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EVALUATING OF SBS POLYMER-MODIFIED BITUMEN EMULSION ON RECYCLED ASPHALT MIXTURE

Parham Hayati[1], Hasan Ziari[2], Sajad Rezaei[3]

[1] *Department of Civil Engineering, Islamic Azad University, Science and Research Branch, Tehran*
[2] *College of Civil Engineering, Iran University of Science & Technology, Tehran, Iran*
[3] *Department of Civil Engineering, Pooyesh Institute of Higher Education, Qom, Iran*

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Abstract

In the base of researches Styrene Butadiene Styrene (SBS) copolymer is one of the best polymers for modifying the bitumen thermal properties. In this research, the effect of SBS with different percentage (0, 3, 4, and 5) on properties of the recycled asphalt mixture (100% RAP) with using Marshal and ITS tests is studied. In the base of experimented case studies such as the asphalt behavior modifying against the ambient the pavement stability increasing against perpetual deforming and the undercut of wheel path in high operational temperatures and consequently it is more stable against ambient temperature changings. It may be concluded that the adhesion of bitumen film to rock materials, the strength against the stresses and the stability against deforming in recycled samples including polymer-modified bitumen emulsion increases while their thermal sensitivity decreases.

***Keywords**: Recycled Asphalt Mixture; Cold recycling; Bitumen Emulsion; Modified; SBS polymer.*

1. Introduction

Many types of research are annually conducted about the modification of bitumen behavior and the performance of asphalt mixtures using modifiers [1-2]. Among the high-consumption modifiers, styrene-butadiene-styrene copolymer is widely used [3]. Since this modifier is a copolymer block of polystyrene and poly butadiene, as the styrene block, and the butadiene block provide the resistance and flexibility, respectively, and the glass transition temperature of polystyrene is 100°C and poly butadiene is 90°C; Therefore, SBS can decrease the temperature sensitivity of the bitumen [4-5] and increase the resistance potential of asphalt mixtures against low temperature cracking, stripping, fatigue, and rutting [6-8].

The polymer-modified bitumen emulsions are produced by dispersing a polymeric phase as an internal phase in bitumen as external phase [9-10]. Although research on the effect of SBS on bitumen behavior and asphalt mix performance is widespread, investigations on the effect of this modifier in the emulsion bitumen are still limited in order to be used in recycled asphalt mixtures. Therefore, in this paper, the performance of the SBS additive in various percentages was analyzed for bitumen PG 64-16 or 60/70 bitumen as the most consumed bitumen in the production of recycled asphalt mixtures in Iran. For this purpose, the performance of the base bitumen and SBS bitumen compounds were evaluated based on softening point, penetration, ductility, elastic recovery, flash point, specific gravity, rotational viscosity and mass loss of RTFO and the performance of cold recycled asphalt mix modified with polymer bitumen emulsion was evaluated based on resistance and flow of Marshal and indirect tensile strength tests.

2. Method

2.1. Materials

The utilized materials in this research are pure bitumen with PG 64-16 (also called 60/70 bitumen) from Tehran Pasargad Oil Company, LG 501 SBS polymer from South Korea LG

Company, emulsifier to stabilize the emulsion production (STABIRAM 4582, CECA France), HCL acid with 35% purity and kerosene, and rock materials from reclaimed asphalt pavement (RAP) recovered by recycling machine from Imam Reza Highway East to West line in Tehran.

Table 1. Chemical composition of base bitumen, Physical and chemical properties of SBS, and Physical and chemical properties of emulsifier

Materials	The experiment	Method of experiment		Standard specification		Result
		AASHTO	ASTM	Max	Min	
bitumen	Specific gravity @25°C	T 228	D 70	1.10	1.00	1.026
	Penetration@25°C	T 49	D 5	70	60	65
	Softening point (Ring and Ball, °C	T 53	D 3398	56	49	50.3
	Ductility @25°C	T 51	D 113	-	100	+100
	Solubility in trichloroethylene	T 44	D 2042	-	99	99.8
	Flash points	T 48	D 92	-	250	312
	Kinematic viscosity in135°C(centiStoke)	T 201	D 2170	-	-	295
	C (poises) 60°C Absolut viscosity in	T 202	D 2171	-	-	1705
	TFOT (163°C -5hours)	T 179	D 1754	-	-	0.1
	Softening point) PI (Penetration@25°C	-	-	-	-	-0.127

