

Preparation and Evaluation of Special Hot Mix Asphalt for Steel Bridge Paving (Laboratory and Field Study)

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Abstract: Bituminous mixes on steel bridges are submitted to very severe strains and stress. Therefore they need special requirements to reduce fatigue cracking. This study aims to improve the long term performance of such mix pavements. Low density poly ethylene (LDPE) at four contents (from 3 to 6%) either alone or combined with 2% styrene butadiene styrene (SBS) were mixed with AC 60/70 penetration grade to produce special asphalt grades. When mixed with aggregates, produce good performance asphalt mixes (wearing surfacing) for steel bridges. Traditional properties of the modified asphalts (penetration, softening point and dynamic viscosity) were examined. The effects of the modified binder on hot mix asphalt were investigated through Wheel Tracking, Marshall properties, indirect tensile strength (IDT) and modulus of resilience (MR) tests. Number of repetitions to fatigue cracking were also investigated. The behavior of the best modified asphalt mixture under traffic loads and environmental conditions was monitored on Dar El-Sallam Steel Bridge in Cairo, Egypt. Production of the best modified binder and construction of the best modified mix were also investigated. Laboratory results showed that, the individual use of LDPE have negative effect on workability and fatigue cracking life of the asphalt mix. The resistance of the modified asphalt mix to permanent deformation at high service temperature and the number of repetitions to fatigue cracking at low service temperature were increased by 72.4% and 77% at 5% LDPE / 2% SBS respectively. Field investigation showed some cracks, raveling and some rutting in the wheel passes in the control section. While the modified section did not show any distress up till now (from March 2006 to November 2008).

Key words: Fatigue cracking • Durability • Modified asphalt mix • Field section

INTRODUCTION

The behavior of the asphalt pavement on steel bridge decks is extremely complex. Indeed, the metallic surface is very flexible and the bituminous surfacing applied to such surfaces are submitted to very high levels of strain [1]. The repetitive deflection associated with the moving wheel loads causes fatigue cracking in the upper wearing surface. They propagate through the thickness of the asphalt layer and can reach the sealing sheet which protects steel plate from corrosion [2]. A variety of materials have been used for wearing surfaces on steel bridge decks. The common bituminous types include, modified asphalt concrete mixes, Gussasphalt, mastic asphalt surfaces and epoxy asphalt surfacing. However many asphalt materials, which have shown promise in the laboratory and in small trials, have failed under traffic loads and different climatic effects [3]. The fatigue life of an asphalt concrete layer depends on many factors, such

as asphalt binder type and its content, air void content; as well as particular loading conditions, such as temperature, frequency and rest periods [4]. The thickness of the surfacing material and its dynamic modulus is another important factor that influences the deck deflection. However there practical limits to the thickness of surfacing that can be used on the steel deck. The most important is the added weight of the thicker surfacing [5]. It well known that continued repeated cyclic loads on steel surfacing can quickly cause cracking, rutting, shoving and breaking bond with the steel deck. Thus a special design asphalt mix is needed on steel bridge deck. Theoretically, fatigue resistance can be improved by designing more flexible mixes; as well as by using thicker binder film around the aggregates so that there is reduced increment of brittleness during service life without compromising other mixture properties [6]. Any wearing surfacing on steel bridge deck must satisfy the following: a) bond to the steel deck to provide composite action and

to prevent delamination and shoving between the steel and surfacing. In addition the surfacing protects the steel from corrosion. b) crack resistance to prevent the entry of water, salts and other corrosive materials to the steel surface. c) poses good stability and not rut and/or shove under traffic loads. d) have a limit light-weight by using either special modified asphalt grades or light-weight aggregates or both. This is a major concern to the designers of bridges [7]. e) last but not least, the repeated loading and deck flexibility make the fatigue strength and resistance to rutting be important parameters for the design of such wearing course.

OBJECTIVES

The Main Objectives of this Study Are:

- Preparation and evaluation special asphalt grades.
- Preparation good performance modified hot mix asphalts.
- Apply the best modified hot asphalt mix on steel bridge as a wearing surface to investigate the behavior of the selected asphalt mix under high levels of strain, traffic loads and different climatic conditions.

