IMPROVING ASPHALT PAVEMENT RUTTING CHARACTERISTICS BY ADDITIVES

تحسين خواص تشكل طبقات الرصف الأسفلتية باستخدام إضافات البيتومين

by

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خلاصة :

هدف هذا البحث هو دراسة تقييم تأثير إضافة نوعين مختلفين من البوليمرات وهما البولى إيثيلين عا
و الإسترين بيتادين المطاطى على خواص التشكل (ظهور أخاديد فى مسار العجلات) فى الخرسانة الأ

وقد تم عمل تجارب مارشال والزحف الإستاتيكى وكذلك إختبار التخدد على الخلطات الأسفلتية بدو
وبعد إضافة البوليمرات لتقييم خواصها. وقد كان محتوى البوليمرات (البولى إيثيلين عالى الكثافة و
بيتادين المطاطى) والذى تم إضافته كنسبة مئوية من وزن الأسفلت هو العامل المتغير فى إختبارات
والزحف الإستاتيكى والتخدد.

وقد أظهرت هذه الدراسة أن إضافة البولى إيثيلين عالى الكثافة و الإسترين بيتادين المطاطى إلى
يحسن معامل الثبات كذلك يؤدى إلى تخفيض ملحوظ فى عمق الأخاديد مقارنة بالخليط التقليدى للأ

ACT

per presents a study in which the main objective was to evaluate the effect of adding ferent types of polymer (high density polyethylene and styrene butadiene rubber) on characteristics of asphalt concrete

ll test, static creep test and wheel tracking test were performed on both control and polymer o evaluate their performance. Polymer types (high-density polyethylene and styrene butadiene as percentages (by asphalt weight) were the variables used in Marshall, static creep and wheel g test

tudy showed that the addition of high-density polyethylene and styrene to asphalt cement causes an improvement of the stability value and an appreciable reduction in rutting when compared with conventional mix.

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INTRODUCTION

The drastic change in traffic characteristics due to accelerated program in Egypt has indicated that rutting is one of the principal distress modes surveyed due to its impact on the pavement conditions.

Many research studies identified the factors, which canse asphalt pavement rutting (1 to 6). Some studies suggested change in the asphalt mix design, material characteristics, material types and construction controls to minimize rutting in future pavement construction (1and 4).

The rate and magnitude of rutting are mostly affected by external and internal factors(7) External factors inclnde load and volume of truck traffic, tire pressure, temperature and construction practice. Internal factors include properties of the biader, properties of mixtures, and the thickness of the pavement layer. These external and internal may affect rutting performance either individually or in combination betweca each other.

There are several modifiers that have been used to reduce rutting, such as, fibers (polyester, asbestos), oxidants (mineral salts), antioxidants (carbon, calcium salts), hydrocarboas (oils) antistripping materials (lines, amiaes), polymers. rubber. extenders (sulfur) and mineral fillers (dust).

The main purpose of this research is to evaluate the effect of adding two different types of polymers (high density polyethylene and styrene butadiene rubber) with variable percentages (by asphalt weight) to a 60/70 penetration grade asphalt cement conventionally produced in Egypt in order to improve the properties of asphalt mixes with a focus on rutting resistance.

TESTING PROGRAM

The testing program was conducted at the highway materials laboratory in the faculty of Engineering. Mansoura University aad the Central Laboratory of the General Authority of Roads and Bridges, Cairo, Egypt.

Various tests have been employed to assess the rutting resistance of bituminous mixtures. These tests can be broadly classified into the following three main categories:

a) Material testing evaluation
b) Traditional standard tests evaluation such as Marshall test.
c) Other functional tests such as static creep test and wheel tracking test.

The tests performed on finished mixes such as Marshall. static creep and wheel tracking test; their results have been correlated to actual pavement performance.

Firstly. Marshall method of mix design was performed according to Asphalt Institute method (8) The various mixes that were used for Marshall test were as follows

a) Mix type (A): combinatioa of aggregate blended with 4 5 to 6 5 percentage of asphalt content by weight of aggregate

b) Mix type (B). combination of aggregate hlended with 4 5 to 6 5 percentage of asphalt content by weight of aggregate. at different percents of high density polyethylene (1 0.2.0.4 0 and ... percentage of asphalt weight)

c) Mix type (C): combination of aggregate blended with 4.5 to 6.5 percentage of asphalt content by weight of aggregate. at different percents of styrene butadiene rubber (0.2. 0 5, 0.7 and ... percentage of asphalt weight)

... ed on Marshall size specimens of the three type of mixes (A, B and C), and the effect of each type of polymer on mix stiffness were studied

Finally, the wheel tracking (rutting) test has been employed to compare dense bituminous mixtures for resistance to deformation. The rutting deformation was recorded against time or number of wheel passes for the different control mixes, (H.D.P.E) mixes and (S.B.R) mixes

MATERIALS CHARACTERISTICS

The asphalt concrete mix was prepared using limestone coarse aggregate, siliceous sand, cement dust filler of specific gravity of 2.75 and 60-70 asphalt cement. The aggregate samples were taken from El-Nile Company for Road Constructions which were originally obtained from Suez quarries

Only one gradation was used in this study. The aggregates were blended together to achieve one gradation which lies within the limits of the Egyptian Standard Specification gradation (4-B). Table (1) represents the used blendgradation and corresponding specification limits.

