SULFUR EXTENDED ASPHALT INVESTIGATION - LABORATORY AND FIELD TRIAL

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ABSTRACT

Production of sulfur as a co-product has considerably grown in Iran (3 million tons annually) due to the increase in number of oil and gas industries and type of sources. The investigation of new applications for sulfur such as Sulfur Extended Asphalt (SEA) has become a challenge for national Iranian oil and gas companies. This paper will outline the laboratory results, field trial, and three years monitoring to investigate the feasibility of utilizing sulfur as a partial substitute of bitumen in road construction. Based on laboratory investigation the asphalt mixture was prepared using 35% by weight of sulfur in binder. The study indicated sulfur has enhanced mechanical properties of pavement and monitoring of 1600-meter wearing course test section under relatively heavy traffic showed good performance without any distresses. Environmental aspects were also studied and results revealed that no significant fume emissions occur if mixing, laying, and compaction temperatures are to be controlled below 150°C. Furthermore, the availability and cost of sulfur in Iran offer the potential to reduce paving binder cost by 25 percent.

Keywords: Sulfur extended asphalt, pavement, sulfur, road construction

1. INTRODUCTION

The development of sour gas and oil resources as well as the increasingly stringent regulations about sulfur present in the fuels has made sulfur readily available in Iran. Sulfur's ability to replace a portion of the bitumen (about 35%) used in asphaltic concrete mixes as well as ability to modify and enhance high temperature properties of asphalt concrete are the main factors for using sulfur extended asphalt in Iran. The availability and cost of sulfur in comparison to bitumen in Iran offer the potential to reduce paving binder costs by 25 percent [1].

2. LABORATORY EXPERIMENTAL PROGRAM

2.1 SEA Binders

The laboratory program was designed to assess physical properties of SEA binders and then to compare performance properties of SEA and asphalt mixes with sieve size type 1/2" (12.5 mm) as per ASTM-D3515 dense aggregate used commercially. Physical properties of SEA binders were evaluated by preparing bitumen/sulfur mixes containing 25, 35, 45 weight percent of sulfur [2].

In this study 60/70 bitumen from Isfahan petroleum refinery was used. The sulfur was in powder form and yellow color and was supplied by Khangiran gas processing company. The mixes of bitumen and sulfur were prepared in a 100 rpm laboratory mixer by adding sulfur into melted bitumen at a temperature of 145±2°C and mixing for 30 minutes. The temperature and the time of mixing were determined by microscopic evaluation, so that a uniform dispersion would be attained with a minimum level of emissions. Physical properties of base bitumen and SEA binders were evaluated according to ASTM standard test methods and results are summarized in Table 1[3, 4].

Table 1 : Physical properties of base bitumen and SEA binders

	Binder Type (Bitumen/Sulfur Ratio)			
	100/0	**75/25**	**65/35**	**55/45**
Softening Point, °C	49.5	46.5	48	48
Penetration @ 25°C, 0.1mm	65	93	94	93
Loss on Heating, wt%	0.01	0.82	0.91	0.98
Ductility@ 4°C, cm	0	2	1.0	1.5
Ductility @ 15°C, cm	96	25	24	19
Ductility @ 25°C, cm	150+	39	36	24
Specific Gravity @ 25/25°C	1.015	1.143	1.199	1.316
Flash point, °C	339	205	201	191
Fraass Breaking Point, °C	-11	-12	-10	-7
Viscosity @ 98.9°C, cSt	2422	1371	2851	1091
Viscosity @ 135°C, cSt	330	154	232	174
Viscosity @ 60°C, P	1372	1119	2188	764
Rolling Thin Film Oven Test (RTFOT):				
Loss @163°C, wt%	0.04	4.57	4.84	4.59
Penetration @ 25°C, 0.1mm	39	41.5	39	37.5
Ductility@ 25°C, cm	100+	33	24	21
Viscosity @ 60°, P	3807	2239	2783	-

To determine the retention of SEA binders on an aggregate surface in the presence of water, the coating and static procedures based on AASHTO T182 standard test method were conducted on the SEA binders [5]. After 1, 24 and 48 hours of immersing a 100 g coated aggregate with 5.5 g binder in 60°C hot water, the percentage of the total visible stripped area of the aggregate was estimated. The results are shown in Table 2.