MATERIALS AND METHODS

Materials

- Local asphalt cement penetration grade 60/70 produced by Alexandria Petroleum Comp. Egypt. Its properties are shown in Table 1.
- Aggregates used in all hot asphalt concrete mixtures are crushed dolomite obtained from a quarry located at Attaka nearby Suez City, Egypt.
- Artificial sand: obtained from Attaka quarry, Suez, Egypt.
- Natural sand: Natural sand obtained from a local quarry located at km 33 of Cairo-Ismailia desert road.
- Limestone dust as mineral filler obtained from Ataka quarry, Suez, Egypt.
- Properties and gradation of mineral aggregates and filler are shown in Table 2 and 3
- Low density poly ethylene: its properties as taken were: density = 0.935g/cm^3 , melting temperature = 112°C , elongation at break = 600% and tensile strength = 16.5 MPa.
- Styrene butadiene-styrene (SBS) Produced by Shell Chemical Co. [Kraton D-1101 is a linear SBS polymer (powdered) containing 31% styrene. The viscosity of

Table 1: Physical properties and chemical constituents of asphalt cement 60/70

Properties	Values
Physical properties	
- Penetration at 25°C 100 g, 5 seconds, 0.1 mm	63.0
- Kinematics viscosity at 135°C , C.st.	274.0
- Absolute viscosity at 60°C , poise.	1120.0
- Flash point, $^\circ\text{C}$ (Cleveland open cup).	250.0
- Ductility at 25°C , 5 cm/min, cm.	+150.0
- Softening point $^\circ\text{C}$ (Ring and Ball).	50.0
- Solubility in trichloroethylene, %.	99.9
Chemical constituents, wt%.	
- (Oils + waxes) %.	25.8
- Waxes %	5.8
- Resins %.	57.1
- Asphaltenes %.	17.0

25% by weight of toluene solution of the polymer was 4 Pa.s.

- Prime coat: A special solvent base rubberized asphalt prime coat produced by Asphalt and Polymers Services Center, EPRI. Egypt was used. Its active material is 55%, Curing time at 23°C is 120 minutes and penetration at 25°C on residue (distillated up to at 360°C) is 69.
- Steel bars: steel bars of 30 to 50 cm length, 2 cm width and 1 cm highest) supplied from, Ezz. Com. Alex. Egypt.

Methods and Testing Program

- Characterization and gradation of aggregates: The characterization and gradation of the used aggregates were carried out according to standard test methods shown in Table 1 and 2, respectively.
- Preparation of Modified Asphalt binders (from B₂ to B₉): Eight modified asphalt binders (MABs) beside the control were prepared through the addition of 3, 4, 5, and 6% low density poly-ethylene (by asphalt weight) either alone or combined with 2% Styrene Butadiene-Styrene (by asphalt weight) as follows: the calculated amount of base asphalt was heated to 180°C . The required amount of LDPE was added gradually while stirring. The temperature was kept within the range of $180\pm 1^\circ\text{C}$ during the polymer addition and the subsequent 2 h. of mixing. The mixer speed was maintained at 125 rpm throughout the mixing process. Finally, the obtained MABs were divided to appropriate amounts. The samples were cooled to

Table 2: Characteristics of the used aggregates

Type	Crushed dolomite			
	Size1	Manufacture sand	Natural Sand	Dust Limestone
Pass (wt)%	Pass%	Pass %	Pass%	Pass%
Sieve size				
1"	100.00			
3/4"	100.00			
1/2 "	92.70			
3/8"	77.80	100.00		
No.4	26.40	97.00		100.00
No.8	9.60	64.00	100.00	100.00
No.16	-	30.20	99.20	-
No.30	4.80	23.60	96.60	94.10
No.50	3.90	14.80	66.60	82.00
No.100	2.80	9.30	10.40	66.50
No.200	2.50	5.00	0.30	51.50
Blend%	45.00	14.00	36.00	5.00
Abrasion Resistance (loss%wt)				
- After500 revolutions	26.00			
- Bulk specific gravity	2.569			
- Bulk specific gravity (SSD basis)***	2.650			
Apparent specific gravity	2.797			
Absorption (wt%)	3.20			

Table 3: Gradiation of the applied mixture

Sieve size	Jop mix formula	Specification Limits (5-B)
1"	100.00	100
3/4"	100.00	100
1/2"	96.70	85-100
3/8"	90.00	-
No. 4	66.60	65-80
No.8	56.60	50-65
No. 30	37.90	25-40
No 50	19.80	18-30
No100.	11.70	10-20
No.200	9.20	3-10

room temperature, sealed with aluminum foil and stored for further testing. In the case of modification with LDPE/ 2% SBS, the calculated amount of styrene butadiene-styrene was added just after the addition of LDPE.

