INFLUENCE OF RUBBER CONSTITUENTS ON PERFORMANCE OF ASPHALT PAVING MIXTURES

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ABSTRACT

Environmental problems created by discarded waste rubbers, such as potential fire and disease hazards, have become significant in recent years. In connection with rubber recycling, a comparative study of laboratory performance of application of two polymer types: styrene butadiene rubber (SBR) and polyethylene–vinyl acetate (PVA) in asphalt paving mixtures is presented. These mixtures are usually employed in construction the surface courses in Iraq. These modified asphalt mixtures were prepared with asphalt cement previously modified by using three percents of polymer (1, 3 and 5) percent by weight of modified asphalt. Two control mixes are adopted for comparison purpose. The first control mix was produced with 40/50 penetration asphalt cement while the second was produced with 60/70 penetration asphalt cement.

To evaluate the mixture characteristics of the modified and conventional mixes: laboratory tests of Marshall, indirect tensile strength, indirect tensile resilient modulus, indirect tensile fatigue and incremental indirect tensile creep were conducted on a compacted Marshall specimens. The VESYS 5W software program was used to investigate the effect of polymer type on rut depth occurring in whole selected pavement structure.

The results of the present study indicated that the modified mixtures exhibited higher tensile strength characteristics than the control mixtures. The modified asphalt mixtures showed overall better performance indices (rut depth and fatigue cracks) than the corresponding control mixtures. Also, the addition of (SBR) polymer type to the mixture improves asphalt mixture performance, especially, when it is added by 1 % by weight of asphalt.

KEYWORDS

Rubber recycling, styrene butadiene rubber (SBR), polyethylene–vinyl acetate (PVA), indirect tensile strength, indirect tensile resilient modulus, indirect tensile fatigue and rut depth.

الخـلاصـــة:-

أن المشاكل البيئية المتولدة عن طرح مخلفات المطاط والمتمثلة بالحرائق والأمراض تعد من القضايا التي اكتسبت اهتمام كبير في السنوات الأخيرة. ولأجل تدوير مخلفات المطاط، تم تقديم دراسة مختبريه للمقارنة بين أداء تطبيق نوعين من البوليمرات هما styrene butadiene rubber (SBR) و polyethylene-vinyl acetate (PVA) في خلطات التبليط الإسفلتي. أن هذه الخلطات تستخدم عادة في إنشاء الطبقة السطحية في العراق والتي يتم تحضيرها باستخدام الإسفلت الأسمنتي والذي يعدّل باستعمال ثلاث نسب من البوليمر (١,3,٥) بالمائة وزناً من الإسفلت المُعَدل. تم اختبار خلطتي سيطرة لغرض المقارنة حيث أن خليط السيطرة الأول أُنتج باستخدام أسفلت أسمنتي ذو اختراق 40/50 بينما الثاني أُنتج باستخدام أسفلت أسمنتي ذو اختراق 60/70.

لتَقييم خصائص الخلطات المُعَدَّلة والسيطرة أجريت الاختبارات التالية على نماذج مارشال المحدولة وهي مارشال، مقاومة الشد غير مباشر، معامل الرجوع الدّ غير المباشر، الكلل شدّ غير مباشر والزحف التراكمي شدّ غير مباشر. تم استخدام برنامج VESYS 5W لبحث تأثير نوع البوليمر على عمق التخدد الحاصل في منشأ التبليط الكلي المختار.

تشير نتائج هذه الدراسة إلى الخلطات المُعَدَّلة أظهرت خصائص مقاومة الشدّ أعلى من خلطات السيطرة. كذلك أظهرت الخلطات الإسفلتية المعدلة عموماً مؤشرات أداء (عمق تخدد وشقوق كلل) أفضل من خلطات السيطرة. كذلك أظهرت الخلطات الإسفلتية المعدلة عموماً مؤشرات أداء (عمق تخدد وشقوق كلل) أفضل من خلطات السيطرة المقابلة. أخيرا" فيما يتعلق بنتائج البحث فان إضافة نوع بوليمر (SBR) إلى الخليط يحسن أداء الخليط الإسفلتي، خصوصاً عندما يضاف بمقدار ١% من وزن الإسفلت.