Table 2 : Stripped area of coated aggregate in hot water

No.	Binder Type (Bitumen/Sulfur Ratio)	Stripped Surface (%)		
		after 1 hours	after 24 hours	after 48 hours
1	100/0	60	65	70
2	75/25	25	45	50
3	65/35	20	35	45
4	55/45	10	20	30

2.2 Sulfur Extended Asphalt (SEA) Mixes

The mineral aggregate selected for the study was a fine-graded 1/2" as per ASTM-D3515. The gradation of the aggregate is shown in Table 3[6].

Table 3 : Aggregate gradation according to ASTM – D3515

Sieve Size	19 mm	12.5 mm	4.75 mm	2.36 mm	0.3 mm	0.075 mm
Mix Designation D-5	100	90-100	44-74	28-58	5-21	2-10
Aggregate Used for Test	100	91.4	68.5	48.3	10	4

As shown in Table 1, binder samples were prepared using different amounts of 25, 35, 45 weight percent of sulfur. Then the asphalt mixes were prepared in a mechanical laboratory mixer. The procedure was to add hot binder to the hot aggregate in a mixing bowl. Mixing was carried out for approximately 5 minutes. The mixing and compaction temperatures were obtained from viscosity – temperature diagrams as illustrated in Figure 1. From the results summarized in Table 4 it is observed that as the sulfur content is increased, the mixing and compaction temperature is decreased.

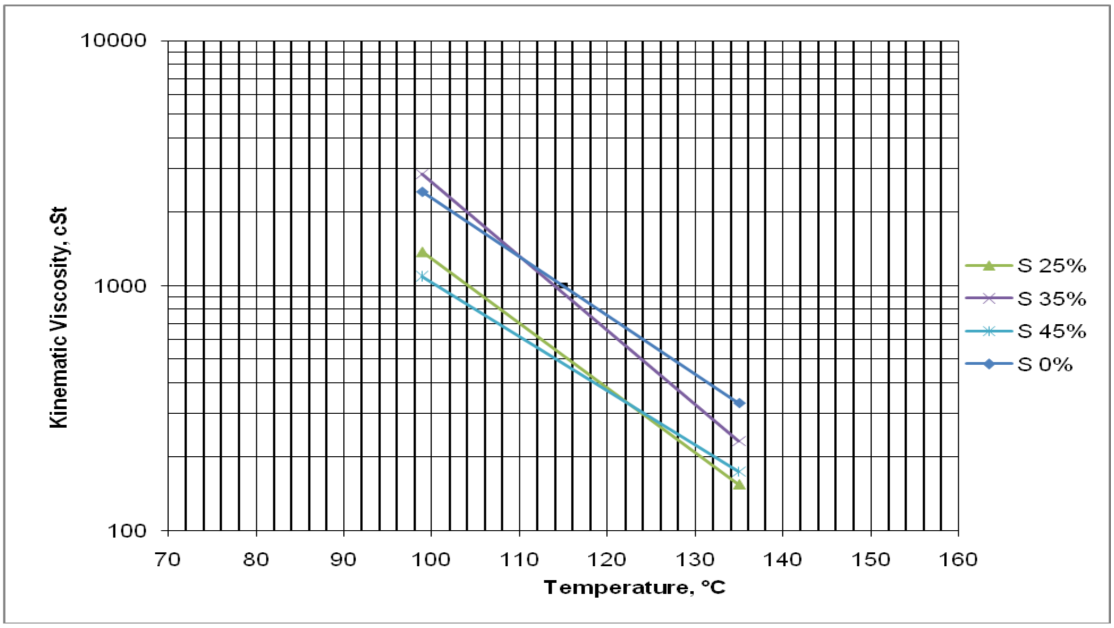

Figure 1 : Temperature-viscosity diagrams of SEA binders

Table 4 : Mixing and compaction temperature ranges for SEA binders

No.	Binder Type (Bitumen/Sulfur Ratio)	Mixing Temp., °C	Compaction Temp., °C
1	100/0	142-147	134-138
2	75/25	129-133	121-124
3	65/35	128-132	119-123
4	55/45	129-132	123-126

Different mixes were designed using the Marshal mix design standard method as per ASTM D 1559 test method, and care has been taken not to exceed 145^{o}C temperature limits for sulfur asphalt mix. Results of mix designs are summarized in Table 5.

