961	99.6
3420	88
2953	52.4
2550	14.3
2202	0.6
1901	0

The microscopic morphology of the recycled glass powder is shown in Fig. 3 as was measured by Scanning Electron Microscopy (SEM).SEM examinations indicated that the glass powders mainly consisted of coarse and angular flaky particles with a broad range of particle size. Moreover, to verify the absorption degree of RGP, the specific surface area test was conducted. According to ASTM C204, the specific surface area of the recycled glass powder was 467 m^2/kg. Therefore, the recycle glass powder had high absorption.

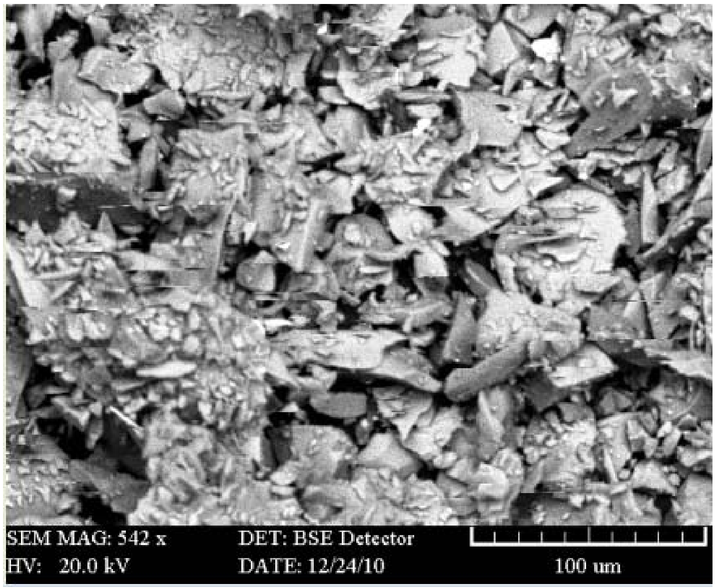

Fig. 3. SEM morphology of RGP

2.2. Preparation Procedure of the Specimen

While modifying the base binder, different percentage of solid-formed SBS and RGP was mixed at 170°C using a high-speed stirrer which rotated at 3,000 rpm. Blending was done for 2 h in order to obtain a homogeneous binder [10, 11].

2.3. Test Procedure

Compatibility of the SBS-RGP Binder

The compatibility of SBS, RGP and asphalt was investigated through the following techniques:

• The dispersion uniformity of SBS and RGP was confirmed by having the binder pass through an ASTM #100 sieve at 170°C. The prepared binder could be stored for the future usage [12].

• The storage stability (separation tendency) of SBS-RGP modified binders was measured in the following way [13]: the sample was put into an aluminum foil tube which was 32 mm in diameter and 160 mm in height. The tube was sealed without an air enclosure and was vertically stored in an oven at 163°C. After 48 h, the tube containing the modified asphalt was cooled down to the ambient temperature and horizontally cut to three equal parts. The upper and lower parts were then melted and stored separately in small cans labeled T and B, respectively, and the softening points of T and B were determined. The sample could be assumed to have good storage stability, when the difference of the softening points between T and B is less than 2.5°C [10, 14].

Marshall Properties

For preparing the mix design, the mix design procedure for SMA was followed which was as proposed in the National Cooperative Highway Research Program (NCHRP) Rep. No. 425 [15]. Locally available materials with normal SMA specifications were used for producing the reference mix which including the 60/70 penetration grade asphalt without any mineral fibers. Laboratory specimens were prepared using 50 blows of the Marshall hammer per side. The optimum asphalt content for SMA mixtures is usually selected for producing 4% air voids and less than 0.3% drain down.

In the present study, all SMA samples were compacted using 50 blows of the Marshall hammer per side. The optimum asphalt content for the control mixture was 6.11% at 4% air voids which was used in preparing SBS-RGP-modified SMA mixtures for maintaining consistency throughout the study. Three identical samples were constructed for each mixture.