INTRODUCTION AND BACKGROUND

Presently and into the future, waste rubber (for example tires, tubes…….etc) could potentially become a serious environmental problem. Many methods have been used to dispose waste rubber. One method is to recycle waste by cutting and scraping them into small sizes down to powder particles and reuse as reclaimed rubber material. The use of reclaimed rubber as an additive in various types of bituminous construction not only solves a waste disposal problem and offers the benefit of resource recovery; it is also of interest to the paving industry because of the additional elasticity imparted to the binder and pavement system (Nukulchai et al., 2007).

Many asphalt additives are polymers and the interaction with asphalt may result in a complex blends. The polymer may have no interaction with the asphalt (phase separate), partial interaction (swollen polymer domains), or strong interaction (thermodynamic dissolution of polymer). Polymer additives differ in molecular weight, shape (linear, branched, star, etc…), repeat unit …etc. Polymer amount, strain and thermal history may alter the morphological and physical properties of the modified asphalt (Wegan and Brule, 1999). In particular, the relationship of fatigue properties to asphalt chemistry is not well understood and the incorporation of additives only complicates an analysis (Little et al., 1999).

The ability of polymer-modified asphalts to improve asphalt pavement resistance to permanent deformation is well documented (Institute for Transportation Studies, 1994 and Bahia et al., 2001). In cases where high-quality aggregates are used, polymer modification for the purpose of permanent deformation resistance may not be necessary, at least for some airfield asphalt mixtures. However, modified asphalt mixtures may either degrade or enhance asphalt mixture fatigue life as measured by flexural beam tests (Institute for Transportation Studies, 1994 and Newman, 2000).

Studies by Harvey and Monismith have shown that the addition of a modifier to certain asphalts may reduce the number of strain cycles to failure or increase the rutting. The same modifier mixed with other asphalt produced opposite results in that the fatigue life increased and rutting decreased (Harvey et al., 1994, Harvey et al., 1995, Harvey et al., 1997). These studies indicated that the modifiers had different effects on mix stiffness, fatigue life and the cumulative dissipated energy. Stiffness of unmodified asphalt mixtures and cycles to failure in flexural beam tests has been shown to correlate well with fatigue life. Fatigue life estimates using ‘surrogate’ stiffness of asphalt mixtures were developed for cases in which beam testing was not available. However, with polymer-modified asphalt mixtures, fatigue life models were unreliable. Khattak and Baladi have shown significant effects of modifier type, concentration on fatigue and indirect tensile properties (Khattak and Baladi, 2001).

Many factors contribute to the degradation of asphalt pavements. When high quality materials are used, distresses are typically due to traffic loading, resulting in rutting or fatigue cracking. Environmental conditions such as temperature and water can have a significant effect on the performance of asphalt concrete pavements as well. The presence of water (or moisture) often results in premature failure of asphalt pavements in the form of isolated distress caused by debonding of the asphalt film from the aggregate surface or early rutting/fatigue cracking due to reduced mix strength. Moisture sensitivity has long been recognized as an important mix design consideration. The moisture affects asphalt mixes in three ways: loss of cohesion, loss of adhesion and aggregate degradation. The loss of cohesion and adhesion are important to the process of stripping. A reduction in cohesion results in a reduction in strength and stiffness. The loss of adhesion is the physical separation of the asphalt cement and aggregate, primarily caused by the action of moisture. The air void system in the asphalt concrete provides the means by which moisture can enter the mix. Once moisture is present through voids or from incomplete drying during the mixing process, it interacts with the asphalt-aggregate interface. Numerous test methods have been developed and used to evaluate the moisture susceptibility of HMA mixes (Taylor and Khosla, 1983 and Khosla, 2000).

* EXPERIMENTAL WORK

Material

Asphalt cement 40/50 and 60/70 brought from Daurah refinery with the physical properties given in Table (1), were used in the present study. Coarse and fine aggregate, Bulk specific gravity of 2.77 and 2.68 respectively, were used in the preparation of the asphalt concrete mixtures. Limestone was used as mineral filler which was obtained from Karbala'a factory with specific gravity of 2.773. Table (2) presents the selected mix gradation for surface course.

