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EVALUATION OF ASPHALT MIXES CONTAINING RUBBER

تقييم الخلطات الأسفلتية المحتوية علي مواد مطاطية

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الملخص العربي:

زيادة حمولة المركات علي الطرق المصرية تسبب الكثير من عيوب الرصف. أشهر عيوب الرصف علي الطرق المصرية هي التخدد والشروخ. العديد من الأبحاث حاولت الحد من ظهور تلك العيوب باستخدام بعض الاضافات للخلطة الأسفلتية. وكثير من هذة الأبحاث نجح في تقليل ظهور التخدد علي الطرق الأسفلتية باسخدام بعض الاضفات ولكن وجد أن تلك الاضافات تزيد من إنتشارالشروخ. وأحد الطرق الغير مكلفة لتحسين الخلطة الأسفلتية هوإستخدام بعض المخلفات المطاطية. وهذة الدراسة تهدف إلي تقييم إستخدام المواد المطاطية لتقليل الشروخ في بلاطة الرصف وحساب خصائص تلك الخلطات المستخدم فيها مواد مطاطية. ولتحقيق أهداف، تلك الدراسة تم دراسة خواص الأسفلت المحسن بإضافة نسب مختلفة من المطاط وكذلك تقييم الخلطات الأسفلتية المستخدم فيها مواد مطاطية. ولذا تم إجراء إختبار مارشال علي عدة خلطات بنسب مختلفة من المواد المطاطية كتعويض لنسب متماثلة من الركام الناعم وهي صفر،٤٥،٤٠،٣٥،٣٠،٢٥،٢٠،١٥،١٠%. ثم تم ايضا عمل بعض الخلطات التي إستبدال فيها جزء من الأسفلت بالمطاط وكانت النسب محل الدراسة هي صفر،١٥،١٠،٥% مطاط من وزن الأسفلت.كما تم ايضاإحراء بعض الأختبارات علي تك الخلطات لتقييم ادائها بعد الأنشاء. وهذة الأختبارات هي : فاقد الثبات وإختبار معامل المرونة وإختبار العجلة الترددية وايضا إختبار الشد الغير مباشر. وقد أظهرت نتائج الدراسة ان إستخدام المواد المطاطية يحسن بدرجة كبيرة مقاومة الخلطة للشروخ وفي النهاية أوصت الدراسة بأستخدام نسبة مواد مطاطية ٢٠%و٥%بالوزن من الركام الناعم والأسفلت علي الترتيب.

ABSTRACT

Increasing truck loads on Egyptian road network cause several pavement distresses. The most common distress types occurring in the Egyptian roads are rutting and cracking. Several research studies trials were conducted to control pavement distresses by mix enhancement. Several trials were done to eliminate pavement rutting by using some additives. However, although these additives increase rutting resistance, it increases the propagation of cracking. One of the cheapest methods for mix enhancement is to use waste materials such as crumb rubber. This study aims at investigating the effect of using crumb rubber on the properties of asphalt binder and evaluating asphalt concrete mixtures modified by crumb rubber for increasing pavement resistance to cracking. To achieve the study objectives, the properties of asphalt binder modified by certain ratios of crumb rubber were measured. Furthermore, Marshall test was conducted on standard mix without rubber as a reference and on two groups of asphalt concrete mixtures. In the first group crumb rubber was used instead of fine aggregate by certain percents. While in the second group, crumb rubber was used instead of certain asphalt percents. Finally, some special tests were performed to measure the different mix characteristics. These tests included loss of stability test, modulus of elasticity test, wheel tracking test and indirect tensile strength test. Analyzing the study results it can be concluded that the use of crumb rubber greatly enhance the pavement resistance to cracking. Finally the study recommended a proposed mix with ٢٠٪ and ٥٪ by weight instead of typical percents of sand and asphalt respectively.

Keywords:
Asphalt Mixes, Crumb Rubber, Marshall properties, Loss of stability, Modulus of Elasticity, Wheel tracking Test and Indirect Tensile Strength.