SBS	Product name	Physical state	Colour	Density	Weight percent of styrene to total weight of polymer	Molecular structure
	LG 501	Solid	White	0.94	31	Linear

Emulsifier	Application	For producing shatterproof cationic emulsions in order to recovering and slurry sill. It should be solved in water in temperature between 40-50 centigrade and then neutralized with HCL to reach to appropriate PH.	
	Dosage (%)	0.4 - 1	
	PH	2 - 4	
	Composition	Quaternary Ammonium salt	
	Physical properties	Aspect@ 20°C	liquid
		Density @ 25°C	1.05
		Solid point	-13°C
		Flash point	40°C
		viscosity @20°C	40cP
	Storage	Stable at normal temperature and stored in closed containers protected from freezing.	
	Package	175 kg barrels	
	Safety precautions	It is not a dangerous material but it is better to wear glove, top coat and safety glasses when it is used.	

Table 2. The results of quality experiments on RAP

Experiment	Standard		Unit	Quality value in the base of standard	Result
	AASHTO	ASTM			
Abrasion by Los-Angeles in 500 rpm	T 96	C 131	%	Max 40	24
Materials weight decrease by sodium sulfate (salt cake)	T 104	C 88	%	Max 12	1.7
Percent of fracture in one front	-	D 5821	%	Min 50	89
Percent of fracture in two fronts	-	D 5821	%	Min 50	71
The maximum size	-	D 8	mm	Max 37.5	37.5
Sand equivalent	T 176	D 2419	%	Min 35	60
Absorption of water	T 84, 85	C 127, 128	%	Max 3	0.91

RAP was used instead of new rock materials to be representative of the real utilized mixture. They were characterized in the laboratory. The bitumen weight percentage was determined by extraction experiment equal to %4.9. The results of rock materials mixture's gradation by bitumen emulsion were consistent with continuous gradation D in bitumen institute method [11]. The properties of bitumen, polymer, and emulsifier are given in Table (1). The results of carried out quality experiments on RAP have been compared with standard values in Table (2).

2.2. Samples preparation

2.2.1. Samples preparation of SBS polymer-modified bitumen emulsion

The weight percent of effective materials in aqueous and bitumen phases were determined for producing stable cationic SBS polymer-modified bitumen emulsion, Table (3).

Table 3. Overall specifications of cationic SBS polymer-modified bitumen emulsion

	Phase of production	Phase percent	Effective materials	Specifications of effective materials	Weight percent
The weight percent of effective materials in SBS polymer-modified bitumen emulsion production with EMULAB device	Aqueous phase pH=2	40	Water	-	38.6
			Emulsifier	STABIRAM 4582 (CECA France)	1.2
			Acid	HCL %35 Purity	0.2
	Bitumen phase	60	Polymeric bitumen SBS= %3, %4, and %5	SBS polymer 60/70 bitumen	60

In the first step and in the bitumen phase, the polymeric bitumen is produced by shear stress of High Shear mixer by 4000 rpm for two hours in 175°C considering the compound formulation and the mixing trend of utilized materials in production of polymeric bitumen with different SBS percentages of 3, 4, and 5 percent of bitumen weight. In next step, aqueous phase (pH=2) containing water plus emulsifier (Quadrivalent Ammonium Salt) also (CECA France), STABIRAM 4582 with HCl (%35 Purity) were spilt in aqueous phase reservoir of EMULAB device at 50°C circulated by pump, then the resultant phase entered into colloidal meal at 90°C and while mead rate was to the maximum (8000 rpm), then the bitumen phase entered into meal, and finally the polymeric bitumen emulsion was extracted at 60–70°C.

2.2.2. Samples preparation of Recycled Asphalt Mixture

Samples of cold recycled asphalt mixture were prepared according to Marshal Method (ASTM D6927-15), Table (4).