Table 1: Properties of used asphalt cement.

Property	Test Results		Requirements Penetration –Graded Asphalt Cement	
			(40/50)	(60/70)
1.Penetration at 25 ^oC , (0.10mm)	48	66	40-50	60-70
2. Ductility at 25 ^oC , (cm)	110	120	>100	>100
3.Specific gravity at 25 ^oC	1.03	1.01	------	-----
4.Flash point ,(^oC)	275	249	>232	>232
5.Solubility in trichloroethylene	99.37	99.26	>99	>99
6.Residue from thin –film oven test - Retained penetration , % of original -Ductility at 25 ^oC, (cm)	 68 57	 61 73	 >55 >25	 >52 >50

Table 2: Selected mix gradation for surface course.

Sieve	19 mm	12.5 mm	9.5 mm	No.4	No.8	No.50	No.200
% Passing	100	95	83	59	43	13	7

In general, polymer types are classified into four main types: polymer latex (or polymer dispersion), redispersible polymer powder, water-soluble polymer and liquid polymer. In particular, the commercial polymer latexes widely used in the world are styrene-butadiene rubber (SBR) and polyethylene–vinyl acetate (PVA). The chemical structures of the (SBR) and (PVA) are (-CH-CH=CH-CH2-CH2-CH-C6H5)$_n$ and (-CH2-CH2-CH2-CH-OCOCH3)$_n$ respectively.

Asphalt mixtures code

The fourteen asphalt mixture types adopted in the present study are listed in Table (3).

Table 3: The code for the six asphalt mixture types.

Asphalt mixture code	Description
Mix 1	Control mix 48 penetration grade asphalt
Mix2	Control mix 66 penetration grade asphalt
Mix3	Modified mix 48 penetration grade asphalt and 1 % SBR polymer
Mix 4	Modified mix 48 penetration grade asphalt and 3 % SBR polymer
Mix 5	Modified mix 48 penetration grade asphalt and 5 % SBR polymer
Mix 6	Modified mix 48 penetration grade asphalt and 1 % PVA polymer
Mix 7	Modified mix 48 penetration grade asphalt and 3 % PVA polymer
Mix 8	Modified mix 48 penetration grade asphalt and 5 % PVA polymer
Mix 9	Modified mix 66 penetration grade asphalt and 1 % SBR polymer
Mix 10	Modified mix 66 penetration grade asphalt and 3 % SBR polymer
Mix 11	Modified mix 66penetration grade asphalt and 5 % SBR polymer
Mix12	Modified mix 48 penetration grade asphalt and 1 % PVA polymer
Mix 13	Modified mix 48 penetration grade asphalt and 3 % PVA polymer
Mix 14	Modified mix 48 penetration grade asphalt and 5 % PVA polymer

Sample prepartions

Asphalt cement content of 5% by weight of total mixture was used based on Marshall Stability mix design method. Polymer of (1, 3 and 5) % by weight of asphalt was used for the tested specimens. The used polymer was blended with the asphalt binder at a temperature of 160^{o}C using conventional mixer. All examined asphalt concrete mixtures were prepared in accordance to (ASTM Designation: D1559-89) (ASTM, 2003) with the standard 75-blow Marshall design method for designing hot asphalt concrete mixtures, designated as using automatic compaction.

Asphalt mixture properties

The Marshall test was performed during the mix design according to the (ASTM Designation: D 1559-89) (ASTM, 2003). This test is performed at a deformation rate of 51 mm/min (2 inch/min) and a temperature of 60ºC. The properties obtained from this test are the Marshall stability and flow. The Marshall stability of an asphalt mixture is the maximum load that the material can be carried when tested in the Marshall apparatus. The Marshall flow is the deformation of the specimen when the load starts to decrease. Stability is reported in (KN) and flow is reported in (mm) of deformation. Three specimens were tested and an average is reported and used in the analysis. Marshall properties at 5% asphalt content by weight of total mix and SCRB (SCRB, 2003) specifications for asphalt mixes used as a surface course are presented in Table(4).

