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The Effect of Diffraction in the Degree of Bitumen Penetration on Asphalt Mixture Used for Surface Layer

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Authors' contributions

This work was carried out in collaboration among all authors. Author MSE designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MEB and AMA managed the analyses of the study. Author AAAA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Objectives: This research discuss the simulation of the bad bitumen which gives a penetration out of the specification limit and Study the effect of crumb rubber on the performance of asphalt mixture in case of low penetration grade and waste cooking oil in case of high penetration grade.

Presentation of Case: Determination of the permissible limits of the diffraction in the degree of penetration for Suez Bitumen and Alexandria bitumen.

Methodology: 14 asphalt mixtures are designed by using two types of bitumen (Alexandria bitumen and Suez bitumen). By using crumb rubber powder (C.R.P) with contents (6%, 8% and

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10%) to decrease penetration for Alex bitumen by (59, 56 and 53) respectively. Then (-C.R.P-) was added with ratios (5%, 6.5% and 8%) to decrease penetration for Suez bitumen by (59, 56 and 53) respectively. after that waste cooking oil was added with different percentages (0.3%, 0.5% and 1%) for each bitumen type to increase penetration by (71, 74 and 77) respectively. Marshall Test was implemented for all asphalt mixtures to determine stability value and flow. The ITS Test was performed for all mixtures to determine tensile properties for mixtures.

Results: The results were showed important conclusions for using bitumen with penetration grades (60/70) with increase or decrease in penetration by 7.

Conclusion: This study recommends using (C.R.P) with ratios (10% and 5%) from bitumen weight for Alex and Suez bitumen respectively for achieving 53, 59 penetration to obtain 29% increase of stability value and 23.64% for Alex and Suez bitumen mixture respectively.

Keywords: Bitumen penetration; crumb rubber powder; waste cooking oil; I.T.S.

1. INTRODUCTION

Bitumen is sticky natural material derived from the fractional distillation of crude oil, and is particularly suitable for a binder for the construction of the road. Normally, at room temperature bitumen is soft with a density of 1 g/cm^3, when its temperature is low it becomes brittle and at high temperature it becomes a viscous liquid Amirkhanian and Gandhi T. S. [1] For asphalt pavements the properties and quality of bitumen depend on structure and chemical composition, which are essential controlled by the nature of crude oil and the methods used during the manufacturing process. Also, the differences in characteristics for bitumen has a low penetration and a high penetration grade are mainly due to the different quantities of the structure particles accompanied by strong interactions. Bitumen with low penetration grade contains a lot of structure particles, that's why it's getting stiffer and more viscous A.H.de Bondt and R. C. van Rooijen, [2]. Bitumen structure and composition change during storage at a high temperature and during production, transport and mixing in asphalt mixtures, this leads to change in bitumen properties significantly A. Srivastava and R. C. van Rooijen, [3].

Bitumen is conventionally represented as a system consists of a dispersed asphaltene micelles or dissolved in a less molecular weight (maltenes). Before using bitumen in asphalt mixture a lot of experiments were performed to make sure that if its properties achieve the specifications limits or not. The depth of penetration is the method, which is relative to the material viscous resistance. Empirical relationships were developed for Newtonian materials to account for the calculation of the depth of penetration using a needle that penetrates the bitumen vertically under the loading conditions, temperature and time D. Lesueur, [4]. Penetration scope can supply information related to chemical bitumen components and almost relative to asphaltene (higher molecular weight which responsible for stiffness and strength), resigns which responsible for adhesion force and ductility and oils (lower molecular weight which responsible for viscosity and fluidity) [5].

The strength of the asphalt material is determined by degree of penetration for bitumen. The use of a particular type of bitumen varies depending on temperature. In cold weather, it is preferable that the used bitumen has a high degree of penetration. In hot countries, the bitumen which has a solid state must be used to prevent asphalt to be more elastic as a result of high temperature [6].