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INTRODUCTION & BACKGROUND

Increasing traffic volumes, heavier loads and poor performance of bituminous mixtures under adverse environmental conditions have led to the increased use and development of modified bituminous binders and asphalt mixtures [1]. The types of modifiers that have been used to improve the mechanical properties under all service conditions included sulphur, rubbers, thermoplastic polymers and thermosetting resins [2]. Many countries around the world are facing challenges regarding their waste materials. One major area of concern is the disposal of wast tires. Today's growing problem has motivated many countries to engage in research to find useful and cost-effective long-term uses for waste tires [3]. In addition to these engineered modifiers waste materials, such as reclaimed scrap tire crumb, have been used to produce Crumb Rubber Modified (CRM) bituminous materials. Such CRM have added environmental benefit of recycling scrap tires that would otherwise be stockpiled. The use of recycled scrap tires in asphalt mixture applications has been used in the asphalt industry for over 30 years.

Several studies were performed to treat the severity of rutting distresses on Egyptian roads. To limit the rutting phenomena many trials were employed. Theses trials included using suitable mix gradation [4], increasing pavement thickness [6], and using asphalt additives [5]. It is of a great importance to notice that, using additives to the mix components will already increases mix stiffness and stability which in turn give higher resistance to rutting [7]. On the other hand increasing mix stiffness will surly increase pavement cracking especially in hot climatic conditions [8]. Several studies recommended to treat the problem of cracking propagation as a result of using asphalt enhancement regarding rutting. Some studies tried to use crumb rubber to discover its ability to resist cracking distresses. It is believed that using rubber increases mix flexibility and therefore minimizes pavement cracking.

Several years ago crumb rubber was used in asphalt mix in the form of either a wet or dry process. In the wet process, CRM binders are produced by mixing finally ground crumb rubber (ranging in size from 0.075 to 1.2 mm) with bitumen at elevated temperatures prior to addition of the aggregate [9]. In the dry process, granulated or ground rubber and/or crumb rubber is used as a substitute for a small portion of the fine aggregate (typically 3 to 4% by mass of the total aggregate in the mixture). The rubber particles (ranging in size from 0.4 to 9.5 mm) are blended with the aggregate prior to the addition of the bitumen.

Chipps et al. [10] reported field implementation of laboratory research. Laboratory work assessed several production methods for blending ground tire rubber with asphalt and also the resulting binder properties, especially as they relate to Superpave performance specifications and durability. Field work included commercial-scale production of high-cure crumb-rubber binders at asphalt supplier sites and monitoring of contractor placement in Texas (1998- 2000). Abd El-Raheem [11] conducted a laboratory study to evaluate the effect of adding synthetic rubber (reclaimed rubber) to asphalt cement on the rutting resistance of asphalt concrete mixes. It was concluded that 10% rubber was the optimum rubber percent which exhibited the greatest improvement for rutting resistance. However the other two percents exhibited an improvement relative to control mix but to less extent.

Research objectives

This study aims at investigating the effect of rubber material on the properties of asphalt binder. It also aims at investigating the use of crumb rubber in producing asphalt concrete mixtures and evaluating the properties of such mixtures regarding to cracking resistance.

METHODOLOGY AND EXPERIMENTAL WORK

To achieve the study objectives, research materials were collected from common sources in Egypt. Qualification tests were conducted on coarse aggregate, fine aggregate, mineral filler, and asphalt materials. The gradation of the different mix materials are presented in Table (1). The properties of asphalt materials mixed with different percents of rubber are presented in Table (2). Results of other material qualification tests are presented elsewhere [12].

Marshall Specimens were prepared for several mixes in two groups. In the first group crumb rubber was used instead of some percents of fine aggregate. While in the second group certain percents of crumb rubber was used as substitution of similar part of asphalt binder. All the properties of the investigated specimens were compared to the original mix without any rubber additives. Some especial tests were conducted on all the investigated mixes. These tests include loss of stability, plastometer, indirect tensile test and wheel tracking test.

Table (1): Gradation of Different Mix Materials (%passing).