The two different types of polymers employed in this study were high-density polyethylene and styrene butadiene rubber. These polymers were obtained from Chemical Industries for Construction Company located in EL-Sadat City, Egypt

The first type of polymer, high-density polyethylene (H.D.P.E) is a semi-crystalline polymer, which is slightly soft at temperatures below the melting point of the resin, 60° C. The blending process, consists of dispersing polyethylene (1.0,2.0,4.0, and 8.0 percents by asphalt weight) whilst asphalt is preheated at a temperature of approximately (130-150° C) by manual continuous mixing for an hour

The second type of polymer is soluble styrene butadiene rubber (S.B.R.). The blend was made by adding (S.B.R) with variable percents (0.2,0.5,0.7 and 1.0 percents by asphalt weight) as latex to preheated asphalt whilst mixing manually for one hour at a temperature of (130-150° C)
The different properties of the polymers used in this study are listed in Table (2)

Table (1) Gradation of Aggregates used in the Investigated Mixtures

Seive Size (mm)		19	12.5	9.5	4.75	2.0	0.6	0.3	0.15	0.074
Passing %	Combined	100	90.88	81.62	58.27	40.0	24.9	15.62	9.03	7.02
	Specification limits (4-B)*	100	80-100	70-90	50-70	30-50	18-29	13-23	8-16	4-10

*Egyptian Standard Specification Limits

Table (2) Polymers Properties

Polymer Type	Density gm/ cm³	Melting Point C	Specific Gravity gm/ cm³	Fire Point C
[illegible]	1.012		1.012	90
[illegible]	1.008	60	0.95	180

Table (3) Penetration of Asphalt Modified Polymers

Asphalt Modified-Polymer	S.B.R						H.D.P.E					
Polymers % by Asphalt weight	0.0	0.2	0.5	0.7	1.0	2.0	0.0	1.0	2.0	4.0	6.0	8.0
Penetration at 25° C	65	59	51	60	68	71	65	61	53	49	54	60

Also, the penetration of asphalt and asphalt modified-polymers for different levels of H.D P E and S B R were determined (Table 3)

TESTING PROCEDURE

MARSHALL TEST

The Marshal test was earried out in conformity with the ASTM test method D-1559. Test specimens were immersed in a water bath at 60° C for 30 minutes before testing The following formulations were selected for analysis.

- Mix type (A): Samples of aggregate were blended with 4.5 to 6.5% asphalt content by weight of aggregate at increments of 0.5%. The mixing process was according to the specification of the standard test.
- Mix type (B): combination of aggregate with the same binder content in (A), were blended after modifying the asphalt with a high density polyethylene (H.D P.E) at 1.0, 2.0, 4.0 and 8.0% by asphalt weight. A group of test specimens were prepared for each level of (H.D.P E) modifier content.
- Mix type (C): The same procedure followed in mix (B) is repeated with (S.B.R) modifier at 0.2, 0.5, 0.7 and 1.0% by asphalt weight. Also a group of test specimens were prepared for each level of (S.B.R) modifier content.

STATIC CREEP TEST

In this test, the deformation characteristics of asphalt pavement were assessed by means of an unconfined constant load compression test on laboratory specimens. The Marshall specimens could be used effectively in the creep test (9). The formulations selected for testing comprised the same mix groups (A), (B) & (C) selected for Marshal testing.

In carrying out the creep test, the manual CBR apparatus was used, with slight modifications regarding the application of the required loading. The compression machine applied incremental loads to test specimens through the loading head at a constant rate of 12.5mm (0.5 inch) per minute until reaching the full stress (10000 N/m^2 = 14.33 psi). Two dial gauges were used to record the specimen strain and for measuring the loads corresponding to the deformation. These dial gauges were supported in a stationary level and their readings measured the settlement of the loading head.

All specimens were fabricated in Marshall monld with the standard height of 6.25 mm (2.5 inch) and diameter 100 mm (4 0 inch). Test specimens for creep test were prepared as that for Marshal method of design for both conventional and polymers mixes. The two flat ends of the specimen were prepared to be completely parallel

After preparing the specimen, it was placed in a specially prepared mould having dimensions of 300 mm (12.0 inches) diameter and 350 mm (14.0 inches) height and laid in a large water bath

The water bath was utilized to transmit the required temperature to testing specimen by using a controlled heating system. A digital electronic thermometer was employed to regulate the specimen temperature until reaching the required test temperature (60° C) which is the same temperature as for both Marshall and wheel tracking test. The specimen is left inside the water bath for a period of time equal to 30.0 minutes before loading. A Mechanical dial gauge system was used to record the specimen deformation. After finishing this process the specimen was conditioned by a pre-load of 18.0 Ib, required to give pre load stress of 1 433 psi (1×10^4 N/m²) for two minutes before complete loading, and then the dial gauge reading is recorded as initial reading The full load 180 0 Ib required to give the final stress 14.33 psi (1×10^5 N/m²) is then applied and the vertical deformation of specimen is recorded, at 15,30,45,60 minutes, 2 0, 3 0 and 4.0 hours

After determining the total deformation, the stiffness of the mix was computed as follows

$\varepsilon_{mix} = \Delta h / h_o$

$S_{mix} = \sigma / \varepsilon_{mix}$

Where:

Δh = total deformation of the specimen under the load (inch)

h_o = the original specimen height (inch).

ε_{mix} = total strain

σ = applied stress (14.33 psi)

S_{mix} = stiffness modulus (psi).