Bitumen Additives are substances which is used as an addition to bitumen to change properties of the final mixture to improve the bitumen qualitative properties, the additives were applied to improve the heat stability, increasing elasticity, improving the aggregate adhesion, decreasing viscosity, increasing the aging resistance to prevent the drainage from the surface of the aggregate The additives categorized by types as, surfactants, emulsifiers, adhesion promoters, anti-strip agents, modifiers (polymeric), organic materials, rejuvenators, fibers, and rubber modifiers [7]. In the current study by using the crumb rubber powder as an additive to control the reduction of penetration and waste cooking oil to increase penetration value.

Using Crumb rubber addition to the bitumen binder enhanced the rubberised bitumen physical properties as mentioned by decreasing in penetration and ductility [8].Crumb rubber was extracted from the reused tires vehicles [9] by increasing amount of crumb rubber in bitumen the penetration value decrease [10]. The use of crumb rubber has an effect on the characteristics of the asphalt mixture. Thus it increases the resistance of the asphalt mixture to permanent deformation in case of high temperature, and improves elasticity at low temperature [11]. The increase of rubber content helps to improve the aging binder resistance and increase the fatigue mixture life, while it leads to decrease the Indirect Tensile Strength [12]. There are two main process to add C. R in bituminous mixture dry and wet process [13]. In dry process C.R is mixed with hot aggregate to add the bitumen, in wet process C.R is added to hot bitumen and permits the reaction occurs between rubber and asphalt, using dry process could enhance the permanent deformation resistance at higher temperature and cracking at low temperature [13], using wet process could obtain the volumetric parameters desired [14].

Waste cooking oil has a harmful effect on aquatic life because of the oxygen is disturbed during the eutrophication process happens in river as a result of preventing the sunlight penetration on the river surface due to the oil layer found on the surface [15,16]. the companies which responsible for collecting waste cooking oil from the industries of the food looks like the restaurants of fast food before recycling [17]. Zhang, et al. [18] has illustrated that the main source of waste cooking oil from the activity of frying during food preparation which represented in the industries of food, residences and restaurants. The waste cooking oil discharged illegally in to the river without treatment. Waste cooking oil recorded annually three billion gallons [19]. It is used for yellow grease [20] And Source of bio diesel production [21]. Some countries which produce waste cooking oil like as USA, China, England, Europe, Malaysia, Japan and Irelands. United States of America produces 55% of waste cooking oil. Meanwhile China produces 25% from it. In England represented 9% from total annual production [22].

Mainly, the performance of the asphalt mixture is estimated from important properties of bituminous pavement such as rutting resistance, cracking and stiff [23]. Baily and Philips [24] reported that the aging mixture stiff reduced by using vegetable oil. Zaumanis, et al. [25] prove that the magnitude of fatigue resistance can be increased by using waste vegetable oil as addition. By the addition of waste cooking oil the viscosity value is reduced but penetration is increased. Therefore, the rutting issue begins to occur because of the soft condition asphalt mixture [26].

In the presented study, asphalt mixtures were implemented by Marshall Design method, for two types of bitumen (Alex bitumen, Suez bitumen), after that crumb rubber powder and waste cooking oil were used by varies ratios to reach the diffraction penetration values required. The results were compared and checked up according to specifications limits.

2. MATERIALS AND METHODS

In the first stage, a series of tests were carried out on the materials used to ensure that their validity for the specifications limits. The following tests were carried out on the aggregates (specific gravity, Los angles abrasion, Water absorption, Clay lumps and friable particles in aggregates and determined job mix for the mixture according to specifications limits). For bitumen, the following tests were performed (penetration, kinematic viscosity, flash point, Softening point, and Ductility). The second stage asphalt mixture was designed for each type of bitumen without any additives and a series of tests were implemented to ensure the performance of the mixture. The third stage design asphalt mixtures with low penetration (59, 56 and 53) for each type of bitumen and make tests (Marshall Test and the indirect tensile strength test). The fourth stage design asphalt mixtures with high penetration (71, 74 and 77) for both types of bitumen and make the same tests which were performed.