Binder Testing: The re-molten modified asphalt blends were tested to their penetration at 25°C, softening point and dynamic viscosity at 160°C according to ASTM D 5, ASTM D 36 and ASTM D 2179, respectively.

Asphalt Mixes Preparation: The optimum asphalt content for all asphalt concrete mixtures (from M₁ to M₉) were determined according to Marshall Procedures (ASTM D1559). Each mix was designed according to The Egyptian specification limits of 5-B wearing surface. The test specimens were prepared with the asphalt content varying at 1% intervals within the range of 4 to 6%. After mixing the hot aggregates with the hot binder at 160°C, each mix was allowed to short term oven age at the compaction temperature for each mix for four hours

(to simulate short term aging that occurred in the mix during transportation, laying and compaction) [5]. After short term oven aging each sample was compacted using 75 blows /side. The samples were tested at 60°C. Each read is the average of three samples.

Mixture Testing: All the prepared asphalt mixtures [From M₁ to M₉] were evaluated at their optimum asphalt contents after aging to, Marshall properties; indirect tensile strength at failure (ASTM D 4123), Modulus of Resilience (ASTM D-4123 and SHRP Protocol PO7 tests [8, 9]. The number of repetitions to fatigue cracking were also calculated [9]. The best modified asphalt mix (M₈) was subjected to Wheel Tracking Test [10].

The behavior of the best modified asphalt mixture (M₈), as a steel bridge wearing surfaces under traffic load and different climatic conditions comparing to M₁ was monitored through a field section.

Field Sections: Two trial sections (100 m long and 3m width for each) were constructed in March 2006 on Dar El-Sallam Steel Bridge in Cairo, Egypt. [The original wearing epoxy layer of this bridge was polished off by traffic consequently, the steel surface of the bridge was subjected to corrosion by environment and the surface became slippery surface]. The damaged epoxy surfacing layer of this bridge was replaced by the untreated asphalt mix (M₁) for the first section and the best modified asphalt mixture (M₈) for the second section. The following steps were carried out.

Production of the Modified Binder: The best modified binder (B_8) was produced in a mixer with a capacity of 1.5 tons/day under the supervision of the Asphalt and Polymers Services Center at the Egyptian Petroleum Research Institute [EPRI] as follows.

The required amount of bitumen was pumped to the mixer at 140°C. The temperature was raised to 180°C. The calculated amount of LDPE was added gradually to the bitumen at 180°C while stirring followed by the calculated amount of SBS. Mixing was continued at this fixed temperature (180°C) for two hours until achieve a completely homogenous blend. The blend was poured and cooled at ambient temperature in the form of blocks (25×25×10 cm) and delivered to the mixing station in polyethylene bags.

Production of Hot Mix Asphalts: The modified hot mix asphalt was produced by production units normally employed for preparation of conventional asphalt concrete mixes as follows.

The required amount of the modified binder was reheated to 160°C before pumping to the weight bucket and transferred to the pug mill for mixing with hot aggregates at 160°C for one min. The mix was transported to the site point in a way similar to conventional hot mix asphalt. The control mix was mixed with the hot aggregates at 150°C.

Surface Preparation: In order to promote a better bond between the prime coat and the steel surface, all old paints and corroded parts were removed by sand blasting. Then the surface was cleaned with a compressed air jet to blow out any dust or foreign materials from the surface.

Steel Bars Application: The mix can move under the steel wheel rollers and shove forward as the steel drum approach, causing a bow to form. To prevent these phenomena steel bars (from 30 cm to 50 cm length, 2 cm width and 1 cm height) were welded on the steel bridge surface in the form of random structure.

Prime Coat Application: Prime coat was applied to:
a) promote adhesion between the steel surface and the construction asphalt mixture. b) prevent slippage or movement of the asphalt mixture during rolling and, c) acts as a water and corrosive chemical protective layer. Prime coat use is an essential step for successful operation so, the surface was thoroughly cleaned and all dust was completely removed by using compressed air jet just before the prime coat application. Prime coat was

painted over the steel surface at a rate of 0.5 L/m². When cured a thin but uniform coating of rubberized asphalt was left on the steel surface.