Sieve size, inch / Material	3/4	1/2	3/8	No.4	No.8	No.30	No.50	No.100	No.200
Coarse aggregate	100	94.5	73.2	32.2	1.1				
sand				100	98.7	57	40.5	12	0.5
Mineral Filler						100	98.5	93.6	81.7
Crumb Rubber				100	98.7	57	35.5	10	0.4

Table (2): Properties of Asphalt Materials Mixed With Cretin Percents of Rubber

Test No.	Test	AASHTO Designation no.	Results for rubber percent				Specefication limits
			0%	5%	10%	15%	
1	Penetration,0.1mm	T-49	64	65	68	69	60-70
2	Softening point, ° c	T-53	52	52	54	56	45-55
3	Flash point,° c	T-48	+270	+265	+255	+250	+250
4	Kinamatic viscosity,cst	T-201	+345	+340	+330	+315	+320
5	Ductility,cm	T-51	130	145	140	125	≥ 95

Marshall Test

Marshall test method, as described in Egyptian specification was used in this study to find the optimum asphalt content and the corresponding characteristics of the investigated asphalt mixture containing different rubber percents. The procedure of the Marshall test as well as the calculations of all mix properties are presented in Egyptian code for highway works.

Loss of Stability Test

loss of stability test was conducted on Marshall specimens as an indicator for resisting water action by pavement constructed with rubber enhancement. In this test Marshall specimens were placed in water bath and tested at several times (0, 1day, 2days, and three days) to measure the loss in mix stability.

Plastometer Test Method

Plastometer apparatus was used to measure dynamic modulus of elasticity. In this method asphalt concrete mix samples of dimensions 4 x 4 x 16 cm was used. These samples were prepared based on the results obtained from Marshall test. The outline of the method is thoroughly explained by Mohamady [13]. Deflection of tested specimens was recorded each one minute. Afterthat modulus of elasticity was determined through calculating the rheological characteristics of asphalt mix specimens. This modulus represents a dynamic modulus of elasticity corresponding to a loading time of 0.02 second for the asphalt concrete mix.

Wheel Tracking Test Results

The wheel tracking test was conducted on some specimens according to the Egyptian code. Several specimens (3 specimens/ mix) were prepared and tested to study the effect of rubber on the pavement capability to withstand rutting phenomena. Table (3) presents a summary of the different variables, number of mixes, rubber percent, conducted testes and number of specimens per each mix.

Indirect Tensile Test

The indirect tensile test used in this study was developed by Carnerio and Barcells [14] in Brazile and Akazawa [15] in Japan. Indirect tensile test was carried out by loading Marshall specimens with compressive vertical loads that act parallel to and along the vertical diameter plane until failure using a constant rate of loading of 0.04 in/mm. A steel loading strip 0.5 in wide with a curved loading surface was used to distribute the load uniformly and to maintain a constant loading area. By continuously monitoring the loads and the vertical and horizontal deformations of the specimen until failure, one can estimate the mixture tensile characteristics at failure by using certain theoretical equations [16]. The simplified relation for estimating the indirect tensile strength 4 in. diameter specimen with 0.5 in. wide covered loading strip is as follows:

Indirect tensile strength, ITS, psi = 0.156 Pf /H Where:

Pf = Total load at failure, Ib;

H = Height of specimen; in.

RESULTS AND DISCUSSION

Analysis of asphalt-rubber mix properties

The properties of asphalt-rubber mix were evaluated and discussed comparing with the corresponding properties of asphalt material alone. Table (4) summarized the results of these tests. Based on the data presented in the table, it can be noticed that as the rubber content increases penetration of asphalt also increases reaching 69 mm at 15% rubber percent, which means that it is still in the penetration category (60-70).Therefore further increase in rubber percent may change the penetration of asphalt to another category. Lower variation of softening point degree was found when using 5% or 10% of rubber. On the other, hand using 15% rubber instead of similar percent of asphalt gives an out of specification value (>55°c).Flashpoint degree decreases with increasing rubber percent.

Table (3) conducted test for the investigated mixes

Mix No. / Property	No. of Tests											
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Rubber Percent, %	0	10	15	20	25	30	35	40	45	5	10	15
Asphalt Binder, %	5.6	5.6	5.5	5.5	5.4	5.3	5.3	5.2	5.2	5.6	5.6	5.6
Marshall Test	21	21	21	21	21	21	21	21	21	21	21	21
Loss of Stability Test	3	3	3	3	3	3	3	3	3	3	3	3
Wheel Tracking Test	3	3	3	3	3	3	3	3	3	3	3	3
Indirect Tensile Test	3	3	3	3	3	3	3	3	3	3	3	3