Table 4. The governing conditions on samples preparation of recycled asphalt mixture using Marshal method

Project	Emulsion cold recycling	Temp of rock materials	25°C
The purpose of plan	Determination of SBS polymer effects on specifications of recovered asphalt mixture	Temp of bitumen	60°C
The place of sampling	Imam Reza multilane highway east to west	Temp of water	25°C
RAP percent at total weight of rock materials	100	Compression temp	60°C
Kind of bitumen	CSS	Treatment temp	60°C
Number of pulses on each side	50	Treatment time	6 hr

2.3. Experiments

The physical experiments including needle penetration in 25°C (ASTM D5), softening point (ASTM D36), ductility in 25°C (ASTM D113) and Elastic recovery in 25°C (ASTM D6084) was done on the base bitumen and SBS polymer-modified bitumen samples. Furthermore, to examine the temperature susceptibility of the modified bitumen, needle penetration index (PI) [12] was used.

3. Results and discussion

3.1. The experimental study of polymeric bitumen samples' specifications with different SBS percentages

For studying the properties of produced polymeric bitumen samples with different percent of SBS, different experiments such as determination of penetration degree, softening point, elastic recovery, flash points, specific gravity, rotational viscosity, mass loss of RTFO, and needle penetration index were conducted on them. The results of these experiments for the base bitumen and SBS polymer-modified bitumen samples with different SBS percentages of 2, 3, 4, 5, and 6 percent of bitumen weight are presented in Table (5). As can be seen, the penetration degree of bitumen samples in 25°C decreases with the increase of polymer percentage and the bitumen becomes firmer. Also the softening point of bitumen samples, viscosity and PI increases with the increase of polymer. This fact shows the modification of bitumen behavior against ambient temperature changing, because it is possible to utilize this modified bitumen in a warmer zone or in a zone with heavier traffic. According to Table (5), given the fact that the maximum amount of SBS providing ductility equals 100 cm is a composite with SBS of 4 weight percent of bitumen.

Table 5. The results of performed experiments on base bitumen and SBS polymer-modified bitumen samples

Type of experiment		Method of experiment	Base bitumen	Polymeric asphalt results				
				SBS 2%	SBS 3%	SBS 4%	SBS 5%	SBS 6%
Penetration @25°C		ASTM D5	65	56	54	48	43	42
Softening point, °C		ASTM D36	50.3	55.5	59.5	79.5	85	84.5
Ductility @25°C (cm)		ASTM D113	>100	>100	>100	>100	98	94
Elastic recovery in 25°C		ASTM D6084	16	37	50.5	62.5	66	67.5
PI		-	-0.127	0.090	0.259	0.790	0.852	0.835
Flash Points (°C)		ASTM D92	312	309	308	307	310	307
Specific Gravity (g/cm^3)		ASTM D70	1.026	1.007	1.005	1.007	1.005	1.002
Rotational viscosity (Pa.s)	120℃	ASTM D4402	0.667	0.858	1.11	1.761	2.136	2.714
	135℃		0.323	0.473	0.615	0.878	1.076	1.371
	150℃		0.162	0.259	0.328	0.473	0.565	0.758
	165℃		<0.100	0.149	0.191	0.267	0.33	0.413
	180℃		<0.100	<0.100	0.111	0.159	0.264	0.292
RTFO (Mass loss %)		AASHTO T240	0.07	0.23	0.24	0.22	0.25	0.27

3.2. Defining percentage of optimizing emulsion bitumen and that of optimizing humidity

Step A: a composite of RAP material with emulsion bitumen with adding filler of cement to optimizing %1.5 was considered. Alteration range of emulsion bitumen is from %0.5 to %4 with growth rate %0.5 to define optimizing emulsion bitumen percent. The mix humidity with material humidity %1 was calculated from the equation (2).

Equation (2) (Percent of humidity of rock material) + (water percentage of emulsion bitumen) = the water must be added

According to the results of Marshal test and specific weight of recycled samples and with controlling percentage of voids ranges between 9 to 14, that of optimizing emulsion bitumen equals %2.3, Table (6).

The step of B: a composite of emulsion and RAP material with adding an active filler of cement is considered and optimizing amount %1.5 in optimizing emulsion bitumen percentage (%2.3) is confirmed. Alteration range of mixture water is %2.5, %3.5, %4, and %4.5 according to the result of Marshal test and specific weight of recycled Sample and with controlling voids percent in ranges from 9 to 14, optimizing humidity percent is equal %3.5, Table (6).