Table 5 : Marshal mix design results

No.	Binder Type (Bitumen/Sulfur Ratio)	Optimum Binder wt%	Marshal Stability kg	Flow mm	Density g/cm^3	Air Void %	Aggregate Air Void %
1	100/0	4.8	1090	2.5	2.340	4.2	14.9
2	75/25	5.6	1280	2.7	2.386	4.1	14
3	65/35	5.6	1215	2.6	2.390	4.2	13.9
4	55/45	5.6	1256	2.5	2.392	4.2	13.7

2.3 Wheel- Tracking

The rut resistance of mixes was determined using wheel-tracking machine according to BS 598 test method [2]. The specimens were prepared in 300×300×50 mm dimensions and then subjected to a wheel load of 520 ± 5 N for 45 minutes with frequency equal to 21 cycle per minutes. Test temperature was 45°C for all specimens. Figure 2 shows the changes in rut depth of samples during the 45 minutes test period. The results of rut depth and rut rate are summarized in Table 6.

Table 6 : Wheel – tracking test results

No.	Binder Type (Bitumen/Sulfur Ratio)	Temperature °C	Density g/cm^3	Rut depth mm	Rut rate mm/hr
1	100/0	45	2.340	1.12	0.46
2	75/25	45	2.386	0.96	0.48
3	65/35	45	2.390	0.82	0.38
4	55/45	45	2.392	0.4	-0.04

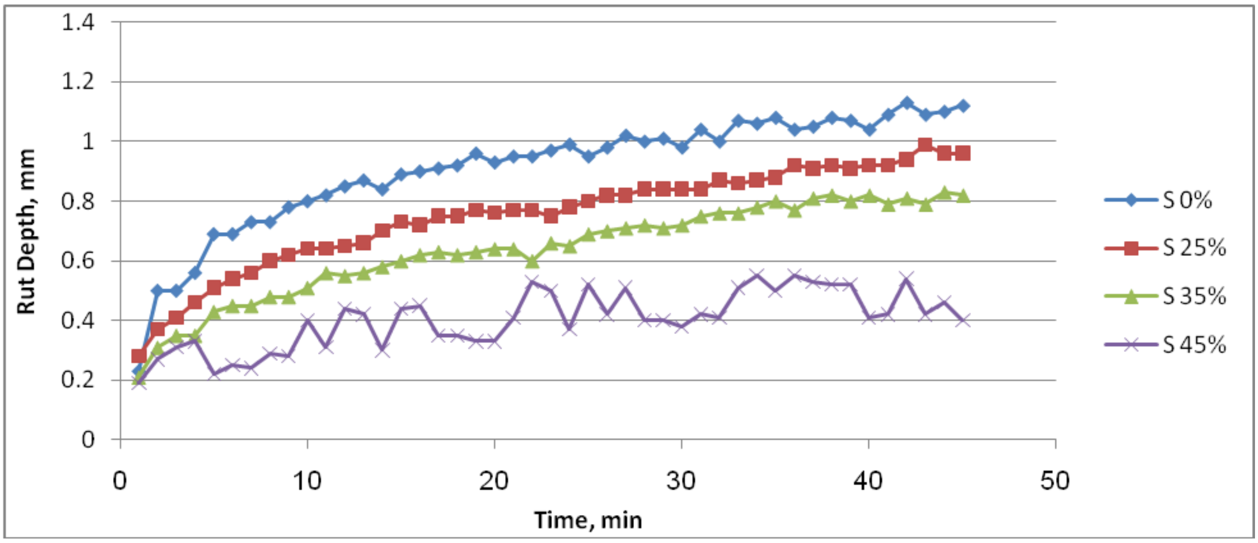

Figure 2 : Influence of sulfur on rut depth

2.4 Indirect Tensile Strength

This test shows the resistance of compacted bituminous mixtures to moisture induced damage through measurement of the change of diametral tensile strength resulting from the effects of saturation and accelerated water conditioning of compacted bituminous mixtures. The test is conducted according to ASTM-D6931 standard test method [7]. Results obtained on both moisture-conditioned (wet) and unconditioned (dry) specimens are summarized in Table 7.