WHEEL TRACKING TEST

Wheel tracking test is a simulative rutting test developed by the British Road Research Laboratory (10), to evaluate the resistance to deformation of dense bituminous mixtures. A series of rutting test samples were formulated on the basis of the Marshall test results, and in particular Marshall density. The following formulations were selected for analysis

- Group mix (A): For the conventional mix at optimum asphalt content
- Group mix (B): For the high density polyethylene mix at 1 0,2 0,4 0 and 8.0 percentage of H D.P E by asphalt weight at optimum binder content for each case
- Group mix (C): For the styrene butadiene rubber mix at 0 2, 0 5, 0.7 and 1 0 percentage of S.B R by asphalt weight at optimum asphalt content for each case

All specimens were tested in a wheel tracking machine under a constant repeated stress of 6 254 kg/cm², equivalent to that of contact stress of a heavy bus or truck The rutting deformation was recorded with time or number of wheel passes (n) The test were performed at the same temperature of the Marshall and static creep test (60° C), which represented the maximum temperature affecting pavement in Egypt during summer

Each testing specimen was prepared in a rectangular mould having inside dimensions of 444× 335× 50 mm. The mould was cleaned and a thin even coating of slurry is applied to the inner surface of the mould to prevent adhesion between the specimen and mold. A quantity of mixture calculated to fill the mould based on the density of the Marshall test results at optimum binder content was mixed thoroughly until a homogenous mixture was obtained. The mixture was then pushed in a pre-heated mould at a temperature of 140° C The amount of material put into the mould was measured to be sufficient to fill the mould. The material was tamped into the mould using a square-ended 60 0 × 60 0 mm steel tamper making sure that the corners of the mould were well filled The upper surface of specimen was covered with a metal plate having dimensions of 430× 320 mm and 20 mm thickness Specimens were compacted under constant static load of about 150.0 ton for five minutes using the compression testing machine till the required density is achieved. The test specimens were compacted using compression testing having a maximum capacity of 180 tons

The mould with the specimen inside was then removed from the machine and allowed to cool for one day prior to testing. The obtained unit weight values of specimens were in the range of 1 0% of that obtained from Marshall test

The wheel tracking machine consists of a 200mm diameter, 50mm width loaded rubber-tyre wheel travelling in a straight line over a reciprocating table. A motor and a reciprocating device give the table a to-and- fro motion of 42 0 passes per minute with a travel distance of 330 mm The reciprocating table, mounted on sealed grease-packed ball races, is driven by a flywheel. A radial arm carrying a calibrated weight and the ball bearing mounted rubber-tyre wheel, pivot on centered bronze bearings on a steel shaft, which is adjustable to the height of the specimen

When running the test, the tyre wheel indents a track in the specimen. A load on the wheel of 62.54 kg is used. This load is obtained by suspending about 13456 g on the hook at the end of the wheel frame. The rut depth is recorded at the midpoint of its length at 5.0 minutes intervals for one hour by a cam and a dial gauge which reads to the nearest 0 127mm (0 005 inch).

Deformation- time curves were drawn and the mean rate of increase of track depth is measured between 30 0 and 45.0 min. of the test period. The results were represented in one rutting parameter, including the tracking rate (TR), which was expressed in mm/hour.

TEST RESULTS AND ANALYSIS

In this respect. H.D.P E. addition, at four levels (1.0,2.0.4.0 and 8 0 % by asphalt weight) as well as the SBR latex addition at four levels (0.2.0 5,0.7 and 1.0 %) were added to asphalt mixes with different asphalt contents (4.5,5 0,5 5,6 0 and 6.5%) The effect of these modifiers on mix properties and especially on rutting properties of asphalt concrete as measured by Marshall, Static creep and Wheel tracking tests were evaluated

MARSHAL TEST RESULTS

The results of this test permit the analysis of the different mixes with respect to the following

Stability

It was anticipated that the dispersion of high-density polyethylene in preheated asphalt at temperature of approximately (120 – 150° C) would import more flexibility to the asphalt mixes It is noticed in Figure (1) that, the high density polyethylene mixes exhibit higher stability than the control mix (H.D.P E=0.0%), and it is found that for mix containing 4 0 % H D P.E. the maximum stability value (3833.0 lb) at optimum binder content (6 0%) is greater than that of the control mix (2440 lb) (at 5.25% asphalt content) which means an increase of the stability by about 57.0 %. Also it is realized that, as the H.D.P E content increases from 1 0 to 4.0 percent, the stability increases from 2550.0 to 3833.0 lb at the optimum binder content for each mix. Also, in Figure (2) and Table (4) the stability of S.B R. mixes increases as the S B.R content increases from 0.0 to 0.5% to reach 3110 lb at 0.5% S B.R which means an increase of 27% above that of the control mix within range of 1 to 4% H D P.E and 0 2 to 0.5% S.B.R both H D.P.E and S.B R binders are still having a suitable consistency to cover all aggregate particles resulting in a strong bond between aggregate particles and leads to higher stability value which explains the increase in stability values.

However when the H.D.P E content is increased from 4 0% to 8 0% and the S.B.R is increased from 0 5 to 1 0% the stability decreased The H D P.E mix stability decreased from 3833 lb at

(4 % H.D.P.E) to 2950 lb (at 8% H.D P.E) which is still higher than the stability value of the control mix 2440 lb. Also the S.B.R mix stability was reduced from 3110 lb at 0.5 % S.B.R to 2140 lb at 1 0 % S B.R , but this latter value is lower than that of the control mix. This decrease of stability could be related to the increase of the penetration of asphalt modified polymers for H D.P.E between 4.0 % and 8.0 % and S.B.R mixes between 0.5 % and 1.0 % as given in Table (3) . and whieh means a weak bond between aggregate partieles leading eonsequently to a mix with lower stability.