Table 6. The Marshal results for (A) percent of optimizing emulsion bitumen and (B) percent of optimizing humidity

Steps	Emulsion bitumen (%)	Cement (%)	Water (%)	Real specific weight (g/cm³)	Max specific weight (g/cm³)	Void (%)	Marshal stability (kg)	Marshal Flow (mm)
A	0.5	1.5	2.8	1.967	2.261	13.00	1033	5.82
	1	1.5	2.6	2.005	2.273	11.80	1072	4.00
	1.5	1.5	2.4	2.038	2.298	11.30	1191	4.02
	2	1.5	2.2	2.071	2.325	10.90	1138	3.53
	2.5	1.5	2.0	2.089	2.339	10.70	1141	3.21
	3	1.5	1.8	2.080	2.313	10.05	1182	3.97
	3.5	1.5	1.6	2.067	2.299	10.10	931	4.00
	4	1.5	1.4	2.057	2.289	10.13	870	4.72
B	2.3	1.5	2.5	2.040	2.310	11.70	979	6.23
	2.3	1.5	3	2.068	2.325	11.06	1065	4.83
	2.3	1.5	3.5	2.085	2.331	10.54	1115	5.17
	2.3	1.5	4	2.073	2.321	10.68	1037	5.47

3.3. Defining percentage of optimizing SBS polymer-modified bitumen emulsion on recycled asphalt mixture

A composite of polymer emulsion bitumen with 0, 3, 4, and 5 percent of SBS in constant optimizing emulsion bitumen (%2.3) with RAP material with adding cement active filler (optimizing percentage= 1.5 and optimizing humidity percentage= 3.5) is considered to define percentage of optimizing polymer emulsion bitumen of recycled asphalt mixture samples. The comparisons and results of Marshal, ITS and Specific weight tests of recycled asphalt mixture samples are based on a various percentage of polymer emulsion bitumen as shown in Table (7) and Figure (1). According to this research, the marshal strength (resistance) increases as SBS polymer percentage increases. It is worth to be mentioned that as the SBS increases, the value of Marshal Resistance increases to %23.85. It is worth mentioning that the rate of Marshal Resistance is from %0 to %3 SBS, approximately %4, from %3 to %4 SBS, %17.73, and from %4 to %5 SBS increases to %1.16. Two above-mentioned cases represent that in equal conditions from the viewpoint of materials, the quantity and quality of active filler, moisture and constant optimum bitumen percentage, the quantity of consolidation against the stresses with the increase of SBS polymer percentage. With increasing percent of SBS, dry and saturation ITS and TSR of recycled samples increased.

Table 7. The effects comparison of SBS polymer-modified bitumen emulsion on recycled asphalt mixture

SBS (%)	0	3	4	5
Emulsion bitumen (%)	2.3	2.3	2.3	2.3
Cement (%)	1.5	1.5	1.5	1.5
Water (%)	3.5	3.5	3.5	3.5
Dry ITS (kPa)	278.8	288.7	294.9	295.1
Sat ITS (kPa)	182.4	192.1	202.9	206.8
TSR (%)	65.4	66.5	68.8	70.1
Real specific weight (g/cm³)	2.085	2.103	2.133	2.135
Max specific weight (g/cm³)	2.331	2.358	2.377	2.379
Void (%)	10.54	10.82	10.26	10.26
Marshal Stability (kg)	1115	1159.5	1365.1	1380.9
Marshal Flow (mm)	5.17	5.31	4.21	4.16

4. Conclusion

As seen in this research, with SBS percent increasing from 0 to 5 could be obtained that Marshal stability of recycled asphalt mixture samples has a positive increasing. With observing dry and saturated tension resistance of recycled samples in different percentage of SBS, it can be concluded that increasing of this parameter have a direct relation to the increase of polymer percentage. With the increase of SBS polymer percentage, TSR in recycled asphalt mixture samples increases and this shows the increasing of wet resistance in recycled samples in comparison with not using polymer situation. Generally according to Marshal Stability, dry ITS, Sat. ITS, and TSR parameters, changes of these parameters from %4 to %5 SBS is insignificant, and the diagram turns into constants mode. So it can be concluded that with economic considerations and improvement of recycled asphalt mixture sample properties, %4 could be recommended as the optimum percent of SBS.