Application of the Modified Hot Mix: Construction techniques and specifications for the successful application of this special mixture have been established in cooperation with Asphalt and Polymers Services Center at the Egyptian Petroleum Research Institute, the Arab Contractors, Highway Engineering Consultancy Unit Faculty of engineering, Ain Shams University. As pointed out earlier the mix was transported to the site point in a way similar to conventional hot mix asphalt. The mix had been spread successfully by hand-raking and by self-propelled finishing machines commonly used in hot mix paving. The temperature of the dense graded mix at the time of placement was approximately 155°C. The thickness of the mix layer was 60 mm. Air temperature was 20°C.

Compaction Operation: In order to obtain the required level of density and smoothness in the asphalt concrete mix at the same time, two different rollers were used to compact the test sections: a vibratory rubber tire roller (8 tons) and double drum steel wheel roller (12.5 tons). The compaction was applied first to the mix at 130°C with the vibratory tire rubber (two rollers passes were carried out over each point in the pavement surface for each section) followed by the double drum steel wheel roller (6 roller passes were carried out over each point in the pavement surface for each section). It is important to report that, the compaction operation was completely finished before the mix surface temperature reaches a level of 100°C. Below this temperature the stiffness of the asphalt cement binder increases so much that it is very difficult to reorient the aggregate particles with continued passes of the compaction equipment [11]. After the compaction process had been completed the bridge was opened to traffic.

RESULTS AND DISCUSION

Modified Asphalts

- Drop decrease in penetration value was observed with B_2 (the lowest LDPE content) as shown in Fig. 1. Slight decrease in penetration value was obtained with increasing LDPE content. The same result was observed when 2% SBS was introduced.

Table 4: Effect of modifier type and its content on Marshall Test results

Mix No.	Bitumen content (%)	Unit weight (t/m ³)	Stability (lbs)	Flow (0.01in)	Air voids (%)	Min. voids (%)
Control (M1)	5.0	2.334	1360	10.5	3.8	15.2
M ₂	5.3	2.330	2019	9.8	3.8	15.3
M ₃	5.4	2.327	2331	9.7	3.9	15.4
M ₄	5.4	2.320	2405	9.5	39.0	15.8
M ₅	5.4	2.321	2419	9.2	3.9	15.8
M ₆	5.5	2.331	2014	11.5	3.6	15.9
M ₇	5.7	2.299	2326	11.1	3.4	15.9
M ₈	5.8	2.297	2399	10.9	3.3	16.0
M ₉	5.8	2.298	2411	10.9	3.3	16.2

The decrease percent in penetration for LDPE ranged between 27 to 38.1% for B₂ and (B₄ and B₅) respectively. While the decrease percent for LDPE/2%SBS ranged between 27 and 36.5% for B₆ and (B₈ and B₉), respectively.

- The results of softening point are shown in Fig. 2. We can see that the highest increase in softening point 40% for blends modified with LDPE was noticed with 5 and 6% LDPE compared to the base asphalt. The inclusion of 2% SBS to LDPE modified asphalt binder did not significantly changed the softening point at the same polymer content. The maximum increase in softening point 38% was observed with B₈ and B₉ respectively for LDPE/2% SBS modification.
- Figure 3 shows the results of dynamic viscosity for modified and unmodified asphalt at 160°C. Sudden increase in dynamic viscosity followed by gradual, increase with increasing LDPE content. The dynamic viscosity of LDPE / 2% SBS modified asphalt is slightly higher than those modified with LDPE alone at the same polymer content. The increase percent in dynamic viscosity for LDPE ranged between 260.8 to 317.5% for B₂ and B₅ respectively while it was 275.8 and 360.8% for B₆ and B₉ respectively relative to the base asphalt.

The improvements of the above examined properties of the modified blends is due to the distribution of fine LDPE particles in the base asphalt which led to stiffness of the resulting blend. That reflects the decrease in the penetration value and increase in both of softening point and viscosity [12]. When 2%SBS was introduced it forms net work structure with the asphalt matrix that reflects the more increase in viscosity [13]. The best improvements were obtained at 5 and 6% LDPE either alone or combined with 2% SBS. There is no significant difference between 5 and 6%.