Table (4): Results of all tests for all investigated mixes

Mix No. / property	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Density (gm/cm2)	2.387	2.375	2.36	2.353	2.34	2.33	2.317	2.303	2.287	2.384	2.376	2.355
Stability (Ib)	2795	2680	2588	2487	2355	2030	1910	1790	1742	2710	2520	2140
Flow, 0.01in	6.2	7.8	8.9	9.95	11.4	13.1	15.4	18	19.9	6.1	6	5.9
AV%	4.8	4.5	4.3	3.9	3.6	3.31	2.3	2.2	1.95	4.1	3.7	3.5
VMA%	14.3	14.7	15.1	15.57	16.1	16.25	16.8	17.5	18.25	14.5	15.2	15.6
%Loss of stability Value(after 3 days)	11	14.21	15.73	17.08	18.1	19.2	19.8	27	31	13	15.7	20
Recorded Deflection, 0.01mm(10min)	73.9	75.4	78.3	81	85.2	89.5	93.8	101.8	108.3	72.7	76.6	83.3
Modulus of Elasticity(E),kg/cm2	10660	10596	10523	10422	10254	10140	10060	9723	9626	10633	10596	10466
Recorded Track Depth0.01inch(60min	4.3	4.4	4.9	5.2	5.5	7.5	9.07	9.4	9.9	4.5	4.7	5.8
Indirect Tensile Strength,psi	41	44	49	56	62	60	50	43	34	43	40	36

This may be related to the higher sensitivity of rubber to fire. However flash point degree is still within the specification range (+250). On the other hand, kinematic viscosity decreased with increasing rubber percent and it goes out specification for rubber percent of 15% (i.e. <320°c).Finally analysis of rubber effect on the ductility of asphalt binder was studied. From the table, it can be noticed that higher ductility was obtained when using 5% rubber percent as a substitution of asphalt. Increasing rubber to 15% decreases the binder ductility to 125cm, which is less than that of pure asphalt although it is still within the specification range.

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loss of stability test was conducted on Marshall specimens as an indicator for resisting water action by pavement constructed with rubber enhancement. In this test Marshall specimens were placed in water bath and tested at several times (0, 1day, 2days, and three days) to measure the loss in mix stability.

Plastometer Test Method

Plastometer apparatus was used to measure dynamic modulus of elasticity. In this method asphalt concrete mix samples of dimensions 4 x 4 x 16 cm was used. These samples were prepared based on the results obtained from Marshall test. The outline of the method is thoroughly explained by Mohamady [13]. Deflection of tested specimens was recorded each one minute. Afterthat modulus of elasticity was determined through calculating the rheological characteristics of asphalt mix specimens. This modulus represents a dynamic modulus of elasticity corresponding to a loading time of 0.02 second for the asphalt concrete mix.

Wheel Tracking Test Results

The wheel tracking test was conducted on some specimens according to the Egyptian code. Several specimens (3 specimens/ mix) were prepared and tested to study the effect of rubber on the pavement capability to withstand rutting phenomena. Table (3) presents a summary of the different variables, number of mixes, rubber percent, conducted testes and number of specimens per each mix.

Indirect Tensile Test

The indirect tensile test used in this study was developed by Carnerio and Barcells [14] in Brazile and Akazawa [15] in Japan. Indirect tensile test was carried out by loading Marshall specimens with compressive vertical loads that act parallel to and along the vertical diameter plane until failure using a constant rate of loading of 0.04 in/mm. A steel loading strip 0.5 in wide with a curved loading surface was used to distribute the load uniformly and to maintain a constant loading area. By continuously monitoring the loads and the vertical and horizontal deformations of the specimen until failure, one can estimate the mixture tensile characteristics at failure by using certain theoretical equations [16]. The simplified relation for estimating the indirect tensile strength 4 in. diameter specimen with 0.5 in. wide covered loading strip is as follows:

Indirect tensile strength, ITS, psi = 0.156 Pf /H Where:

Pf = Total load at failure, Ib;

H = Height of specimen; in.