Table 4: Marshall properties of different asphalt mixture types.

Mix type	Asphalt paving properties				
	Marshall stability (KN)	Marshall flow(mm)	Voids in total mix (%)	Voids in mineral aggregate (%)	Voids filled with asphalt (%)
Mix 1	13.6	2.9	4.2	16.2	70.1
Mix2	10.3	3.1	4	15.9	74.8
Mix3	12.7	3.0	4.1	16.0	74.4
Mix 4	12.0	3.1	3.9	14.9	73.8
Mix 5	12.4	3.1	3.9	14.9	73.8
Mix 6	10.7	3.2	3.8	14.9	74.5
Mix 7	10.4	3.2	4.1	16.3	74.8
Mix 8	10.0	3.3	4.2	16.0	73.8
Mix 9	9.5	3.1	4	15.9	74.8
Mix 10	9.0	3.3	3.9	15.8	75.3
Mix 11	8.6	3.3	4.2	16.0	73.8
Mix12	8.5	3.4	4.3	16.3	73.6
Mix 13	7.5	3.3	4.3	16.2	73.5
Mix 14	7.2	3.3	4.4	16.5	73.3
SCRB specification	Min. 8 KN	2-4 mm	3-5 %	Min.14	65-85%

* MECHANICAL BEHAVIOR TESTS

The mechanical behavior of the polymer-modified and unmodified mixtures was evaluated based on the indirect tensile strength**,** indirect tensile resilient modulus, indirect tensile fatigue and the unconfined compressive strength.

Indirect tensile strength test

The indirect tensile strength tests were conducted using the standard method ASTM D4123 (ASTM, 2003). The experimental procedure used to determine the tensile, or splitting, strength of a cylindrical specimen is based on loading it diametrically in compression to create a tension zone along the specimen's loaded diameter. The expression for the maximum tensile strength generated can be stated as:

$$s_t = \frac{2P_{\max}}{p\,HD} \qquad (1)$$

Where σ_t is the indirect tensile strength, Pa, P_{max} is the maximum applied load, N, and H&D is the height and the diameter of the specimen in m, respectively.

Indirect tensile resilient modulus test

The indirect tensile resilient modulus test is conducted at temperatures of 5, 25 and 40ºC according to the modified ASTM D4123 (Mohammad and Paul, 1993). It is a repeated load indirect tension test for determining the resilient modulus of the asphalt mixtures. The recoverable horizontal deformation, δH, was used to calculate the indirect tensile resilient modulus, M_R in eq.2.

$$M_R = \frac{P(0.27 + m)}{t.dH} \qquad (2)$$

Where M_R Resilient Modulus, Pa, P Applied vertical load, N, t Sample thickness, m, µ Poisson's ratio (assumed equal to 0.35 for asphalt concrete mixtures) and δH Horizontal deformation, m.

Indirect tensile fatigue test

To determine the fatigue resistance of the asphalt concrete samples, this test was conducted at 25^oC temperature and applied on the Marshall specimen (101.6mm diameter X 63.5 mm height). The (10%) of the test failure load obtained from indirect tensile test was used as the peak value of the cyclic load with loading duration of 0.10 second followed by a rest period of 0.90 second was applied to the test specimen (Loulizi et al., 2002).The number of cycles were monitored through the duration of test and the test was terminated when the specimen reached to failure. The fatigue testing procedure is described in NLT-350 standard (Spanish Ministry of Public Works, 1990). The failure criteria are related to a decrease in the needed load below 50% of the initial value for each imposed strain. A total of three Marshall Specimens are tested to measure average fatigue life for each mix being studied.