2.1 Materials

The asphalt concrete mixes tested in this study were com-posed of aggregate, bitumen, and mineral filler. The engineering properties of the applied materials were deter-mined by conducting laboratory tests according to the American Association of State Highway and Transportation Officials (AASHTO), as presented below.

2.1.1 Bitumen

Two types of bitumen were used in this work, first type Alexandria bitumen and the second type was Suez bitumen (60/70) penetration grade, specific gravity equal 1.02 g/cm^3 for each type of bitumen. Table 1 presents the different properties of this two type's bitumen.

2.2 Aggregate

Table 2 presents the properties of the used aggregate according to the Egyptian specification of asphalt concrete mixes. Table 3 presents aggregate design gradation and Specification limits according to Egyptian code.

2.3 Sample Preparation

By adding (6%, 8% and 10%) of the rubber powder to Alexandria bitumen and ratios (5%, 6.5% and 8%) were added for Suez bitumen to achieve penetration (59, 56 and 53) respectively for each type of bitumen, after that three mixtures are then designed for each type of bitumen (an asphalt mixture is designed for each grade of penetration). On the other hand, the ratios which represent (0.3%, 0.5% and 1%) of the waste cooking oil were added to the Suez bitumen and Alexandria bitumen to achieve penetration (71, 74 and 77) respectively for each bitumen type and design three bituminous mixtures for each type (Mixture for each degree of penetration).finally The following tests (Marshall test and indirect tensile strength test) were performed for all asphalt mixtures to make sure their conformity for the specifications limits.

2.4 Optimum Bitumen Content (OBC)

Two HMA mixtures were designed with a mixture of each bitumen type, the first mixture (M1) was designed by using Alexandria Bitumen and the second mixture (M8) was designed by using Suez Bitumen. Varies bitumen contents (4.5, 5.0, 5.5, 6.0, and 6.5%) without any additives, the Marshall design was performed for the wearing surface mix (mix 4C) to determine the mixtures properties according to AASHTO T-166 [20]. Also these two mixtures were tested by using Marshall Apparatus to determine stability and the value of flow .Then; the results were compared to determine optimum bitumen content. The penetration 65 for M1 and penetration 63 for M8 achieve maximum stability, suitable flow, actual specific gravity and acceptable percentage of air voids.

2.5 Crumb Rubber Powder Content (CRPC)

Six mixtures were designed by using Suez bitumen and Alexandria bitumen with the selected

Table 1. Properties of two types of bitumen used

Test no.	Test	AASHTO designation No.	Suez bitumen	Alexandria bitumen	Specification limits
1	Penetration (0.1 mm)	T-49	63	65	60-70
2	Softening point (ºC)	T-53	48	46	45-55
3	Flash point (ºC)	T-48	+270	+270	+250
4	Kinematic viscosity (cst)	T-201	436	435	+320
5	Ductility (cm)	T-51	+100	+100	≥ 95

Table 2. Aggregate properties according to specification limits of asphalt mixture in Egypt

Test no.	Test	AASHTO designation no.	Results	Specification limits
1	Los Angeles abrasion (%)After 100 rolls	T-96	4%	≤ 8%
	After washing after 500 rolls		25%	≤ 40%
2	Water absorption (%)	T-85	1.4%	≤ 5%
3	Bulk specific gravity (g/cm^3)	T-85	2.623 g/cm^3	
4	Total specific gravity saturated dry surface%	T-85	2.663 g/cm^3	
5	Nominal specific weight %		2.715 g/cm3	
6	Clay lumps and friable particles in aggregates	T-112	0.2	≤ 1%

Table 3. Aggregate gradation

Sieve size		Design gradation	Specification limits
Inch	Mm		
1	25	100	100
3/4	19	95.8	80-100
1/2	12.5	86.1	--
3/8	9.5	77.9	60-80
No.4	4.75	50.2	48-65
No.8	2.36	35.9	35-50
No.16	1.18	27.9	--
No.30	0.6	21.4	19-30
No.50	0.3	13.3	13-23
No.100	0.15	9	7-15
No.200	0.075	7.9	3-8

content of optimum bitumen (5.1%, 5.2%, and 5.25%) with different crumb rubber contents (5%, 6.5% and 8%) respectively for Suez bitumen mixtures. The optimum bitumen content for Alexandria bitumen mixtures (5.2%, 5.85% and 5%) with crumb rubber contents (6%, 8% and 10%) respectively. The six mixtures were prepared, and then the Marshall Design test was implemented to calculate the change in stability value, unit weight and flow for six mixtures and direct tensile strength.