Tensile Strength Testing

Tensile strength testing is used for evaluating the asphalt mixture's fatigue potential and moisture susceptibility. Previous studied have indicated that the tensile strength of hot-mix asphalt is related to fatigue cracking [16]. Higher tensile strength means that asphalt pavement can tolerate higher strains before failing (i.e., cracking). Furthermore, the moisture susceptibility of the asphalt mixture could be evaluated by comparing the tensile strength of asphalt mixtures in wet and dry conditions [17]. In this study, the tensile strength of all samples was tested according to AASHTO T283. The indirect tensile strength was done at 25°C with 50.8 mm/min deformationrate and a Universal Testing Machine (UTM Zwick 1498) was also applied. The indirect tensile strength was determined using the following equation: $ITS = (2P_{max})/(\pi dh)$ where P_{max} represents the breaking load (N) of the specimens under diametral compression and d and h are average values of the diameter (mm) and height (m) of the Marshall specimens, respectively.

Water sensitivity of mixture can be evaluated using the value of tensile strength ratio (TSR) in the following way: $TSR = ITS_1/ITS_2$ where ITS_1 is the average indirect tensile strength of the conditioned specimen, MPa and ITS_2 is the average indirect tensile strength of unconditioned specimen, MPa.

Toughness Index (TI) as a parameter which describes the toughening characteristics in the post-peak region was also calculated according to the IDT test results [18]. The normalized stress and strain were achieved through dividing their values by the maximum stress and strain values. A dimensionless TI was calculated as shown below:

$$TI = \frac{A_\varepsilon - A_p}{\varepsilon - \varepsilon_p} \quad (1)$$

Where TI is the toughness index, A_ε is the area under the normalized stress–strain curve up to strain A_p, A_p is the area under the normalized stress–strain curve from ε_p to ε, ε is the strain at the point of interest and ε_p is the strain corresponding to the peak stress. TI is used for comparing the performance of a specimen with that of an elastic, perfectly plastic reference material for which the TI remains a constant of 1 [18]. In the case of an ideal brittle material with no post-peak load carrying capacity, the value of TI equals zero. Here, TIs were calculated up to the tensile strain of 0.01 plus the strain at failure.

Compression Strength Test

A Zwick 1498 universal testing machine was used for performing the compression strength test. In order to accurately apply the axial compressive loading on the specimen, two-end surfaces must be kept parallel through very smooth cutting. The compression strength test was done under a load controlled mode which had the loading rate of 10 KN/min and the maximum load was recorded during the test. Ninety-six Marshall specimens were used in this test, which were set into four groups. The first group was cured in air at room temperature for 24 h; the second group was cured in a 25°C water bath for 24 h; the third group was subjected to 25 cycles of freezing and thawing and were put in plastic freezing bags and about 10 ml of water was added to each bag. They were kept in a freezer at -20°C for 4 h followed by 4 h of thawing at 25°C. The fourth group was cured in an oven at 50°C for 4 h. The first three groups were subjected to the compression strength test at 25°C and the fourth group was tested at 50°C.

The results of all the compression strength tests were used for obtaining the coefficients mentioned below [1].

The following equation was applied in order to compute K_h

$$K_h = R_{25}/R_{50} \quad (2)$$

K_h is coefficient of heat resistance, R_{25} is compression strength (MPa) at 25°C and R_{50} is compression strength (MPa) at 50°C.

The following equation was used for calculating K_f

$$K_f = R_f/R_w \quad (3)$$

K_f is coefficient of frost resistance, R_f is compression strength after 25 cycles of freeze-thaw (MPa) and R_w is compression strength of water absorbed specimen (MPa).
K_w was computed using the following equation:

$$K_w = R_w/R_{25} \quad (4)$$

K_w is the coefficient of water resistance.