Modified Asphalt Mixtures

- Marshall results are shown in Table 4. We can see that, LDPE modified asphalt binders increased the optimum asphalt content (OAC) in the asphalt mixtures by 6 and 8% for M₂ and (M₄, M₅ and M₆), respectively comparing to the control mix. While the inclusion of LDPE combined with 2% SBS to the base asphalt produced modified asphalt mixes with higher OAC. The increase percent in OAC for M₆ was 10% while it was 16% for both M₈ and M₉ respectively relative to the control mix. Increase the OAC in the asphalt mix is an important factor in view of workability and aging resistance [14]. The increase in the OAC may be due to the highest viscosity value of the modified binder comparing to the base asphalt binder. Marshall stability value of the modified asphalt mixes are higher than that of the base asphalt mix. Hence surfacing may be suitable for heavy traffic at high temperatures (60°C) and bridge decks, where reduced surfacing thickness is required to cut down on dead load coming on the structure. The highest stability values were obtained with the higher LDPE content in the binder mix (5 and 6%) either alone or combined with 2% SBS. The increase percent in the stability were 76.8, 77.9, 67.4 and 77.3% for M₄, M₅, M₈ and M₉, respectively relative to control mix. We can notice that, The asphalt binders modified with LDPE alone produced asphalt mixes with stability values approximately similar to those modified with the both polymers at the same polymer content. The highest stability value of the modified mixes is due to the more stiffness of the modified asphalt binders in such mixes comparing to the base asphalt binder in the control mix. Asphalt mixes modified with LDPE alone has lower flow values than the control mix. The flow values decreased with increasing LDPE content. The reduction percent in flow ranged between