Also, it has to be noted that the maximum value of stability obtained with S B.R mixes is 3110 lb at 0.5 % S B.R (with optimum binder content equal 5.9 %) is lower than the value (3833 lb) obtained with high density polyethylene mix with 4.0% H.D.P.E at optimum binder content 6 0%

Table (4) Marshall Test Results for Different Mixes at Optimum Binder Content

	Mix Type	O.B.C* %	Stability Lb	Density gm/cm³	Flow 0.01 inch	AV %	VMA %
	Control Mix	5.25	2440	2.308	11.5	4.00	15 23
	1%	5.3	2550	2.304	10.0	4.0	15.4
	2%	5.6	2849	2.301	10.8	4.0	15.5
H D P.E	4%	6.0	3833	2.283	12.0	4.0	16.6
	8%	6.2	2950	2.281	14.3	4.0	16.8
	0 2%	5.6	2820	2.299	10.5	4.0	15.8
S.B.R	0.5%	5.9	3110	2.289	11.1	4.0	16.4
	0.7%	6.0	2710	2.287	11.4	4.0	16.6
	1.0%	6.2	2140	2.281	14.6	4.0	16.9

- O.B C = Optimum Binder Content

Density

It was notieed that, during dispersion of high density polyethylene particles in pre-heated asphalt cement, it swells up to 1.1 to 1.2 times its original size This high increase in binder volume is accompanied by constant binder weight. Thus, by keeping the aggregate weight constant, the density of high-density polyethylene mixes would be lower than that of the control mixes at different levels of H.D.P.E. These swollen particles collect filler particles around them forming larger particles, which restricts the sliding of aggregate against each other during compaction and results in lower densities especially for higher H.D.P E. percentage such as 8.0% H.D P.E.
The same behaviour was noticed with the addition of styrene butadiene rubber to asphalt leading to a lower density of mix than in case of conventional mix (S B R =0 0 %). This decrease in density is due also to the increase of swollen styrene butadiene rubber particles. which may restrict the aggregate particles from sliding against each other's easily during compaction process The density values for high density polyethylene and styrene butadiene rubber mixes at optimum binder content of each mixare given in Table (4)

Flow ·

When examining the flow values of high-density polyethylene mixes and styrene butadiene rubber mixes given in Table (4), it is noticed that the mixes at 1, 2 and 4% H D P E and mixes with 0.2, 0 5 and 0.7% S.B R at optimum binder content of each mix exhibited flow values less than that of the control mix This could be explained by the previously mentioned fact, that the high-density polyethylene particles and styrene butadiene rubber particles during dispersion of particles in pre-heated asphalt cement tend to collect filler particles around them forming larger particles which increase friction between aggregate particles, and as a result, decrease the flow of the mix.
On the other hand, the measured flow values for the mixes at 8 0 % H.D.P E and 1% SBR are higher than that of control mix at optimum binder contents of each mix.

Air Voids :

Since the % air voids is a function of both compaction and density and the density of high-density polyethylene mixes and styrene butadiene rubber mixes exhibited lower density than control mix at all levels of binder content, therefore an increase in % air voids is anticipated.

As discussed before the density decreased as H.D P.E or S.B R percent increased due to the increase of resistance to compaction resulting from the formation of large particles around H D P.E or S B R particles. This effect resulted in rooms between aggregate particles, which, consequently increased the air voids for H D.P E mixes and S B.R mixes at all levels of asphalt content than for control mix (without additives).

In this study, the 4 0 percent air voids is considered the key value for design This value is considered the central premise in superpave mixture design (11) Fortunately, other design criteria (stability 1980 Ib, V.M A min 13 5 and flow 8-16) have been satisfied for all mixes at 4 0% air voids.

Voids in Mineral Aggregates:

From Table (4), it is notieed that, H D.P.E mixes and S B.R mixes at optimum binder content of each mix exhibit higher V.M.A values than control mix. The V.M.A values increase as H D P E or S.B R percent increases.
This could be explained by the fact that the high consistency of asphalt modified with H.D.P E or S.B R forms a thicker film around aggregate particles and consequently less absorption of the binder resulting in an increase of V.M A for H.D P E mixes and S B R mixes than that for control mix

Also, the increase of H.D.P E or S B.R content produce higher consistency of asphalt modified binder. and in presence of filler, forms large particles that restrict the compaction process. This effect results in an increase of V M A values for H D.P.E mixes and S B.R mixes with the increase of H.D P.E or S.B R content

STATIC CREEP TEST RESULTS

The detailed list of creep test results carried out on control mixes at variable binderpercentages (4.5,5.0,5 5.6.0 and 6.5 %) are given in Table (5). It is expected that, the increase of binder content above the optimum reduces the mix stability and thus, raises the ability of mixes to flow under loads which explain the decrease of stiffness at higher asphalt content (above optimum value of binder content). The creep curves after two hours (120.0 min.) are determined with enough accuracy to allow comparison between different mixes Therefore, the stiffness after 120 0 minutes will be kept fixed in this analysis to study the effect of binder content on creep strain for various mixes.