2.6 Waste Cooking Oil Content (OMC)

The other six mixtures were designed by using the same two types of bitumen with the selected materials, OBC (4.25%, 4.2%, and 4.4%) with different waste cooking oil contents (0.3%, 0.5% and 1%) respectively. For Suez bitumen mixtures the optimum bitumen content for Alexandria bitumen mixtures (5.2%, 5.85% and 5%) with waste cooking oil contents (0.3%, 0.5% and1%) respectively. After preparing all mixtures, the same previous tests were implemented; Table 4 shows the Marshall percentages for optimum bitumen content and different content of crumb rubber powder and waste cooking oil, whereas Table 8 presents the properties of the mixtures.

Table 4. The properties of the OBC for each mixture

Bitumen type	Code	Description	Penetration of bitumen	Function	Rubber ratio added	Waste cooking oil added
Alexandria bitumen	Mix 1	OBC 4.75 % AC 60/70	65	Control mix1	-	-
Alexandria bitumen	Mix 2	OBC %5.2% AC 60/70	59		6%	
Alexandria bitumen	Mix 3	OBC 5.85% AC 60/70	56		8%	
Alexandria bitumen	Mix 4	OBC 5% AC 60/70	53		10%	
Alexandria bitumen	Mix 5	OBC 4.4% AC 60/70	71		-	0.3%
Alexandria bitumen	Mix 6	OBC 4.4% AC 60/70	74		-	0.5%
Alexandria bitumen	Mix 7	OBC 4.4% AC 60/70	77		-	1%
Suez bitumen	Mix 8	OBC 4.75% AC 60/70	63	Control mix2	-	
Suez bitumen	Mix 9	OBC 5.1% AC 60/70	59		5%	
Suez bitumen	Mix 10	OBC 5.2% AC 60/70	56		6.5%	
Suez bitumen	Mix 11	OBC 5.25% AC 60/70	53		8%	
Suez bitumen	Mix 12	OBC 4.25% AC 60/70	71		-	0.3%
Suez bitumen	Mix 13	OBC 4.2% AC 60/70	74		-	0.5%
Suez bitumen	Mix 14	OBC 4.4% AC 60/70	77		-	1%

3. RESULTS AND DISCUSSION

3.1 Effects of Crumb Rubber Powder Content and Waste Cooking Oil Content on Marshall Properties for Alexandria Bitumen Mixtures

In Table 5, the results illustrate that the Marshall Stability value for mixtures (M2, M3 and M4) were increased due to increase of crumb rubber powder ratio in bitumen and achieve a maximum value equal 1652 kg at 10% crumb rubber powder content (M4) represent 29% increase compared with control mix 1 (M1) and the flow equal 3.9 mm according to specification limit the allowable value [2-4 mm]. For the mixtures (M5, M6 and M7) the magnitude of stability decrease due to the addition of waste cooking oil content reaching the minimum value of 910 kg at 1% percentage according to specifications limits the minimum value of stability equal 900 kg. This illustrate that the mixtures (M3 and M4) achieve a high stability and acceptable flow values which achieve allowable range [2-4 mm]. The mixtures (M6 and M7) were achieved minimum stability (980 kg, 910 kg) greater than the minimum value 900 kg and realize flow value (2.4 and 2.1) respectively acceptable according to specification limit.