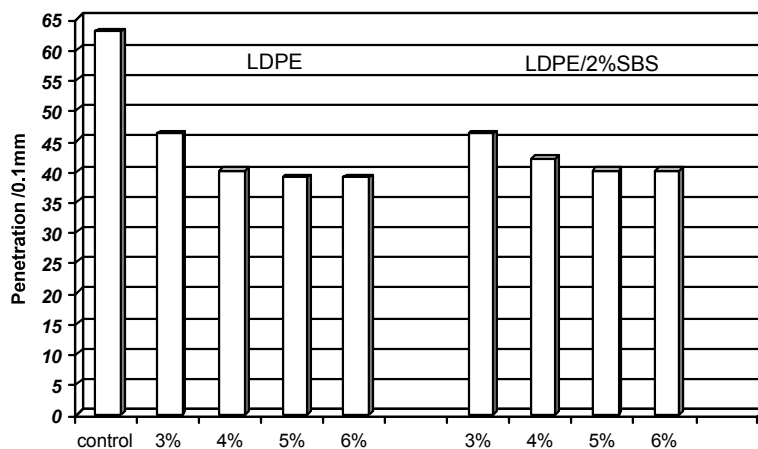


Fig. 1: Effect of polymer type and its content on penetration at 25°C

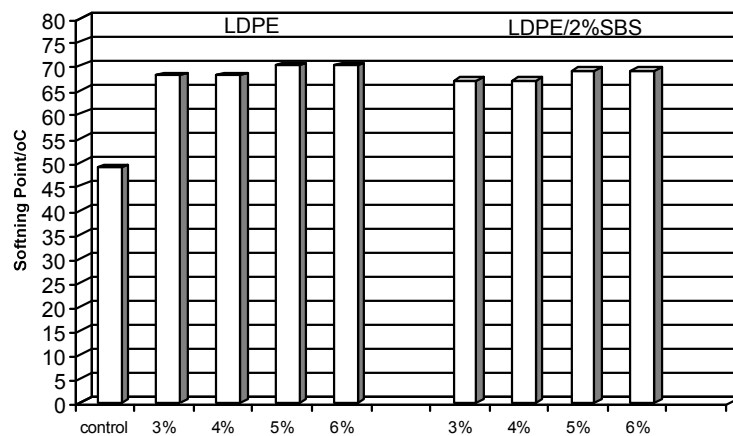


Fig. 2: Effect of polymer type and its content on softening point

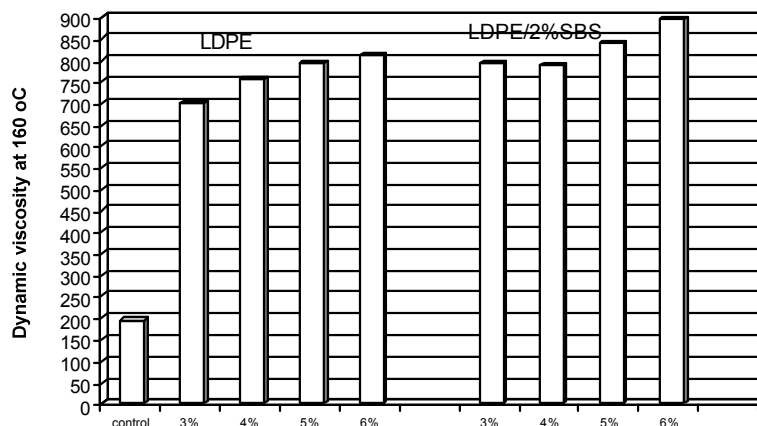


Fig. 3: Effect of polymer type and its content on dynamic viscosity at 160°C

6.7 to 12.4% for M_3 and M_5 , respectively. While the asphalt binders modified with the two polymers produced mixes with higher flow values comparing to the control mix and consequently those modified with LDPE alone. The increase percent comparing to the control mix were 9.5 and 3.8% for M_6 and both of (M_8 and M_9) respectively. The highest flow value of such mixes is due to the flexibility effect of SBS comparing to the stiff nature of LDPE. Flow value, is an important property for polymeric asphalt mixtures in view of crack resistance [14]. Slight increase (2.6%) in air voids percent was observed, in asphalt mixtures modified with LDPE at high polymer content (M_3, M_4 and M_5). This may be due to the more harder of the binder of these mixes comparing to the base asphalt. More decrease (13.2%) in air void percent was observed with LDPE/ 2% SBS modification at high polymer content (M_8 and M_9) comparing to control mix. This may be due to the highest OAC and the more flow values of the asphalt mixes comparing to all other mixes. Non effective decrease in density was obtained with all modified mixes compared to control mix.

- Indirect tensile strength (IDT) of all examined mixes at 5°C, 25°C and 40°C are shown in Table 5. It is clear that, the indirect tensile strength of all modified mixes increased with increasing LDPE content in the asphalt binder. In general, there is significant increase percent in IDT at all examined temperatures. The increase percent in IDT for mixes modified with LDPE ranged between 5.6, 8.7 and 42%, at 5°C, 25°C and 40°C respectively for M_2 and 17.1, 17.4 and 78.9% at 5, 25 and 40°C, respectively for M_3 comparing to the control mix. While, it was ranged between, 2.8, 6.5 and 21.1% at 5, 25 and 40°C, respectively for M_6 and 15.4, 15.2 and 57.9% at 5, 25 and 40°C, respectively for M_9 relative to control mix. It is clear that the more increase in the IDT of modified mixes relative to control mix was obtained at high temperature (40°C). This means that such mixes are more resistant to plastic deformation at high service temperatures. We can see also that mixes modified with LDPE / 2% SBS have less increase percent in IDT than those modified with LDPE alone. This is due to the flexibility effect of SBS comparing to the stiffness effect of LDPE.
- The effect of polymer type and its content on Modulus of Resilience (MR) at 5, 25 and 40°C are shown in Table 6. Although all examined modified asphalt mixes have higher MR values at the three

Table 5: Effect of Polymer Type and its Content on IDT at Different Temperatures

Mix No.	Pult,* (lbs)			IDT		
	5°C	25°C	40°C	5°C	25°C	40°C
Control (M1)	4669.81	1502.2	310.3	286	92	19
M 2	4931.10	1632.8	440.9	302	100	27
M 3	5078.00	1665.5	489.8	311	102	30
M 4	5420.90	1747.1	522.5	332	107	32
M 5	5469.90	1763.4	555.2	335	108	34
M 6	4800.40	1600.1	375.5	294	98	23
M 7	4980.00	1632.8	440.9	305	100	27
M 8	5731.90	1714.4	373.5	329	105	29
M 9	5388.20	1830.8	489.9	330	106	30

* Applied load to failure

tested temperatures, they showed the largest difference from the control mixture at the higher temperature (40°C). It is clear also that LDPE/2% SBS combination produced mixtures with approximately the same MR as the LDPE alone at the same polymer content. The highest increase percent in MR at 5, 25 and 40°C (18.2 and 17.3%), (20.5 and 20.2%) and (57.3 and 65.1%) were obtained with 6% LDPE and 6% LDPE/2% SBS respectively. The results showed that, MR of mixes modified with LDPE alone have higher MR values at low temperature and less MR values at high temperature than those modified with LDPE/2SBS combination at the same LDPE content. This because, the viscosity of the base asphalt at high temperature is low enough to allow the dispersed LDPE to flow easier than SBS which formed network structure with the base asphalt and delay its flow. This lead to, produce stiffer asphalt binder at low temperatures and more viscous at high temperatures [13]. Unlike SBS which is plastic elastic polymer and form net work structure with the asphalt binder leading to produce more flexible asphalt binder at low temperature and more elastic recovery at high temperature [13]. It is an important value in view of both fatigue cracking and rutting as well be shown later.