When examining the creep test results in Table (5), it is noticed that the stiffness for control mixes at variable binder percentages (4 5,5.0,5 5,6.0 and 6.5 %) increases by 25.3% as asphalt content increases from 4.5 to 5 5%, while it decreases by about 10% as asphalt content increases from 5.5 to 6 5 %. Consequently, as given in Table (5) the total strain decreases as the binder content increases from 4 5 to 5 5%. This total strain increase above optimum aspbalt content may be explained by the increased ability of mix to flow under loads at higher binder contents

Table (5) Static Creep Test Results for Conventional Mix (Mix A) at Variable Asphalt Contents

A.C %	Time (min)	15	30	45	60	120	180	240
4.5	Strain (in/in $x10^{-3}$)	5.82	6.07	6.28	6.52	6.76	6.97	8.57
	Stiffness (psi)	246.2	236.0	28.1	219.7	211.9	205.5	167.2
5.0	Strain (in/in $x10^{-3}$)	5.097	5.34	5.543	5.741	5.899	6.079	6.241
	Stiffness (psi)	281.1	268.3	258.5	249.6	242.9	235.7	229.6
5.5	Strain (in/in $x10^{-3}$)	4.505	4.795	5.0	5.18	5.396	5.33	5.654
	Stiffness (psi)	318.1	298.9	286.6	276.6	265.6	259.1	253.4
6.0	Strain (in/in $x10^{-3}$)	4.864	5.107	5.339	5.529	5.643	5.839	5.964
	Stiffness (psi)	294.5	280.6	268.4	259.2	253.9	245.4	240.3
6.5	Strain (in/in $x10^{-3}$)	5.121	5.315	5.370	5.698	5.876	5.996	6.18
	Stiffness (psi)	279.8	269.6	257.2	251.4	243.8	238.9	231.8

Creep test was also run on different H.D P.E mixes (Mix B) and S.B R mixes (Mix C) with binder eontents (4.5,5.0,5.5,6.0 and 6.5%) at different percentages of H D P.E (1.0, 2.0, 4.0 and 8.0 %) for H D.P.E mixes and S.B R pereentages of (0.2, 0.5, 0.7 and 1.0 %) for S.B R mixes The stiffness value versus time for mixes B and C are illustrated in Figures (5) and (7) respectively Also, the test results at 120 minutes for the different mixes (B and C) at optimum binder content are given in Table (6) and the deduced maximum stiffness of each mix at optimum binder content versus H.D P E % and S B.R % are given and Figures 6 and 8 respectively and Table (7)

From Table (7) it is noticed that the stiffness of H.D P E mixes increases from 272 to 611 (psi) as H.D.P E content inereases from 1 to 4% respectively, while it decreases from 611 to 339 (psi) with the increase of H.D P.E from 4 to 8 %. Also, the stiffness of S B.R mixes increases from 334 to 461 (psi) as S.B.R content increases from 0 2 to 0 5 percent respectively, while the increase of S B R content from 0.5 to 1.0% S B R is accompanied by a decrease of the stiffness from 461 to 324 (psi) at the optimum binder content for each mix respectively

Table (6) Static Creep Test Results for (Mixes B & C) after 120 min.

A.C %		H.D.P.E %				S.B.R. %			
		1.0	2.0	4.0	8.0	0.2	0.5	0.7	1.0
4.5	Strain (in/in $x10^{-3}$)	5.765	4.951	3.362	4.487	5.21	3.67	4.56	5.36
	Stiffness (psi)	248.6	289.4	426.2	319.4	275	390.5	314.2	258.66
5.0	Strain (in/in $x10^{-3}$)	5.567	4.387	2.707	4.471	49.1	3.14	4.46	4.77
	Stiffness (psi)	252.73	334.3	529.4	320.48	291.9	456.4	341.3	300.4
5.5	Strain (in/in $x10^{-3}$)	5.018	3.565	2.284	4.40	4.39	3.14	3.54	4.42
	Stiffness (psi)	285.6	401.95	627.41	325.61	326.4	456.4	404.8	324.2
6.0	Strain (in/in $x10^{-3}$)	5.527	3.875	2.345	4.016	3.92	3.1	3.3	4.15
	Stiffness (psi)	2.593	369.8	611.18	356.8	365.6	462.3	434.2	345.3
6.5	Strain (in/in $x10^{-3}$)	5.756	4.037	3.0525	5.103	4.981	3.44	3.78	4.89
	Stiffness (psi)	248.95	354.9	469.52	289.84	287.7	416.6	379.1	293.0

Table (7) Deduced Stiffness (psi) of Various Mixes (B & C) at Optimum Binder Content

Mix Type		Optimum Binder Content (%)	Stiffness (psi) (After 120.0 min.)
Conventional Mix		5.25	256
HDPE	1%	5.3	272
	2%	5.6	395
	4%	6.0	611
	8%	6.2	339
SBR	0.2%	5.6	334
	0.3%	5.9	461
	0.7%	6.0	434
	1.0%	6.2	324

For H.D P.E and S.B R mixes, it is noticed that the maximum stiffness occurs at 4.0% H.D.P E with 6 0 % binder content (optimum value) and at 0.5 % S.B R with optimum binder content 5 9% respectively, where the binder content is still having low consistency This low consistency together with the high effective binder content strengthen the bond between aggregate particles, which increases the mix stiffness, while above the optimum value for each H D P E and S B R mixes (especially at high binder content such as at 8.0 % H.D.P E and at 1% S.B.R) the binder imparts more flexibility to the asphalt concrete and consequently increases the total strain and decreases the mix stiffness.