Resilient Modulus

The resilient modulus (MR) shows the ratio of an applied stress to the recoverable strain which takes place after removing the applied stress. Here, it was determined from doing tests on cylindrical specimens for each mixture at the designed asphalt contents in an indirect tension mode. Approximately 15% of the indirect tensile strength of each mixture was applied on the vertical diameter for the conventional and SBS-RGP modified specimens. The frequency of load application was 1 Hz with the load duration of 0.1 s in order to represent field conditions and the resting period of 0.9 s.

The tests were conducted at 25°C which was according to ASTM D4123. Using an environmental air chamber, the test temperature was maintained. Each specimen was placed inside the chamber at the set temperature for 3 h before testing. Three samples were made for each of the eight kinds of evaluated mixtures and their averages represented MR for each mixture.

3. Test Results and Discussion

Compatibility of the SBS-RGP Binder

Table 4 compares the difference of the top and bottom sections of the SBS-RGP modified binders. The maximum difference was 1.4 in softening points for SBS-RGP modified binders, which indicated that the storage stability of SBS-RGP modified binders was effectively improved.

Table (4) Basic properties of SBS-RGP modified asphalt binders

Property	5%SBS +0%RGP	4.5%SBS +0.5%RGP	3.5%SBS +1.5%RGP	2.5%SBS +2.5%RGP	1.5%SBS +3.5%RGP	0.5%SBS +4.5%RGP	0%SBS +5%RGP
Penetration, (d-mm)	42	41	41	40	40	40	39
Flash Point,(^{o}C)	256	260	260	262	268	270	283
Ductility (cm)	102	105	109	122	115	109	103
Specific gravity	0.963	1.003	1.042	1.085	1.124	1.169	1.208
Loss on heating, wt (%)	.47	.43	.39	.38	.33	.28	.24
Storage Stability							
Top ring and ball, (^{o}C)	62.6	62.8	62.9	63.1	63.4	63.5	63.8
Bottom ring and ball, (^{o}C)	61.8	61.9	61.9	62.0	62.2	62.2	62.2
Difference	0.8	0.9	1.0	1.1	1.2	1.3	1.6
Penetration Index (PI)	1.02	1.00	1.01	.98	1.02	1.03	1.00

The basic properties of the SBS-RGP modified asphalt binder were evaluated and the results are presented in Table 4. The results demonstrate that SBS-RGP is effective for improving the basic properties of asphalt cement. Table 4 shows that the softening point of SBS-RGP modified asphalt binder is higher than that of asphalt cement whereas the least increase is 26.9% for 5%SBS and the most increase is 30.6% for 5%RGP. Moreover, penetration and percent loss of heat and air (aging) of the SBS-RGP modified asphalt binder is lower than those of asphalt cement whereas, in penetration, the least reduction is 36.4% for 5%SBS and the most reduction is 40.9% for 5%RGP. In aging, the least reduction is 50.0% for 5%SBS and the most reduction is 75.5% for 5%RGP.

The temperature susceptibility of asphalt binders is quantified using the penetration index (PI). The maximum calculated values of PI are 1.03 and -0.87 for SBS-RGP modified asphalts and asphalt cement, respectively. Higher value of PI indicates lower temperature susceptibility of the binder. Thus, the temperature susceptibility of the SBS-RGP modified asphalts is lower than that of the asphalt cement.

Marshall Properties

Results of the Marshall test are summarized in Table 5. SBS and RGP addition raised the Marshall quotient (MQ) and stability of the control mixture by 78.95 and 80.15%, respectively, whereas irregularity in flow value was observed by adding this modifier. Higher stability may be caused by higher viscosity of the SBS-RGP modified asphalt binder compared with asphalt cement.