3.2 Effects of Crumb Rubber Powder Content and Waste Cooking Oil Content on Marshall Properties for Suez Bitumen Mixtures

In Table 6, the results illustrate that the Marshall Stability value for mixtures (M9, M10 and M11) were increased due to increase of crumb rubber powder ratio in bitumen and achieve a maximum value equal 1830 kg at 8% crumb rubber powder content (M11) represent 19% increase compared with control mix 2 (M8) but the flow equal 5.4 mm according to specification limit the allowable value [2-4 mm]. For the mixtures (M12, M13 and M14) the magnitude of stability was decreased due to the addition of waste cooking oil content reaching the minimum value of 1070 kg at 1% percentage according to specifications limits the minimum value of Stability equal 900 kg. This illustrate the mixtures (M10 and M11) achieve high stability but flow greater than the allowable value (>4 mm). The mixtures (M12, M13 and M14) achieve minimum stability (1270 kg, 1180 kg and 1070 kg) greater than the minimum value 900 kg and realize flow value (3.2, 2.8 and 2.2) respectively acceptable according to specification limit. For mixture (M9) the stability equal 1635 kg represent 9.5% increase compared with control mix2 (M8) and the value

Table 5. Properties of mixtures with crumb rubber powder content and waste cooking oil content for Alexandria bitumen mixtures

Mix. no. properties	M1	M2	M3	M4	M5	M6	M7
Stability (kg)	1280	1480	1560	1652	1150	980	910
Flow (mm)	3.3	3.5	3.7	3.9	3.1	2.4	2.1
Specific gravity (g/cm^3)	2.382	2.37	2.372	2.374	2.381	2.389	2.374
% Air voids	4	4	4	4	4	4	4
% Voids in Mineral Aggregate (VMA)	14	14.8	14.6	14.5	12.52	12.23	12.95
% Voids Filled with Asphalt (VFA)	71	73	72.5	72	69.73	70.07	70
% crumb rubber powder content in bitumen	-	6%	8%	10%	-	-	-
% Waste cooking oil content in bitumen	-	-	-	-	0.3%	0.5%	1%

Table 6. Properties of mixtures with crumb rubber powder and waste cooking oil content for Suez bitumen mixtures

Mix. no. properties	M8	M9	M10	M11	M12	M13	M14
Stability (kg)	1480	1635	1725	1830	1270	1180	1070
Flow (mm)	3	3.7	4.5	5.4	3.2	2.8	2.2
Specific gravity (g/cm3)	2.384	2.374	2.37	2.366	2.383	2.386	2.378
% Air voids	4	4	4	4	4	4	4
% Voids in Mineral Aggregate (VMA)	13.85	14.5	14.7	15	13.8	13.4	13.84
% Voids Filled with Asphalt (VFA)	72	72	72.6	73	71	69.5	70.5
% crumb rubber powder content in bitumen	-	5%	6.5%	8%	-	-	-
% Waste cooking oil content in bitumen	-	-	-	-	0.3%	0.5%	1%

of flow equal 3.7 mm lay between the allowable ranges [2-4 mm].

3.3 The Indirect Tensile Strength Test

The indirect tensile strength test used for calculating the tensile properties of the asphalt mixture which related to the pavement cracking properties, cracking due to low temperature, fatigue and rutting. Several studies have determined that the asphalt pavement performance is related to the tensile strength of the mixture. The relation which used to determine the value of ITSis ($2×P×10^6/3.14×h×d$). The test gives information on the tensile strength of the mixture, permanent deformation and fatigue, Table 7 and Table 8 determine the ITS values for Alex bitumen mixtures and Suez bitumen mixtures respectively Fig. 1 and Fig. 2 illustrate the change in tensile strength value for Alex and Suez Asphalt mixtures due to different degrees of penetration.

Fig. 1 shows the relationship between the changes in tensile strength value of the asphalt mixtures for Alex bitumen due to the change in the degrees of penetration. The tensile strength value is inversely proportional with the degree of penetration for bituminous mixture. The maximum value of tensile strength (1634.32 k.pas) at M4 with penetration 53 by increasing rate 3% comparing to control mix1 (M1). The minimum value of tensile strength equal (1345.27 k.pas) at M7 with penetration 77 by decreasing rate 15.16% comparing to (M1).