Also, from Table (6) it can be clearly realized that at 4% H.D.P E at optimum asphalt content for (Mix B) and at 0 5% S.B.R. at optimum asphalt content for (Mix C), exhibit the lowest total strain if compared with those of control mix and other H.D.P E and S.B R mixes respectively

The increase of asphalt content above the optimum reduces the mix stability and consequently the mix stiffness decreases and the total strain increases at higher asphalt contents

As we previously mentioned the swollen high density polyethylene and styrene butadiene rubber particles, increases the friction resistance and consequently restrict the sliding aggregate particles during compaction and thus, the mix stiffness is increased for H.D.P E mixes and S B R mixes if compared with control mix (without additives) In addition to the previous reason, the presence of sulfur content in rubber particles may mix with filler particles forming small needles which in turn increase the friction between particles and, thus, increase the mix stiffness for each styrene butadiene rubber at all S.B R content than control mix.

The low values of strain for mixes with 4 0 % H.D.P.E and 0.5% S.B.R at all levels of asphalt content indicate that, these percentages of H.D P E and S.B.R are respectively the optimum values for improving creep properties of compacted mixes.

Also, it is clear that the obtained maximum stiffness at 0 5 % S.B R (optimum value for S B R mixes) which is 461 (psi), is lower than that obtained at 4 0 % H.D P E (optimum value for H D P.E mixes) which reached 611 (psi)).

WHEEL TRACKING TEST RESULTS

The control mix (A) as well as the polymer mixes (B and C), were tested by wheel tracking machine at the optimum binder content for each mix type

The track depth value after 45 0 minutes is retained as the base of comparison between various mixes The wheel tracking test results are represented in one rutting parameter, including the tracking rate (TR) Which is defined as the rate of increase in track depth measured between 30.0 and 45.0 min of the test period It is used to assess the rutting resistance of bituminous mixes under simulated field conditions and is expressed in mm/hour (12)

The wheel tracking test was run on the control mix at optimum binder content of 5.25 % (without additive), also on H D P.E mixes with variable percentages (1.0,2.0,4.0 and 8 0 % H D P E by asphalt weight) with corresponding optimum binder content (5 3, 5 6, 6.0 and 6.2% by asphalt weight) respectively and on S.B R mixes with S.B R contents (0 2, 0 5, 0 7 and 1 0 %S.B R by asphalt weight)) with corresponding optimum binder content (5 6, 5 9, 6 0 and 6.2 %) respectively Figures (9 and 11) show the measured rut depth for these mixes as a function of loading time during rutting test.

When examining Figurs (9 and 11), it can be noticed that, the rut depth measured for the different mixes increases with time during the first 45.0 minutes. During the last 15 0 min. of the test (between 45.0 and 60.0 min.) the rate of increase of rut depth is small. The rut depth increases at high rate during the first five minutes of the test and than the rut rate decreases with the increase of time to reach its lowest rate (almost negligible) during the last 15.0 min. of the test.

The values of the measured rut depth (after 45.0 minutes) for the different H.D.P E mixes as shown in Figure (10) are 1.194, 0.935, 0.814, 0.689 and 1.187 for 0.0, 1.0, 2.0, 4 0 and 8.0% H D.P.E respectively. The rut depth measured for the mix with 4.0 % H.D.P E is noticed to be the lowest value And referring to Table (8), we find that the measured tracking rates (TR) were (0.965, 0.589, 0 55, 0 344 and 0.644 mm/hr) for (0.0, 1.0, 2.0,4 0 and 8 % H D P E) respectively which proves that the tracking rates for all H.D.P E mixes exhibit lower values than that of the control mix (0.0 % H.D.P.E) The TR value for 4 0 % H D.P.E is lower than those for other mixes (0.0, 1.0, 2.0 and 8.0 % H.D.P.E) by about 60 0 %, 37 0 %, 32.0 % and 40.0 % respectively

Table (8), Wheel Tracking Test Results for Various Mixes at Optimum Binder Content

Mix Type		*Bulk Density (gm/cm³)*	*Wheel Tracking Rate (mm)*
Conventional Mix (A		2.308	0.965
Mix (B) HDPE	1%	2.304	0.589
	2%	2.301	0.505
	4%	2.283	0.344
	8%	2.281	0.644
Mix (C) S.B.R	0.2%	2.299	0.516
	0.5%	2289	0.452
	0.7%	2.287	0.532
	1.0%	2.281	0.724

Also, when examining Figure (12) which illustrates the relation between the rut depth at 45 min and mixes with different percentages of SBR , it is noticed that, the rut depth decreases as the S.B.R content increases from 0.0 % to 0 5 % S.B R. while it increases at SBR content of 1% This trend could be related to the measured resulting decrease in asphalt penetration from 65.0 to 51.0 for mixes with 0.0 % to 0.5 % S.B R and the measured increase of asphalt penetration to 68.0 for mix with 1 0 % S.B R content at temperature of 25° C . The same trend is also noticed for H.D P E mixes and can also be related to the asphalt mix penetration, where the measured penetration decreased from 65 to 49 for mixes with 0.0 % to 4 % H.D P E and increased to 54 and 60 for mixes with 6% and 8 % H D.P E content respectively at temperature of 25° C.