Table (5) Marshall Test Results of Control and SBS-RGP Asphalt Mixtures

Sample No.	Mixture type	BSG	VTM(%)	VMA(%)	VFB(%)	Stability (kN)	Flow (mm)	MQ (kN/mm)	Drain down(%)
1	60/70 binder	2347	4.33	14.92	70.11	6.822	4	1.71	0.287
2	5%SBS +0%RGP	2341	4.24	14.97	71.68	11.58	5.3	2.18	0.272
3	4.5%SBS +0.5%RGP	2340	4.09	14.84	72.45	10.61	4.9	2.17	0.269
4	3.5%SBS +1.5%RGP	2332	3.65	14.97	75.62	10.716	5.7	1.88	0.269
5	2.5%SBS +2.5%RGP	2312	4.09	15.54	73.67	12.29	5.5	2.23	0.267
6	1.5%SBS +3.5%RGP	2326	3.85	14.74	73.88	10.098	3.3	3.06	0.265
7	0.5%SBS +4.5%RGP	2323	3.64	14.68	75.21	9.946	4.3	2.31	0.264
8	0%SBS +5%RGP	2280	3.96	15.93	75.15	8.982	3.7	2.43	0.261

Note: BSG = bulk specific gravity; VTM = volume of total mix; VMA= volume of voids in mineral aggregates; VFB= volume filled with binder.

Tensile Strength Testing

The tensile strengths of control and SBS-RGP asphalt mixtures are given in Fig. 4. It can be seen that the indirect tensile strength was improved by adding SBS and RGP to the base bitumen and the 1.5% SBS plus 3.5% RGP mix achieved the highest value.

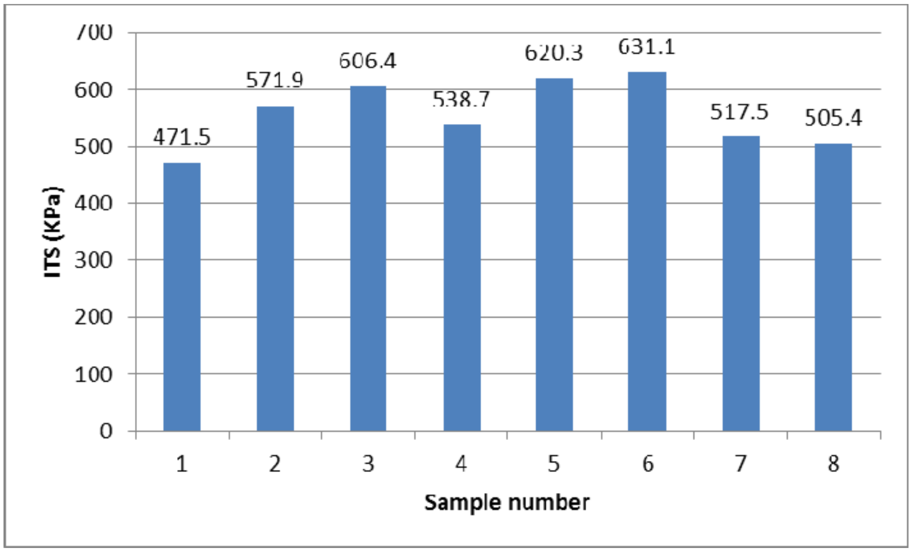

Fig. 4. Indirect tensile strength of unmodified and modified mixtures

Fig. 5 summarizes the result of the tensile strength ratio (TSR) for the samples conditioned with water.It is observed in this figure that the modified samples have higher TSR values compared with the unmodified control mixture. Overall, it can be concluded that adding RGP and SBS reduces a mixture's moisture susceptibility in most cases.