3-4) Incremental indirect tensile creep test

At testing temperature of 40^oC, a compressive stress of 0.138 MPa (20 psi) was applied on the Marshall specimen. The loading times include (3, 5, 10, 100 and 1000 seconds) and rest periods are (2, 2, 2, 4 and 8 minutes). The total permanent strains, ε_P (in/in), at the end of each rest period were measured. In last loading time (1000 seconds), the creep deformations were measured after (3, 6, 10, 30, 60,100, 300, 600, and 1000 seconds) durations. The creep compliance, C (t), at each of these loading durations is calculated as follows:-

$$C(t) = \epsilon(t) / \sigma_o \qquad (3)$$

Where C(t) creep compliance at (1/MPa), $\epsilon(t)$ vertical strain at loading duration t (mm/mm) and σ_o applied stress (MPa).

* RESULTS AND DISCUSSION

Laboratory characteristics of mixtures

Only the surface course mixtures were evaluated in the paper. An average of three specimen results was reported. The air voids for the laboratory test specimens were 4±1%. Fig.1 presents the results of Marshall Tests. It shows that the conventional mixtures had higher or equal values of Marshall Stability than the polymer modified asphalt mixtures.

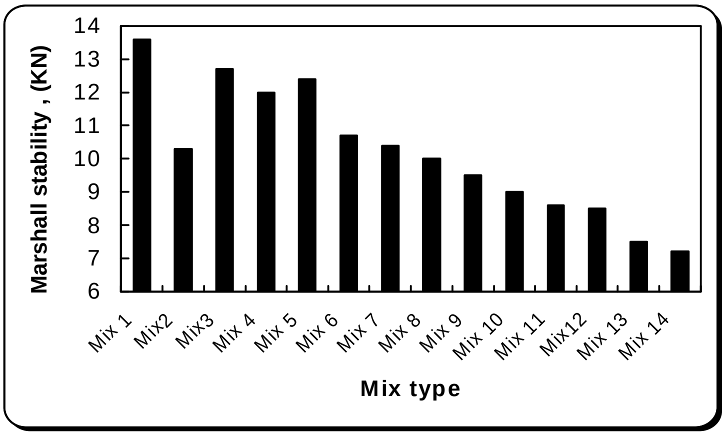

Fig.1: Effect of mix type on Marshall Stability values.

Fig.2 presents the average results of the indirect tensile strength (ITS) test for the surface course mixtures. The present modified mixtures exhibited higher indirect tensile strength values than the two control surface course mixes. Especially, the 1% SBR or PVA polymer modified asphalt mixtures have higher strengths than the other mixture types wearing course mixes. Higher strength indicates the mixes to be more resistance under tension. This characteristic is desired for mixtures to resist fatigue cracks.

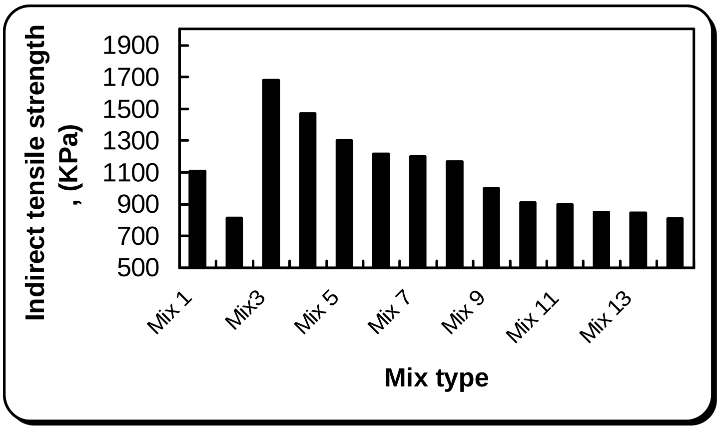

Fig.2: Effect of mix type on indirect tensile strength values.

Fig.3 presents the results of the indirect tensile resilient modulus (MR) of the surface course mixtures at 40°C test temperature. The test results indicated that the modified mixtures exhibited higher values of M_R than the control asphalt mixtures.