The relation between the tracking rate (TR) and styrene butadiene rubber content (0 0, 0 2, 0 5, 0.7 and 1 0 %S B.R by asphalt weight) at the optimum binder content for each mix, is illustrated in Table (8) The T R value for 0.5% S.B.R is lower than those for other mixes (0 0, 0 2, 0 7 and 1 0% S B.R) by about 54.0 %, 10.3 %, 15 7 % and 37 7% respectively Consequently it can be deduced that the best resistance to rutting of asphalt concrete mixes, can be achieved by using 0.5 % styrene butadiene rubber But this improvement is considered low when compared to that obtained using 4.0% H.D P.E

CONCLUSIONS

The main conclusions deduced from the results obtained during this experimental investigation of the effect of adding two types of polymers (high density polyethylene and styrene butadiene rubber) on rutting characteristics of asphalt mixes could be summarized as follows

1 Polymer mixtures (high-density polyethylene and styrene butadiene) exhibit higher stability, lower flow values, lower unit weights, higher air voids and higher voids in mineral aggregate than conventional mixes.

2 The highest mix stiffness values obtained in standard creep test corresponded to mixes with 4 0 % H.D P E (by asphalt weight) and 0 5 %S.B R (by asphalt weight) for high density polyethylene mixes and styrene butadiene mixes respectively.

3. The increase of binder content (above the optimum value) reduces the mix stability and thus. raises the ability of mixes to flow under loads resulting in a decrease of the mix stiffness.
4 The addition of high-density polyethylene or styrene butadiene rubber to asphalt eement improves the workability of mixes by improving the mechanical properties of the aged asphalt.
5 The penetration measured decreased as H D.P.E and S B.R percentages increased up to 4 % and 0 5 % respectively, while the penetration increased with the increase of additives percentages above these optimum values
6 The asphalt penetration could be considered as an indicative parameter of the degree of improvement of asphalt mixes to rutting resistance
7 The addition of high-density polyethylene and styrene butadiene as a binder to mixes causes an appreciable reduetion in rutting depth when compared with conventional mix especially at high temperatures

REFERENCES

1 Dawely, C.B., Hogewiede, B L. and K.O Anderson. " Mitigation of Instability Rutting of Asphalt Concrete Pavements in Leth bridge, Al berta, Canada, Syposium: Additives, Modifiers and Other Means for Improved Rut Resistanee of Asphalt Concrete Mixtures, AAPT Journal, Volume59, 1990
2 Davis. R . " Discussion on In Place Rutting", AAPT vol.58.1989
3. "Asphalt pPavement Rutting, Western states". Report No. FHWA. Ts-84/211,Mey 1985.
4 Monismith, C.L "Rutting Prediction In Asphalt Concrete Pavements", Transportation Research Record No 616, Washington, D.C 1976
5. Monismith, C L "Rutting Prediction In Asphalt Concrete Pavements". Transportation Researeh Record no 616, Washington, D.C 1976.
6 Van de Loo, P.J. " Practical Approach to the Prediction of Rutting in Asphalt Pavements. the Shell Method". Transportation Research Record No 616,Washington D.C . 1976.
7 Anani, B.A., Balghunaim, F.A. and Al-Hazzaa, A.S . "A Laboratory and Field Study of Pavement Rutting in Saudi Arabia". TRB, 69th Annual Meeting, Washington, D.C., Jan., 1990, PP.1-31.
8 Asphalt Institute, " Mix Design Methods for Asphalt Concrete ", College Park, M.D., M S -2. 1988.
9. Brauer, M.G.. " An Evaluation of the Sheel Creep Test Procedure to Predict Rutting in Asphalt Pavements." Final Report on Phase 2. January, 1982
10 "Procedure for the Manufacture and Testing of Wheel tracking Test Specimens." Materials Division, TRRL, London, March, 1976.
11. Gennis, Mc, R B., "Back Ground of SUPERAVE Asphalt Mixture Design Analysis", FHWA-SA-95-003, U.S.A, 1995.
12 Please, A., "A Wheel-Tracking Test to Compare the Resistance to Deformation of Rolled and Mastic Asphalt", 4th International Asphalt Congress, London, 1982
13 El-Said., M A., "Effect of Mixing Technology on Hot Asphaltic Mixtures Properties", M. Sc . thesis, Zagazig University, 1996
14. Lewandoski, L.H., "Polymer Modification of Paving Asphalt Binder" Rubber Chemistry and Technology, Vol. 67 No 3, 1994.
15. Kamal, H S.. "Improvement of Rutting Resistance of Recycled Hot Asphaltic Concrete Mixes", M.Sc Thesis, Al-Azhar University,1995

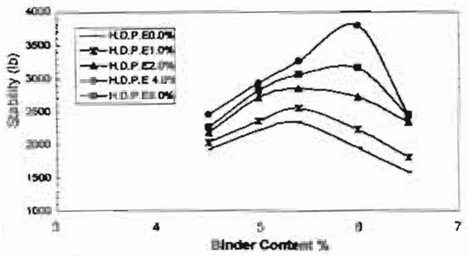

Figure (1) The Stability for different Levels of H.D.P.E at valable Binder Content

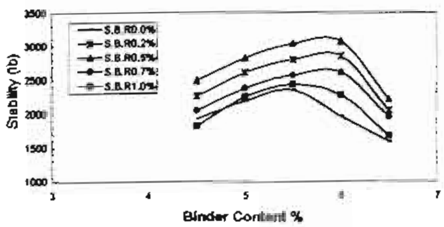

Figure (2) The Stability for different Levels Of S.B.R. at Variable Binder Content