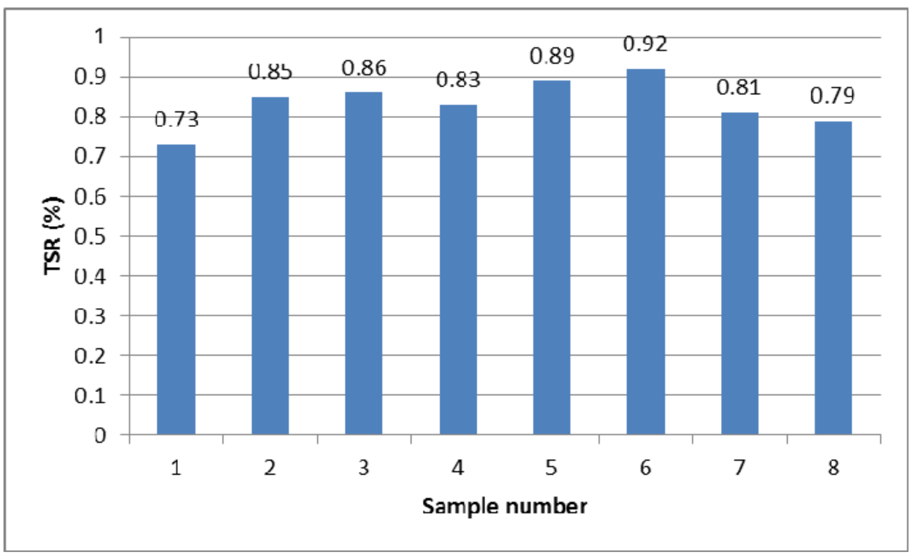

Fig. 5. Comparison of tensile strength ratio for unmodified and modified mixtures

Most pavement agencies suggest that the TSR value should be greater than 70–80% in their mix design specifications [19]. As shown in Fig. 5, the average TSR value of the SBS-RGP modified mixtures (85%) is by about 16% greater than that of the conventional mixture (73%).
As can be seen in Fig. 6, the toughness index increased for four modified mixtures. Thus, the mixtures' strength and their resistance to the fatigue cracking which is associated with the brittleness increased by adding SBS and RGP to the base bitumen.

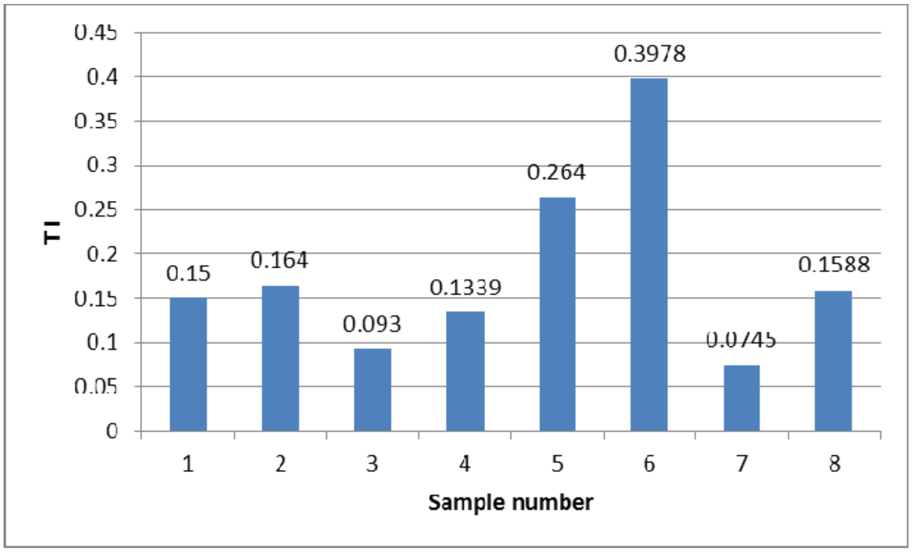

Fig. 6 Toughness index (TI) of unmodified and SBS-RGP modified mixtures

Compression Strength Test

According to Table 6, modified mixtures have satisfactory results of compression strength and higher coefficient of water, heat and frost resistance than the control mixture. In addition, the mixture modified by 2.5% RGP + 2.5% SBS outperforms all other modifiers.