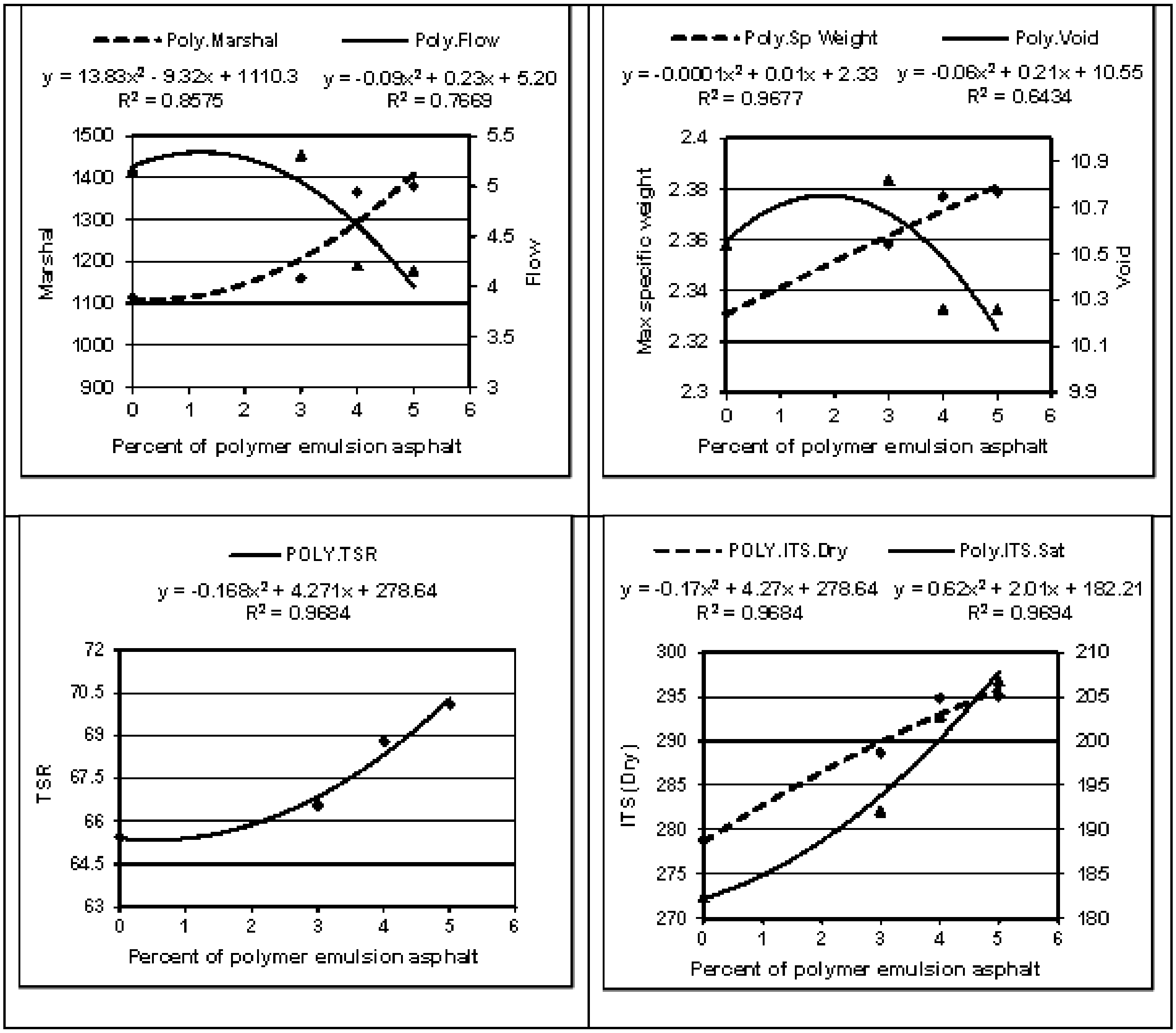

Figure 1. The diagrams of results of Marshal, ITS and specific weight tests of recycled asphalt mixture samples base on various percent of polymer emulsion bitumen

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To whom correspondence should be addressed: Dr. Parham Hayati, Department of Civil Engineering, Islamic Azad University, Science and Research Branch, Tehran