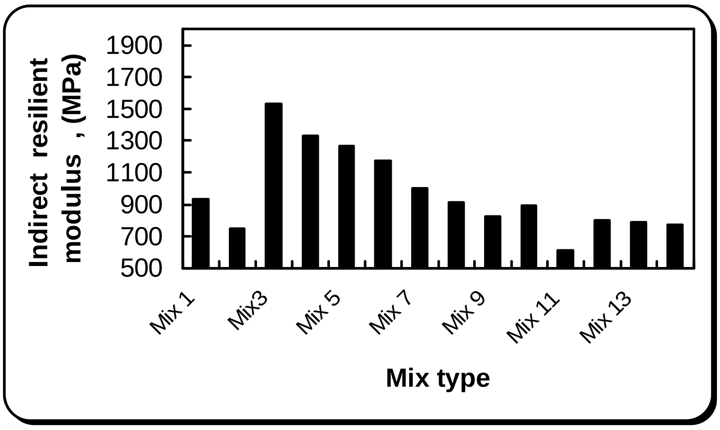

Fig.3: Effect of mix type on indirect resilient modulus values.

The results of the indirect tensile fatigue test for various mix types are presented in Fig.4. While evaluating the fatigue resistance of asphalt concrete mixes, the number of cycles to failure is used as performance indicators. A high number of cycles to failure are the desired properties to resist fatigue cracking.

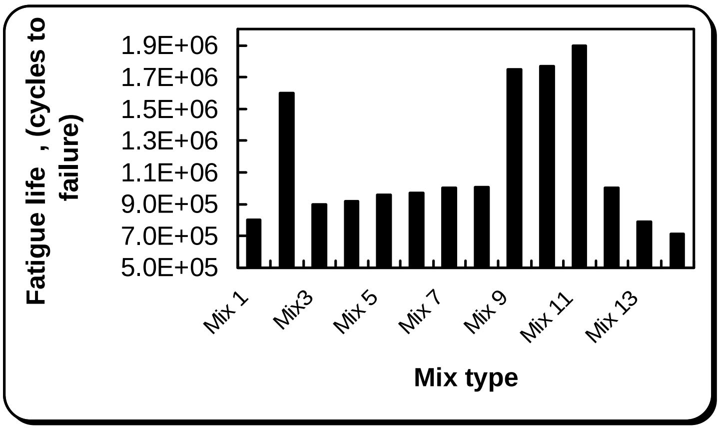

Fig.4: Effect of mix type on indirect fatigue life values.

Fig.4 indicates the modified asphalt mixtures with two selected polymer types (SBR or PVE) exhibited higher resistance to fatigue than the control mixes and the asphalt grade has effect on fatigue life values of modified asphalt mixtures.

Rut depth calculations

VESYS 5W software program is short from Visco-Elastic Pavement System Analysis Program Prediction (FHWA, 2003). The rut depth computed by the VESYS 5W software program is the summation of the permanent deformation of all layers. Therefore, the input data required to the

VESYS 5W software program are material properties of the layers, the thicknesses of each layer, traffic data and environmental conditions. These input data will be described in as follows:

To obtain input parameters required for the VESYS 5W software, an average curve of creep compliance C(t) versus time is constructed on a log-log graph and extrapolated backward to obtain values of C(t) at 0.1 and 0.30 seconds. The total permanent strain versus incremental time of loading is, also, plotted on a log-log graph and the best-fit line is obtained. The intersection of the line with the vertical axis is denoted by (i) and the slope by (s). The permanent deformation properties μ and α are determined as follows: $\mu = (i\times s)/\varepsilon$ and $\alpha=1-s$ where ε is the recovered strain which was obtained from resilient modulus test. Creep properties of various asphalt mixtures at average test temperatures of 40 ^{0}C are obtained by conducting incremental creep test on various mix types.

Resilient modulus values α and μ parameters for surface course were determined from laboratory tests. Cross section of flexible pavement used for a multilane highway is considered in the present study. The selected pavement structure consists of five courses as shown in Fig.5.