Table 7 : Indirect tensile strength (IDT) test results

No.	Binder Type (Bitumen/Sulfur Ratio)	IDT (kg/cm^2)		IDT Ratio
		dry	wet	
1	100/0	8.2	7.5	0.91
2	75/25	7.9	7.3	0.92
3	65/35	8.3	7.6	0.92
4	55/45	9.4	8.9	0.95

3. FIELD TEST

According to laboratory results and to evaluate SEA technology, one test road section has been constructed on the Quchan-Sabzevar road located in northwest of Iran in June 2008. A test road section of 1600 m long and 7.3 m wide and 4 cm thickness as wearing course was constructed to include a 35/65 sulfur- bitumen mix, in addition to one test section of conventional asphalt mix as shown in Figure 3. Sub base and base courses for SEA and conventional asphalt mixes were prepared using the same binder type. The road test sections include two parts of 800 m in different lane in vicinity of conventional asphalt mix. Test sections were evaluated for performance under local environment and loading conditions and monitored for the progress of rutting and cracking for a period of three years. Test road has been subjected to a total equivalent standard axle load of 5.2×10^5 (ESAL).Traffic survey carried out during two separate intervals and results are as follows:

No. of vehicles/day		
Cars	Trucks	Trailers
370	2614	135
560	3125	151

Figure 3 : Construction of test section

The road was opened to traffic in July 2008. Condition surveys were carried out at regular intervals to evaluate pavement performance [8]. Core samples were also taken from the various sections of road as shown in Figure 4 and analyzed in laboratory. Results showed that no unexpected change exists between measured physical properties of binders extracted from core samples.

Figure 4: Condition survey and sampling

In particular, road surface was evaluated for distresses like cracks, and rutting. Up to date, no wheel path depressions or cracking were observed and pavement condition (PCI) was generally excellent. Typical pavement condition is shown in Figure 5.

Figure 5: Pavement condition of SEA test road

4. ENVIRONMENTAL ASPECTS

As part of the study, intensive testing was carried out to determine the environmental aspects of the SEA. Measurements were made at different locations as shown in Table 8. The results indicate that levels of hydrogen sulfide and sulfur dioxide generally meet existing air quality objectives.

Odor levels near completed test road are noticeable but are not objectionable. No measureable changes in soil or run-off water quality (PH and sulfur content) in the vicinity of the test sections of road were observed [9].

Table 8: Emission of sulfur compounds

Sampling Location	H_2S (ppm)	SO_2 (ppm)
Over mixing tank(bitumen and sulfur)	5-15	3-7
Over pug mill during production	1-5	0.05-0.2
Over paver and roller	0.02-3.7	0.07-0.4

It should be noted that there is no practical experience on SEA recycling in Iran yet but it has been stated in many references that SEA paving mixtures have been successfully recycled in double-drum continuous plants and in batch plants. As is the case with mixture production in general, temperature control is the key to avoiding problem. Maintaining the discharge temperature at around 130 ℃ minimizes the risk of emissions at the plant or paving site [10]. Also, test results from laboratory and field experiments carried out by Taylor and Kennepohl [9] indicated that emission levels obtained during the recycling of SEA pavement are similar to, or lower than, emission levels obtained during production of fresh SEA material and environmental problems are not anticipated at recycle plants.

5. CONCLUSION

Based on results obtained from laboratory investigations and field trial, the following conclusions can be made:

5.1 Laboratory results

- For sulfur asphalt mixes, temperature shall not be exceeded 145°C, essential to minimize SEA mix odor and emission of fumes.

- Softening Point of bitumen was not changed considerably by adding sulfur but penetration increased and viscosity decreased lead to better workability and lower mixing and compaction temperatures.

- Sulfur improves adhesion of binder to mineral aggregate in presence of water.

- Marshal stability and rut resistance of SEA is better than conventional asphalt.

- Optimum binder content for SEA is approximately one weight percent more than conventional asphalt.

- The laboratory characterization of SEA showed that sulfur modified asphalt mixtures exhibited better ITS and adhesion of binder to aggregate.

5.2 Field results

- The three years field monitoring study showed that the road sections were free of any distresses, such as cracking and permanent deformation.

- SO_2 and H_2S emissions remain below the limited values, if the temperatures during construction and laying operations are controlled to be less than 150°C.

- No necessity to change road construction equipments for SEA application.

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