Table 7. ITS values for Alexandria bitumen mixtures

Mix NO.	ITS values (Kpas)
M1	1585.64
M2	1616.81
M3	1625.81
M4	1634.32
M5	1400.83
M6	1356.38
M7	1345.27

The maximum value of tensile strength (1650.83 k.pas) at M11 with penetration (53) by increasing rate (5.31%) comparing to control mix2 (M8). The lowest value of tensile strength (1422.71 k.pas) at M14 with penetration (77) by decreasing rate (9.24%) comparing to (M8).

Table 8. ITS values for Suez bitumen mixtures

Mix NO.	ITS values (Kpas)
M8	1567.58
M9	1601
M10	1628.78
M11	1650.83
M12	1522.76
M13	1466.73
M14	1422.71

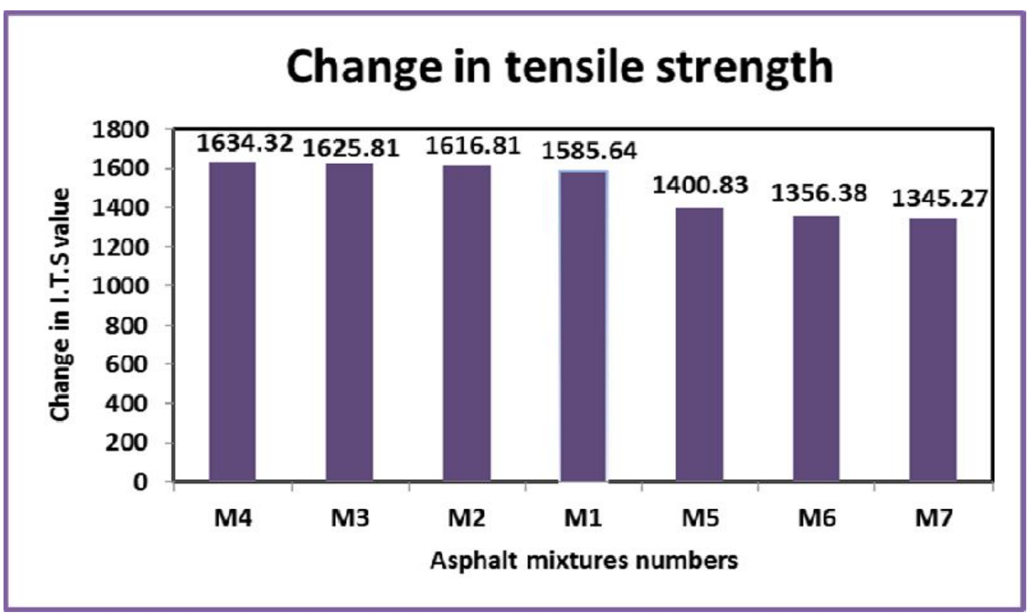

Fig. 1. Illustrate the change in tensile strength for Alex Asphalt mixtures due to different degrees of penetration