Table (6) Compression strength test results

	60/70 Binder	5%SBS +0%RGP	4.5%SBS +0.5%RGP	3.5%SBS +1.5%RGP	2.5%SBS +2.5%RGP	1.5%SBS +3.5%RGP	0.5%SBS +4.5%RGP	0%SBS +5%RGP
R_{50} (Mpa)	1.63	1.69	1.80	1.91	1.96	1.94	1.88	1.71
R_f (Mpa)	1.72	2.21	2.45	2.87	3.12	2.97	2.65	2.05
R_{25} (Mpa)	2.21	2.54	2.77	3.15	3.35	3.29	3.03	2.42
R_w (Mpa)	1.98	2.35	2.58	2.96	3.18	3.09	2.81	2.20
K_w	0.90	0.93	0.93	0.94	0.95	0.94	0.93	0.91
K_h	1.36	1.50	1.54	1.65	1.71	1.69	1.61	1.41
K_f	0.87	0.94	0.95	0.97	0.98	0.96	0.94	0.93

Resilient Modulus

Fig. 7 presents the MR test results. This figure demonstrates that the MR values for the control and SBS-RGP modified asphalt concrete samples were between 1535 and 3493KPa. The percentage increase in the average MR was comparatively significant.

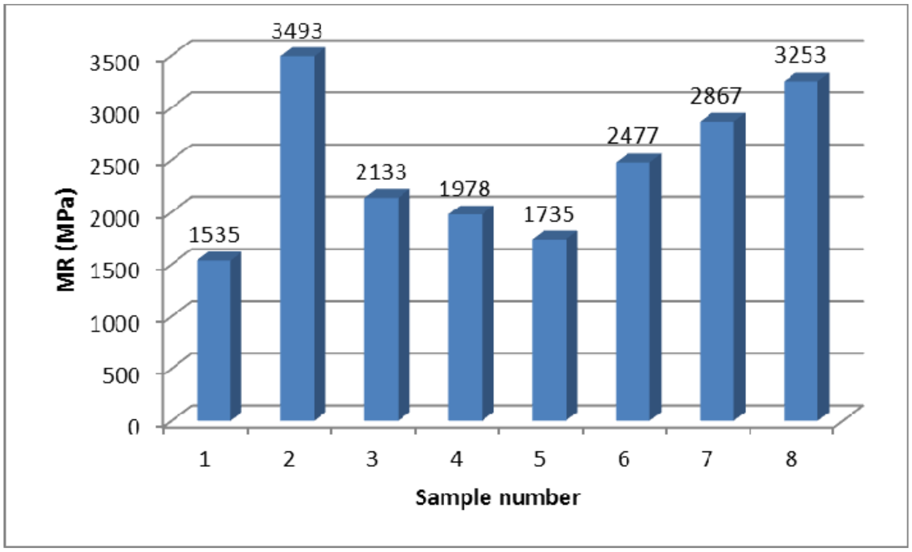

Fig. 7. Resilient modulus of unmodified and modified mixtures

For comparing the workability obtained from different tests, the data from Marshall stability, indirect tensile strength, tensile strength ratio, toughness index, compression strength and resilient modulus for unmodified and SBS-RGP modified mixtures, respectively, were ranked, as summarized in Tables 7. The test results did not clearly indicate better asphalt type because rankings may change from one test to another. The K_w and K_f results showed no large difference between mixture types. However, more testing is needed before a definite conclusion can be taken.

Table (7) Workability ranking of unmodified and SBS-RGP modified mixtures

Tests	60/70 Binder	5%SBS +0%RGP	4.5%SBS +0.5%RGP	3.5%SBS +1.5%RGP	2.5%SBS +2.5%RGP	1.5%SBS +3.5%RGP	0.5%SBS +4.5%RGP	0%SBS +5%RGP
MQ	8	5	5	7	4	1	3	2
ITS	8	4	3	5	2	1	6	7
TSR	8	4	3	5	2	1	6	7
TI	5	3	7	6	2	1	8	3
K_w	8	4	4	2	1	2	4	7
K_h	8	6	5	3	1	2	4	7
K_f	8	5	4	2	1	3	5	7
MR	8	1	5	6	7	4	3	2

In comparison with other test types, a completely different picture was demonstrated by TI results. According to the ranking, the SMA modified by the 1.5% SBS plus 3.5% RGP performed best while the base SMA ranked the last. This is in agreement with the binder tests. Overall, test results exhibited that the modified binders increased the resistance of the SMA. However, a specific combination of SBS and RGP which was better than others could not be clearly identified.