- The calculated number of repetitions to fatigue cracking (N_F) at constant strain level of 645, asphalt mix thickness of 5 cm and at temperatures of 5, 25 and 40°C are shown in Table 6. It is clear that although the inclusion of LDPE alone to the base asphalt binder improved all the above examined asphalt mixture properties, it has negative effect on N_F comparing to control mix as shown in Fig. 4. This is

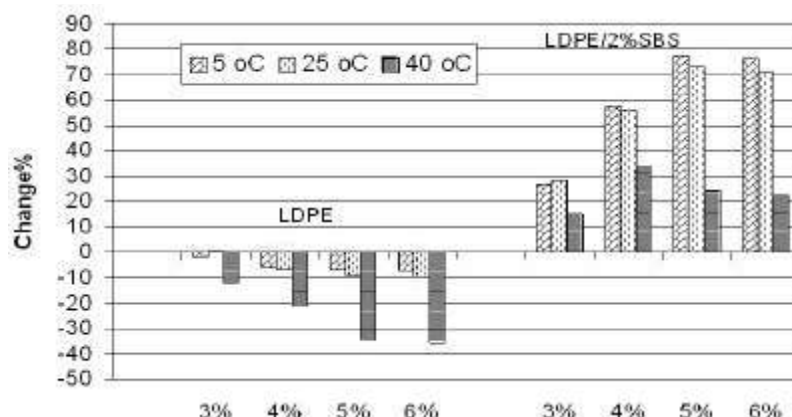


Fig. 4: Effect of polymer type and its content on number of repetitions to fatigue cracking relative to control

Table 6: Effect of polymer type and its content on MR* and N_F**

Mix No.	Applied Load /N			MR/MPa			N _F		
	5°C	25°C	40°C	5°C	25°C	40°C	5°C	25°C	40°C
Control (M ₁)	2004.5	1002.3	334.1	7732	2523	497	173113.5	726736.0	5832715.2
M ₂	2178.8	1089.4	363.1	8900	2850	623	169420.2	728580.3	5109689.6
M ₃	2222.4	1111.2	370.4	9050	2969	667	162588.0	677862.4	4590394.6
M ₄	2331.3	1165.7	388.6	9100	3028	770	16444.5	660989.5	3819096.1
M ₅	2353.0	1176.5	392.2	9136	3041	782	160630.0	657372.0	3744185.5
M ₆	2135.2	1067.6	355.9	8810	2846	611	219277.1	934989.2	6692503.1
M ₇	2178.8	1089.4	363.1	9001	2956	658	272542.7	1134772.2	7775595.7
M ₈	2287.7	1143.8	381.3	9040	3001	765	306348.7	1258027.4	7245986.7
M ₉	2443.0	1221.5	407.2	9070	3032	776	305051.3	1241574.5	7114673.4

*Modulus of Resilience. ** Number of repetitions to fatigue cracking at Constant strain level 645×10^{-6} , thickness of 5 cm and dual axle P=60000 N, with inflating pressure of 120 Psi

due to the stiffness effect of LDPE on the asphalt binder as mentioned above. The highest decrease percent in N_F 7.2, 9.5 and 35.8% at 5, 25 and 40°C, respectively were obtained with 6% LDPE alone comparing to control mix. When 2% SBS was introduced to the asphalt binder that was modified with LDPE, N_F of the produced mixes were increased over the control mix. The highest increase percent in N_F was obtained with 5% LDPE/2% SBS then began to slight decrease at 6% LDPE/2% SBS. The increase percent relative to the control mix at 5, 25 and 40°C for M₈ were 77, 73.1 and 24.4%, respectively. It is important to note also that, the increase percent in N_F at low temperature is higher than, that at high temperature. This may be due to, un-treated asphalt binder is more rigid at low temperature and more soft at high temperature and also the brittleness of LDPE at low temperature. Unlike SBS which is softer

at low temperature and more flexible at high temperature as previously mentioned [13].

Based on the above results the individual use of LDPE is excluded due to its negative effect on the number of repetitions to fatigue cracking at all applied contents at 5, 25 and 40°C and also its negative effect on flow value in Marshall test as previously mentioned. So 5% LDPE combined with 2% SBS modified asphalt binder produced the best asphalt mix. This best modified mix (M₈) was selected to test against rutting through Wheel Tracking Test.