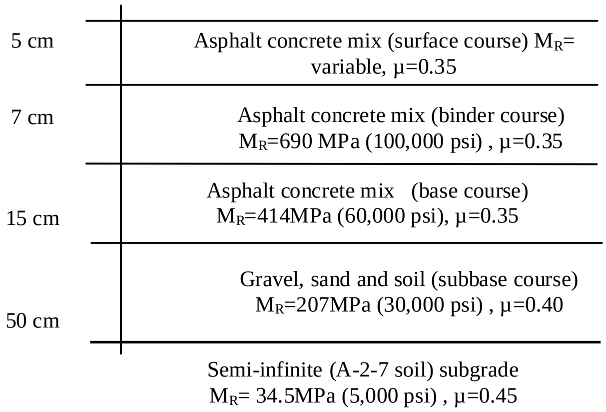

Fig.5: Cross section of the selected pavement structure.

Initially an equivalent 124 MPa (18000 psi) single axle load (ESAL) with dual tires was adopted. Traffic loading is assumed to be one million ESAL with tire pressure of 552 KPa (80 psi) and radius of contact area is 6 inches. Annual growth rate is assumed to be 8 percent. Average temperature of 40^{o}C was used in estimation of rut depth value within selected pavement structure. Fig.6 illustrates the effect of various mix types on rut depth values.

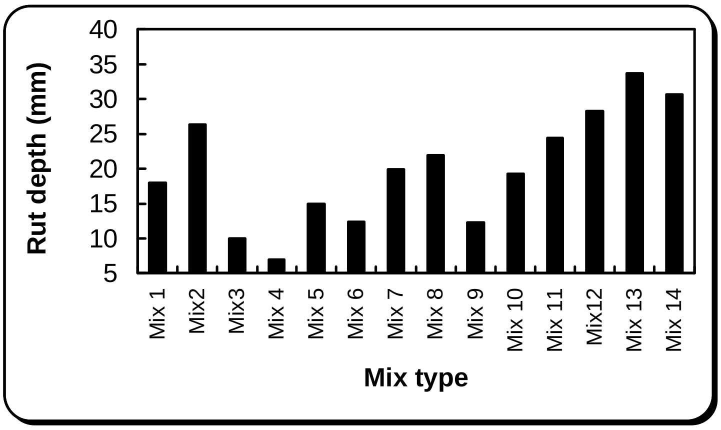

Fig.6: Effect of mix type on rut depth values.

As shown in Fig.6, the addition of polymer to asphalt paving mixture reduces the rut depth values in case using the modified asphalt mixes in construction of surface course for the selected pavement structure especially for modified mixes containing polymer percent of 1% by weight of modified asphalt. Also, the modified mixture with SBR polymer gives rut depth values lower than that modified mixture with (PVA) polymer regardless the polymer percent.

* CONCLUSIONS

- Modified asphalt mixtures with 1% SBR or PVA polymer have higher strengths than the other mixture types. Higher strength indicates that the mixes to be more resistance under tension. This characteristic is desired for mixtures to resist fatigue cracks.
- For the particular asphalt used in the present study SBR and PVA modified polymer mix types affect the number of cycles to failure and would be expected to provide an increased level of protection against cracking due to repetitive loads. Also, the modified asphalt mixtures with two selected polymer types exhibited higher resistance to fatigue than the control mixes and the asphalt grade has effect on fatigue life values of modified asphalt mixtures.
- The rutting distress analysis results shown that the addition of polymer to asphalt paving mixture will reduce the rut depth values in whole pavement courses structure especially for modified mixes which containing polymer percent of 1% by weight of modified asphalt.
- The modified asphalt mixtures with (SBR) polymer show excellent performance (high fatigue life, high tensile strength, low rut depth), especially, at 1% when compared with other modified with (PVA) polymer and control asphalt cement mixes.

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SYMBOLS

$C(t)$	Creep compliance	[1/MPa]
D	Diameter of the specimen	[m]
H	Height of the specimen	[m]
P_{max}	Maximum applied load	[N]
P	Applied vertical load	[N]
M_R	Resilient modulus	[Pa]
t	Sample thickness	[m]

Greek symbols

δH	Horizontal deformation	[mm]
$\epsilon(t)$	vertical strain	[mm/mm]
m	Poisson's ratio	[unitless]
σ_o	Applied stress	[Pa]
σ_t	Indirect tensile strength	[Pa]