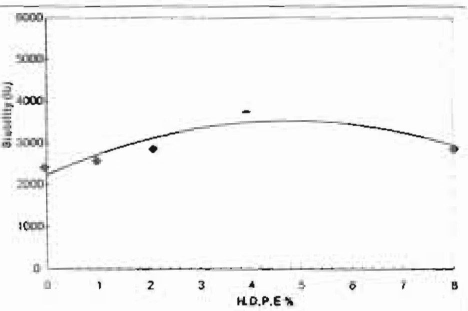

Figure (3) Variation of Stability with H.D.P.E % at Optimum Binder Content

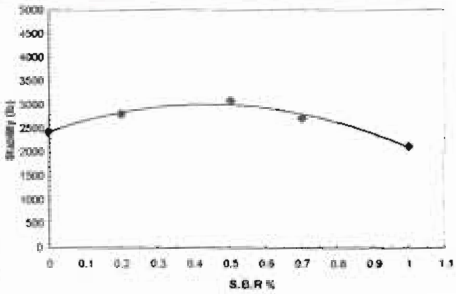

Figure (4) Relationship between Stability and S.B.R % at optimum Binder Content

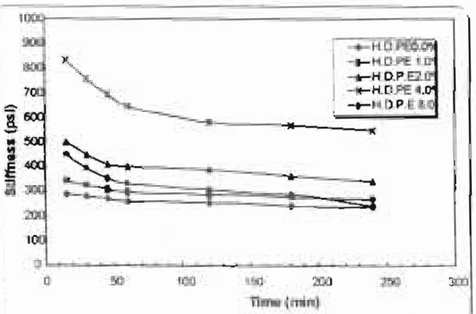

Figure (5) Stiffness versus time for Different Levels Of H.D.P.E at Optimum Binder Content

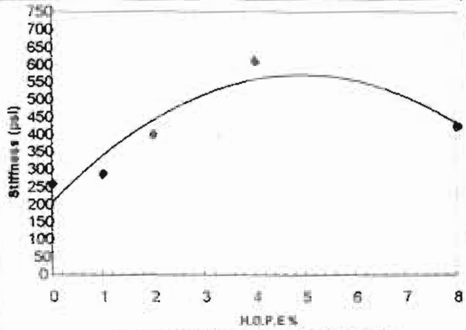

Figure (6) Relationship between Stiffness and H.D.P.E % at Optimum Binder Content

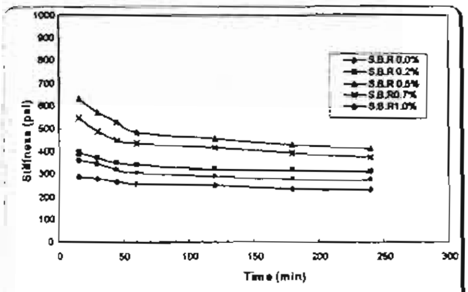

Figure (7) Stiffness from Static Creep Test for Different % of S.B.R. at Optimum Binder Content

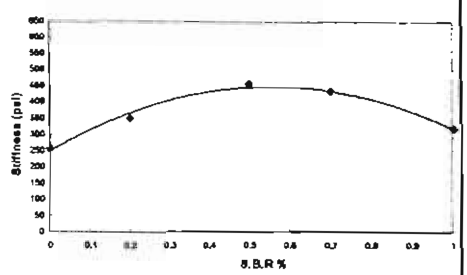

Figure (8) Relationship between Stiffness and S.B.R % at Optimum Binder Content

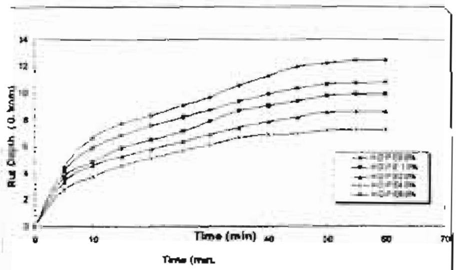

Fig (9) Rut depth versusTime Measured for Different %of H.D.P.E. Mixes at Optimum Binder Content.

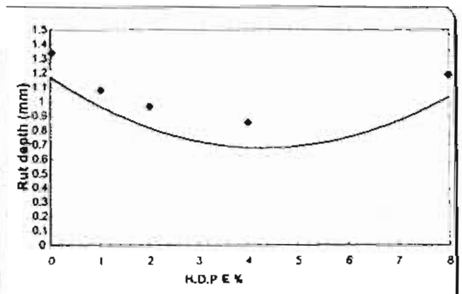

Figure (10) Relationship Between Rut Depth after 45 min. and H.D.P.E. % at Optimum Binder Content

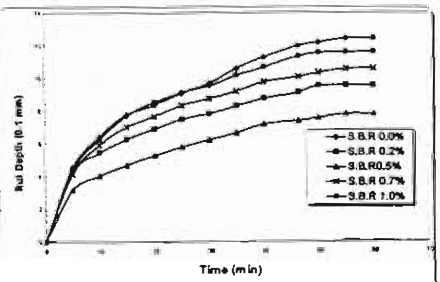

Figure (11) Rut Depth versus Time for Different % of S.B.R. Mixes at Optimum Binder Content.

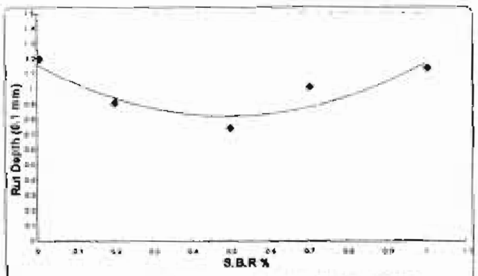

Figure (12) Relationship between Rut Depth after 45 min. and S.B.R % at Optimum Binder Content