- Wheel Tracking results are shown in Table 7. It is clear that rutting depth of M₈ is less than the control mix. The decrease percent in rutting depth of M₈ was 72.35% relative to control mix. This may be due to the effect of modifiers on the asphalt binder of this mix.

Table 7: Results of WTT* for M_1 and M_8

Number of wheel passes (n)	Time Min.	Rutting depth (mm)	
		M_1	M_8
0	0	0	0
210	5	0.956	0.411
420	10	1.669	0.531
630	15	2.375	0.632
840	20	3.011	0.781
1050	25	3.727	0.857
1260	30	4.112	0.994
1470	35	4.442	1.175
1680	40	4.625	1.281
1890	45	4.700	1.311
2100	50	4.721	1.303
2310	55	4.732	1.312
2520	60	4.741	1.321
Rutting Depth (mm)		4.700	1.311

* WTT: Wheel tracking Test

Which lead to an increase in softening point, dynamic viscosity at high temperature, MR value, IDT comparing to the base asphalt binder of the control mix.

According to the above results of modified binders and modified mixes, M_8 (it is asphalt binder was modified with 5% LDPE/2% SBS) was considered the best modified asphalt mix and selected to apply as a wearing surfacing on Dar El-Sallam Steel Bridge instead of the damage epoxy layer to investigate its performance under different traffic loads and deferent environmental conditions.

Field Sections

Production and Construction Observations: Construction of the control and modified test sections occurred without significant incident. The modified asphalt mixture behaves much like conventional asphalt concrete mixing, transportation, laying and compaction but with the following two exceptions: a) the mixing temperature of the modified asphalt with the hot aggregates was higher than that of the control mix (160°C and 150°C respectively.) b) the compaction temperature of the modified asphalt was higher than the control mix (130 and 113°C, respectively).

Field Performance: The two field trial sections on Dar El-Salam steel bridge has been in service from March 2006 up till now. Comprehensive pavement performance analysis would require a long term performance follow-up according to the Egyptian specification (needs three years

at least). It is therefore recommended that monitoring of the two experimental sections be continued for at least an additional year. At this study the field performance of the section is being monitored every three months by the author. Visual observation revealed some non-significant defects in the control section after 12 months (winter and summer) i.e. raveling in the form of loss of fines, that may be caused by the abrasive action of tires. Some cracking were noticed on the extreme edges of the control section and the paving surface of the control section became paler than the modified one. Some rutting in the wheel passes in the control section was observed after two years. While the modified section has performed well and have no defects up till now (November 2008).

CONCLUSIONS AND RECOMMENDATIONS

Based on the laboratory results on the binders; the laboratory evaluations of asphalt mixes and field application, the following conclusions and recommendations are drawing.

Conclusions

- Test results indicated that addition of 5% LDPE combined with 2% SBS to asphalt base is the best polymers content for all examined properties. The following conclusions could be obtained at 5% LDPE/2% SBS:
- Softening point and dynamic viscosity at 160°C of modified asphalts were increased by 40 and 318%, respectively which may decrease tire rut potential. While the penetration, at 25°C was reduced by 36.5%.
- Marshall stability, indirect tensile strength and resilience modulus values of modified mixes were increased by 67.4% at 60°C, 14.1% at 25°C and 18.9 at 25°C% respectively. Thus modified mixes may be useful for bridge paving as reduced thickens is required.
- Marshall flow was also increased, leading to more resistance to crack, where fatigue resistance is a main concern for steel bridges.
- The fatigue life values of modified mix was increased to 77, 73 and 24.4% at 40, 25 and 5°C respectively, by the addition of low density polyethylene up to 5% LDPE/2% SBS then decreased by the addition of excess LDPE in asphalt mix i.e. 6% LDPE/2% SBS.
- Rutting depth of the modified asphalt mix is less than the control mix by 72.35%.

- Field investigation showed some hair cracks, raveling and some rutting in the wheel passes in the control section. While the modified section did not show any distress up till now (from March 2006 to November 2008).

Recommendations

- Field trial results proved that, 5% LDPE /2% SBS modified asphalt binder could successfully produce a durable hot asphalt mixture (good Marshall Properties, more resistance to rutting and fatigue cracking). That could be used as a corrective maintenance (thin layer) on steel bridges instead of the damage epoxy layer.
- This mix may be successfully applied as an overlay on damaged road paving surfaces where flexible low thickness asphalt paving is required.

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