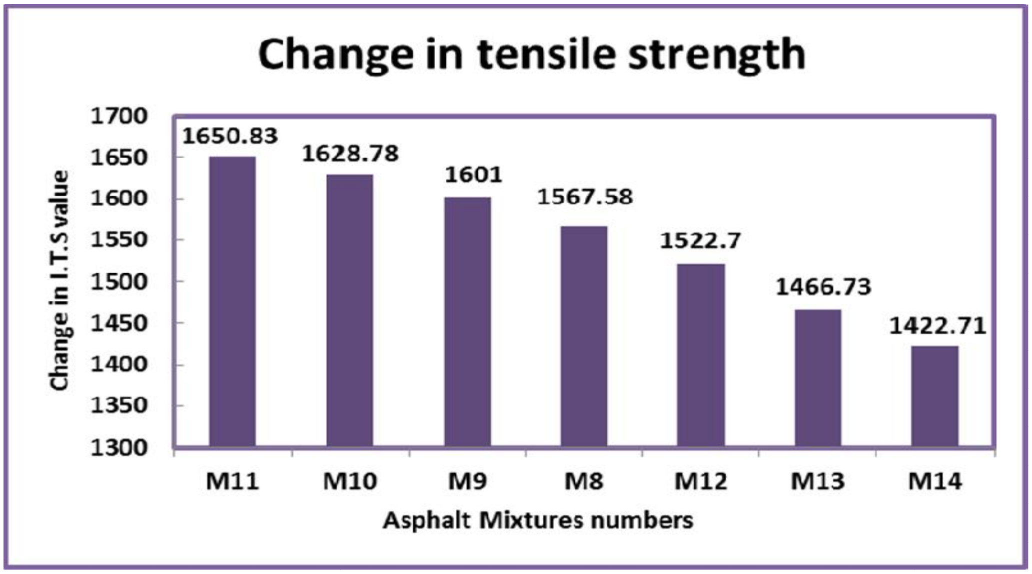

Fig. 2. Illustrate the relationship between the changes in tensile strength value of the asphalt mixtures for Suez bitumen due to different degrees of penetration

4. CONCLUSION

Based on the results of this study, the following conclusions can be obtained:

1. By increasing the proportion of crumb rubber powder in Suez bitumen, this increased the stability value of the mixture, The stability magnitude (1830 kg) was increased by 23.65% from the control mix (1480 kg) by adding crumb rubber powder ratio 8% from bitumen weight.
2. By adding 8% of crumb rubber powder in bitumen, the flow value (5.4 mm) increased by 80% from the value of control mix flow (3 mm) ,but this value greater than the allowable range [2-4 mm], so this ratio wasn't suitable for the asphalt mixture
3. The optimum content of crumb rubber powder at ratio 5% which realize degree of penetration equal 59 mm for Suez bitumen because of this ratio achieves increase of stability value by (10.47%) compared by the control mix (M8) and increase of the flow value about 23.33%.
4. The optimum content of crumb rubber powder at ratio 6% which realize degree of penetration is 59 mm for Alexandria bitumen. This ratio achieves an increase of stability value by (15.62%) compared with the control mix (M1) and decrease of the flow value about 22.58%.
5. The use of waste cooking oil as an addition to bitumen by ratios (0.3%, 0.5% and 1%) led to increase penetration for Suez bitumen to (71, 74 and 77) respectively, with reduce in stability value reaches (1070 kg) for degree of penetration 77 and decrease in flow value by 2.2 mm.
6. By using the same ratios of waste cooking oil in case of Alexandria bitumen give the same penetration degree (71, 74 and 77) with decrease in stability of mixture reaches (910 kg) and decrease in flow value reaches 2.1 mm.
7. The indirect tensile strength value was increased by 3.07% as a result of decreasing penetration of bitumen to 53 grades for Alex bitumen mixture.
8. ITS value for Suez bitumen mixture was increased by 5.25% at bitumen penetration 53 grades.
9. At degree of penetration 77 for Alex bitumen IT'S decreased by 17.86% (1345.27 Kpas).
10. At degree of penetration 77 for Suez bitumen ITS value decreased by 9.24% (1422.71 kpa).

5. RECOMMENDATIONS

1. It is possible to use bitumen penetration + 7 for the allowable range according to specifications limits for Egyptian code.
2. Using crumb rubber powder as additive for bitumen at rate reach to 10% from bitumen weight for Alexandria bitumen and by ratio 5% for Suez bitumen. This led to improve

the asphalt mixtures performance, especially increasing the stability value and improving the tensile properties of the mixture.

3. By using waste cooking oil as an addition to bitumen by 1% of the bitumen weight, this increased the grade of penetration by 77 and led to use bitumen in the design of asphalt mixtures, especially in low temperature areas.
4. Other waste materials should be inspected for using in the asphalt mixtures production, to improve the performance of the mixture and overcome the worst pavement distresses.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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