RESULTS AND DISCUSSION

Analysis of asphalt-rubber mix properties

The properties of asphalt-rubber mix were evaluated and discussed comparing with the corresponding properties of asphalt material alone. Table (4) summarized the results of these tests. Based on the data presented in the table, it can be noticed that as the rubber content increases penetration of asphalt also increases reaching 69 mm at 15% rubber percent, which means that it is still in the penetration category (60-70).Therefore further increase in rubber percent may change the penetration of asphalt to another category. Lower variation of softening point degree was found when using 5% or 10% of rubber. On the other, hand using 15% rubber instead of similar percent of asphalt gives an out of specification value (>55°c).Flashpoint degree decreases with increasing rubber percent.

Table (3) conducted test for the investigated mixes

Property \ Mix No.	No. of Tests											
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Rubber Percent, %	0	10	15	20	25	30	35	40	45	5	10	15
Asphalt Binder, %	5.6	5.6	5.5	5.5	5.4	5.3	5.3	5.2	5.2	5.6	5.6	5.6
Marshall Test	21	21	21	21	21	21	21	21	21	21	21	21
Loss of Stability Test	3	3	3	3	3	3	3	3	3	3	3	3
Wheel Tracking Test	3	3	3	3	3	3	3	3	3	3	3	3
Indirect Tensile Test	3	3	3	3	3	3	3	3	3	3	3	3

Table (4): Results of all tests for all investigated mixes

property \ Mix No.	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Density (gm/cm2)	2.387	2.375	2.36	2.353	2.34	2.33	2.317	2.303	2.287	2.384	2.376	2.355
Stability (ib)	2795	2680	2588	2487	2355	2030	1910	1790	1742	2710	2520	2140
Flow, 0.01in	6.2	7.8	8.9	9.95	11.4	13.1	15.4	18	19.9	6.1	6 .	5.9
AV%	4.8	4.5	4.3	3.9	3.6	3.31	2.3	2.2	1.95	4.1	3.7	3.5
VMA%	14.3	14.7	15.1	15.57	16.1	16.25	16.8	17.5	18.25	14.5	15.2	15.6
%Loss of stability Value(after 3 days)	11	14.21	15.73	17.08	18.1	19.2	19.8	27	31	13	15.7	20
Recorded Deflection, 0.01mm(10min)	73.9	75.4	78.3	81	85.2	89.5	93.8	101.8	108.3	72.7	76.6	83.3
Modulus of Elasticity(E),kg/cm2	10660	10596	10523	10422	10254	10140	10060	9723	9626	10633	10596	10466
Recorded Track Depth0.01inch(60min	4.3	4.4	4.9	5.2	5.5	7.5	9.07	9.4	9.9	4.5	4.7	5.8
Indirect Tensile Strength,psi	41	44	49	56	62	60	50	43	34	43	40	36

This may be related to the higher sensitivity of rubber to fire. However flash point degree is still within the specification range (+250). On the other hand, kinematic viscosity decreased with increasing rubber percent and it goes out specification for rubber percent of 15% (i.e. <320°c).Finally analysis of rubber effect on the ductility of asphalt binder was studied. From the table, it can be noticed that higher ductility was obtained when using 5% rubber percent as a substitution of asphalt. Increasing rubber to 15% decreases the binder ductility to 125cm, which is less than that of pure asphalt although it is still within the specification range.

Effect of rubber content on Marshall properties

Effect of Rubber Content on Marshall Stability

Based on the results in Table (4), It can be noticed that Marshall mix stability for the first nine mixes(groupI) decreases as rubber percent increase, achieving the highest

stability value of 2795 Ibs at zero rubber percent (M1).The lowest stability value reached 1742 Ibs at 45% rubber and 55% fine aggregate (M9). This means that substituting 45% of sand in the mixes by rubber decrease Marshall stability by about 1053 Ibs, i.e, 40%of the original mix stability. Moreover, mixes M8 and M9 given out of specifications stability values (less than 1800 Ib) according to Egyptian code. These results indicate that the maximum rubber percent that can be used is 35% of the fine part of asphalt mix to ensure acceptable mix stability. For the three mixes M10, M11and M12, as rubber percent increase mix stability decreases. However the stability was 2140 Ibs at 15% rubber compared with original mix stability (M1) of 2795 Ibs with no rubber. This means that increasing rubber percent up to 15% of asphalt binder decreases the mix stability value by about 23.4 %. Based on these results, it can be concluded that the replacement of asphalt binder by rubber has a pronounced effect on mix stability at replacement percent of 15% or more.