5. Conclusions

In the present paper, a series of tests was conducted using SBS-RGP modified SMA mixtures. According to the tested mixtures, the following cases can be concluded:

1. The binder test results exhibited higher softening point, less temperature susceptibility, less percentage loss in weight and susceptibility to aging and satisfactory compatibility of SBS-RGP with the base asphalt cement.

2. The mixture test results demonstrated up to 79% higher stability, 34% higher tensile strength in the temperature range of 25°C, up to 26% lower moisture susceptibility, 167% higher toughness index, higher compression strength in different conditions and 127% increase in resilient modulus values at 25°C.

3. In sum, test results showed that the modified binders increased SMA resistance and workability.

4. According to the ranking, the SMA modified by 1.5% SBS plus 3.5% RGP performed best while the base SMA ranked the last.

5. The TI results showed a completely different picture compared with other test types.

6. K_w and K_f results demonstrated no high difference between mixture types.

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References

[1] Ahmedzade P., Tigdemir M., Kalyoncuoglu S.F. Laboratory investigation of the properties of asphalt concrete mixtures modified with TOP–SBS. Construction and Building Materials **21**, 626 (2007).
[2] Gorkem, C., andSengoz, B. "Predicting stripping and moisture induced damage of asphalt concrete prepared with polymer modified bitumen and hydrated lime." Constr. Build. Mater., **23**, 2227 (2009).
[3] Al-Hadidy, A. I., and Tan, Y.."Effect of polyethylene on life of flexible pavements." Constr. Build. Mater., **23**, 1456 (2009a)
[4] Al-Hadidy, A. I., and Tan, Y.. "Mechanistic approach for polypropylene modified flexible pavements." Mater.Des., **30**, 1133 (2009b)
[5] Awanti, S. S., Amarnath, M. S., and Veeraragavan, A.. "Laboratory evaluation of SBS modified bituminous paving mix." J. Mater. Civ. Eng., **20**(4), 327 (2008)
[6] Xiao, F., Amirkhanian, S., and Juang C.H. J. Mater. Civ. Eng., **19**(6), 475 (2007).
[7] Model Material and Construction Guidelines, SMA Technical Working Group, (TWG), FHWA, 1994.
[8] ASTM.(2002). "Standard test methods for sand equivalent value of soils and fine aggregate." D2419.
[9] ASTM.(2002). "Standard test methods for specific gravity of soil solids by water pycnometer."D 854.
[10] Wen, G., Zhang, Y., Zhang, Y., Sun, K., Fan, Y. Polym. Test., **21**, 295 (2001).
[11] Jin, H., Gao, G., Zhang, Y., Zhang, Y., Sun, K., and Fan, Y. Polym. Test., **21**, 633 (2002).
[12] Punith, V. S., Veeraragavan, A. J. Mater. Civ. Eng., **19**(6), 500 (2007).
[13] ASTM. (2005). "Standard practice for determining the separation tendency of polymer from polymer modified asphalt." D7173, West Conshohocken, PA.
[14] Ouyang, C., Wang, S., Zhang, Y., and Zhang, Y. Polym.Degrad. Stab., **87**, 309 (2005).
[15] Brown, E. R., and Cooley, L. A. (1999). "Designing stone matrix asphalt mixtures for rut-resistance pavement." NCHRP Rep. No. 425, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC.
[16] Goh S W, Akin M, You Z, Shi X. Construction and Building Materials **25,** 195 (2011).
[17] Akisetty C, Xiao F, Gandhi T, Amirkhanian S. Construction and Building Materials **25,** 950 (2011).
[18] Huang B., Dong Q., Burdette E.G. Construction and Building Materials **23,** 3451 (2009).
[19] Lee H J, Lee J H, Park H M. Construction and Building Materials **21**, 1079 (2007).