Effect of Rubber Percent on Marshall Flow

The data presented in the Table (4) show that the flow values of investigated mixes increase as the rubber percent increase substituting certain percent of fine aggregate part of the mix. The rubber-sand replacement give suitable flow values up to about 30% rubber percent. On the other hand, the use of rubber percent instead of similar percent of asphalt binder mixes (M10 through M12) has little effect on the mix flow. This result may be due to the similar nature of both rubber and asphalt as bonding materials. The increase in the mix flow already increases mix flexibility and therefore enhances the pavement ability to resist different types of cracking

Analysis of loss of stability test results

Loss of stability test was performed to measure the ability of asphalt mix to serve with time. The percent loss of stability was used as an indicator to mix durability under different conditions. Table (4) shows that the loss of stability percent increases as immersion time increase with decreasing rate. The first seven mixes suffer loss of stability with the acceptable range (<20%).Based on these results it can be concluded that the use of rubber percent up to 30% instead of fine aggregate may be achieved. In mixes M10, through M12, the loss of stability increases with increasing immersion time with monotonically decreasing rate. It must be noted that the loss of stability percents are in the allowable range, in spite of the mix M12 in which the rubber reaches 15% of asphalt binder which can be accepted by the mix durability and hence the pavement performance with time will be acceptable.

Analysis of plastometer test results

The data presented in Table(4) show that the modulus of elasticity decreases as rubber percent increase from 0% to 30% by weight of sand (i.e. from the mix M1 to mix M7).The values of modulus of elasticity are 10660 kg/cm2 and 10060 kg/cm2 for the mixes M1 and M7, respectively. This means that the value of the modulus of elasticity was decreased only by about 5.5% as the rubber percent increased from zero to30%.Afterthat, the values of the modulus of elasticity are sharply decreased as the rubber percent increases. It is of a great importance to state that the elastic modulus values were decreased by 4.5% as the rubber percent increased only from 30% to 40% by weight of sand (from the mix M7 to the mix M9).

Relationship between stability and modulus of elasticity

Figure (1) shows the measured values for both the stability measured by Marshall test and modulus of elasticity measured by the Plastometer test. It can be easily noted that both measurements have almost the same trend for all mixes. Since both measurements represent the pavement strength. This would provide some validity of the results from both tests. Figure (2) shows the relationship between the stability and modulus of elasticity. There is a good correlation between the two properties (The R-squired value is 0.86).The correlation between the stability and modulus of elasticity is given by the following equation:

$$E = 0.8766\,S + 8281.3$$

Where:

E= Modulus of elasticity,kg/cm2

S=Marshall stability,ib

Analysis of wheel tracking test results

To study the effect of rubber on the pavement capability to withstand rutting phenomena, several specimens were prepared and tested Table (4) shows that the rut depth is of higher values in the last four mixes [from the mix M6 to the mix M9]. The mix M5 achieved rut depth 1.28 times of the original mix M1, whereas the mix M9 achieve 2.3 times that of the mix M1.Based on this analysis, it can be seen that the use of rubber percent up to 20% of fine aggregate does not greatly affect the pavement resistance to rutting. Mixes M10, and M11 are of nearly equal values of rut depth at the end of test time ranges between 4.3(0.005 inch) and 4.7(0.005inch).

On the other hand, the mix M12 achieved higher rut depth value of 1.34 times that of the mix M1.

Based on these results it can be concluded that the use of rubber instead of asphalt binder does not affect mix resistance to rutting up to 10% rubber percent.

Analysis of indirect tensile strength test results

The indirect tensile strength test was conducted on all the investigated mixes. The main purpose of performing this test is to measure the ability of asphalt mixtures modified by rubber to resist cracking. The test specimens were of dimensions exactly as Marshall samples. Table (4) shows that the indirect tensile strength was increased with increasing rubber percent (group I) up to the mix M5, in which the rubber percent reaches 20% by weight of the fine aggregate. It can be discovered that; increasing rubber percent from zero to 20% leads to increase in the indirect tensile strength by about 51% of the corresponding value at the original mix M1. This may attributed to flexible behavior of the rubber material. However, increasing rubber percent more than 20% leads to a decrease in the indirect tensile strength achieving a decrease by 17% for the mix M9 than that of the original mix M1.Noting that this percent reaches about 45% as compared by the best mix M5.

Since the main goal of using rubber in the asphalt mixtures is to increase pavement flexibility and therefore pavement resistance to cracking, the mix M5 is the most preferable mix. Thus, the rubber percent of 20% by weight of fine aggregate is considered the optimum alternative. In the group (II), it can be noted that the indirect tensile strength is increased by about 5% only of the original mix M1 when using replacement ratio of 5% by weight of asphalt binder. After that, further increase in rubber percent leads to a decrease in tensile strength achieving lower values than those of mix M1. Based on this analysis, it can be concluded that the use of rubber percent instead of asphalt binder is not effective in the mix properties. However replacement 5% by weight of asphalt cement with rubber can be recommended.

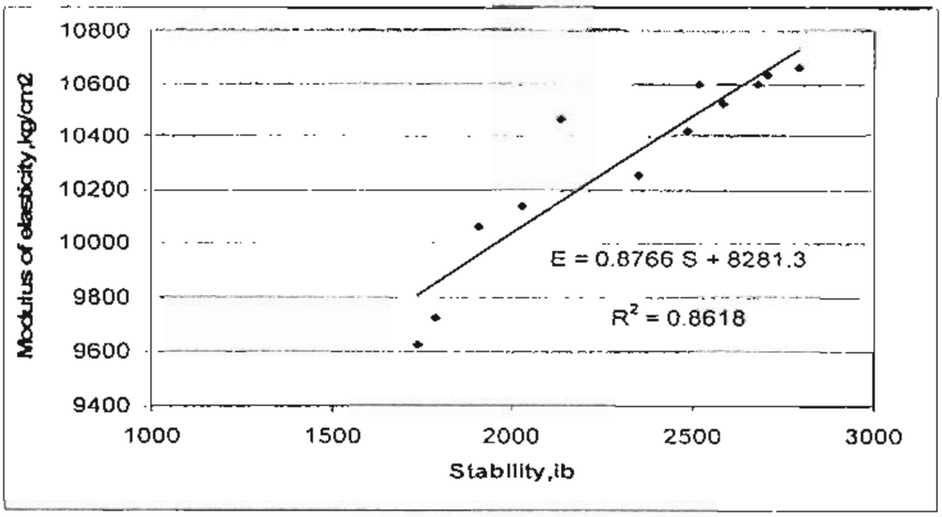

Figure (1): Relationship between the stability and the modulus of elasticity

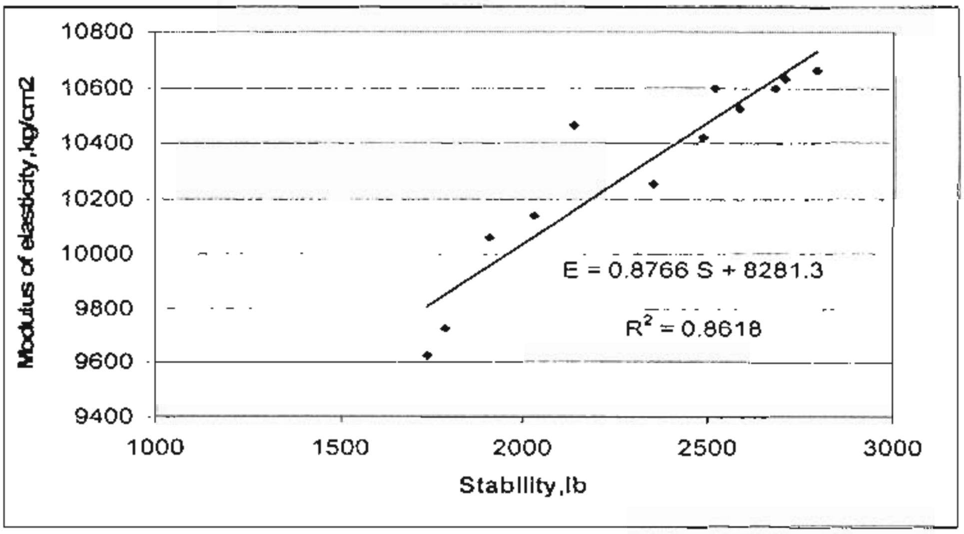

Figure (2): Correlation between the stability and the modulus of elasticity

VALIDITY OF STUDY RESULTS

Based on the previous analysis for the different conducted laboratory tests shown in Table (4), it can be said that the optimum mix properties may be achieved with 20% rubber percent instead of similar percent of fine aggregate as well as 5% rubber percent as a replacement ratio of asphalt binder. Based on the previous rubber content, a proposed mix was prepared to evaluate the different mix characteristics. The main goal of this step is to check the validity of study results. Several samples of proposed mix were prepared to conduct all tests used through the research. The results of the proposed mix are shown in Table (5). From the table it can be noted that the stability of the proposed mix (2570ibs) is greater than that of the mix M5 by about 10%.However stability of the proposed mix is less than that of the original mix M1 by about 8% only. From the table it can also noted that the loss of stability is 16.2%.after three dayes immersion time, This means that it is of acceptable range (<20%).

Table (5): Results of the proposed mix

property	value
Density (gm/cm2)	2.33
Stability (ib)	2570
Flow 0.01in	11.7
AV%	3.8
VMA%	15.7
%Loss of stability Value(after 3 days)	16.2
Recorded Deflection,0.01mm(10min)	80.5
Modulus of Elasticity(E),kg/cm2	10460
Recorded Track Depth0.01inch(60min)	5.3
Indirect Tensile Strength,psi	64

The modulus of elasticity of the proposed mix is increased by 2% than that of mix M5 and decreased by about 2% also than that of mix M1.The indirect tensile strength of the proposed mix is 64 psi. This value is greater than that of all investigated mixes. This agrees with the main target of this study which is enhancing the ability of the asphalt pavement to resist pavement cracking. Based on this analysis it can finally recommend to use the proposed asphalt mix. In this mix 20% of fine aggregate can be replaced by rubber and 5% of asphalt binder can also replaced by rubber at the same time.

CONCLUSIONS

Based on the previous analysis as well as the results of the proposed mix the following conclusion can be said:

1. Marshall stability decrease as rubber percent increase. The stability reduction is of lower values up to 25% rubber instead of fine aggregate.
2. Replacement of asphalt binder by rubber has unpronounced effect on mix stability values up to percent 10% rubber. However, sudden decrease of mix stability was noticed for 15% rubber.
3. Mix flow increases as rubber percent increases, which may enhance pavement resistance to cracking.
4. The loss of stability was in the acceptable range (<20%) when using rubber percent up to 30% of fine sand. However, more increase in rubber percent leads to higher stability loss, which may be out of specifications and leads to unfavorable performance with time.
5. The use of rubber instead of asphalt binder has a little effect on stability losses with time, and it remains in the accepted range during study values (15%rubber).
6. The modulus of elasticity values are not greatly affected by using rubber instead of sand up to 30% rubber. On the other hand, using rubber percent up to 10% by weight of asphalt has a very little effect on modulus of elasticity values.
7. Good correlation was found between Marshall stability (S, ib)and modulus of elasticity (E, kg/cm2) for asphalt mix tures in the form:

   $$E = 0.8766\,S + 8281.3$$

   R-squired value is 0.86
8. The use of rubber percent up to 20% by weight of sand or 5% by weight of asphalt has a great effect on pavement resistance to rutting (wheel tracking test).
9. Increasing rubber percent from zero to 20% by weight of sand increase the indirect tensile strength by about 51% of the original mix (without rubber). This greatly enhances the pavement resistance to cracking.
10. The use of rubber instead of asphalt binder has unpronounced effect on the tensile strength values. However, the use of 5% rubber by weight of asphalt gives favorable results.
11. Based on the study results, a proposed mix was prepared with 20% rubber by weight of sand and 5% rubber by weight of asphalt. The proposed mix gave a suitable mix property for almost all properties and it is recommended.

Recommendations

Based on the study results and the drawn conclusions, the following recommendations are suggested:

1. Using of rubber material in manufacturing asphalt concrete mixtures is recommended to enhance cracking resistance of the pavement.
2. Using rubber percent of 20% by weight of fine aggregate as well as 5% by weight of asphalt give satisfactory properties of asphalt mix, which in turn would provide optimum field performance and limit pavement cracking by a considerable extent.
3. Other materials should be investigated in production of asphalt mix to overcome some dangerous pavement distresses. Elimination of pavement cracking is considered as a vital goal in these investigations.

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