USE OF CRUMB RUBBER AS A WAY TO IMPROVE PERFORMANCE GRADE FOR ASPHALT CEMENT

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ABSTRACT

The purpose of this research is to study the performance grade of asphalt cement with scrap tire in form of crumb rubber (CR) as additive material. It also emphasizes on determining the optimum proportion of additive to be used in the mixing process. In this research, the materials used have been originally taken from the available sources in Iraq. One type of asphalt cement with penetration grade is equal to (40-50) from Al-Nasseryia refinery was used with one type of locally polymer is Crumb rubber with different particle sizes from scrap tires as asphalt modifier. The results showed that modified binders outperformed conventional asphalt cement in term of performance grade. It can be concluded from this research that the use of crumb rubber as additive material is the best alternative. Due to its domestic availability, crumb rubber is more suitable for road making in the scrap tire producing countries and to the fact that the utilized scrap tire as additives tend to improve viscosity and rheological and mechanical properties of asphalt cement and bringing greater service life expectancy. The suggested proportion of crumb rubber in blending with asphalt cement is 18 percent by total weight.

Keywords: Crumb rubber, Asphalt cement, Binders, Performance grade, Superpave tests

INTRODUCTION

Hot mix asphalt concrete (HMAC) is composed of two materials: aggregate and asphalt binder. About (94% to 96%) by weight of the mix consists of the aggregate, and the remaining (4% to 6%) by weight of the mix consists of the asphalt binder. Although the percentage of the asphalt binder is relatively small, the asphalt binders greatly influence pavement performance more than the aggregate because environmental factors, such as heat and sun radiation, affect the asphalt binder more than aggregate [1].

Bitumen can be described as a viscous liquid or solid consisting essentially of mineral oil (having a variety of hydrocarbons with high molecular weight, which are asphaltic in nature and having small proportions of oxygen, nitrogen and sulphur), hydrocarbon derivatives (such as asphaltenes , maltenes), which are soluble in carbon disulphide, and is substantially non-volatile and softens gradually when heated. Depending on its mode of derivation, it is either black or brown in colour, possesses water-proofing and adhesive properties and has a variable hardness and volatility [2].

Asphalt paving roads shows limitation on temperature, softens when the temperature is high and cracked when the temperature is low. In addition, hard traffic and high loading weight will damage the roads earlier than usual and cause expenses to repair and maintenance. Therefore, it is necessary to improve the quality of asphalt by the material which can play the role as a binder to achieve the following properties: -

1. Increasing viscosity and Elasticity.

2. Diminution of temperature susceptibility.
3. Higher softening point and aging resistance.
4. Ameliorate of cohesion [3].

Waste tires constitute a serious environmental problem that many countries have to face as they accumulate rapidly and they are not easily disposed off. Many approaches have been considered in recent years for treating and improving the conventional asphalts, such as the introduction of the additives in order to improve their properties. The use of crumb rubber from waste tires in asphalt, giving origin to the term asphalt rubber, has been an alternative to minimize their ecological impact and, simultaneously, to improve the mechanical properties of the asphalt mixtures [4].

EXPERIMENTAL WORK

Materials

Asphalt Cement

One type of asphalt cement is used with (40-50) penetration grade brought from Al-Nasseryia refinery.

Crumb Rubber (CR)

Crumb rubber has the name (40 mesh crumb), it is brought from tires factory in AL-Najaf governorate. It is black granules and recycled from used tiers (specific gravity is 1.13). Three various practical sizes are obtained from sieving analysis at sieves (1.18, 0.5 and 0.425 mm). Also been used three different percentages of crumb rubber (CR) are (6%, 12% and 18%) by weight of asphalt cement.

Crumb rubber (CR) is the recycled rubber obtained by mechanical shearing or grinding of tires into small coarse crumb rubber. Tires are composed of several different types of rubber compounds. The major variations are in the synthetic rubber content, natural rubber content, total rubber hydrocarbon content, and acetone extractable. Ash and carbon black contents are typically similar for different tire rubber compounds. The major CR compositional effect on asphalt rubber (AR) physical properties is the total rubber hydrocarbon content with additional effects from the natural rubber content [5].

Company for Tire Industry in AL-Najaf City – Engineering Office -Technology Department , 2009.

Table 1. Physical properties and materials specification of 40 mesh CR [6]

Property or Characteristic	*Unit*	*Requirement or Value*
Specific Gravity	----	1.13
Density	gm/m3	1.320
Young's Modulus (E)	MPa	2600 – 2900
Tensile Strength (σt)	MPa	40 – 70
Elongation at Break	%	25 – 50
Melting Point	Cº	200
Rubber Hydrocarbon	%	48 min
Carbon Black	%	25 – 35
Acetone Extract	%	10 – 20
Ash at 550	%	8.0 min
Metal Content	%	0.03 max

Binder Mixing

The process of mixing crumb rubber with asphalt binder used in this study is the wet process, in which crumb rubber is added to the asphalt binder before introducing it in the asphalt concrete mixture. Crumb rubber will be directly blended with asphalt binder in blending machine. The blending machine is used to blend the crumb rubber with 700g of asphalt cement at blending speed 4700 rpm. Crumb rubber was added within the first two minutes of mixing and mixing continued for 60 minutes while the temperature of the binder was maintained at 190 ^{o}C for the duration. After mixing, each can of binder was allowed to cool to room temperature for 24 hours before being reheated for testing. The process of mixing was conducted at ministry of roads and build cities /The central husbandry in Tehran governorate / Iran.'

Sample Symbols

Table 2. Coded Samples

Symbol	*Sample*
S	Pure asphalt
D1	Asphalt + 6% of CR with 1.18 mm for particle size
D2	Asphalt + 12% of CR with 1.18 mm for particle size
D3	Asphalt + 18% of CR with 1.18 mm for particle size
E1	Asphalt + 6% of CR with 0.5 mm for particle size
E2	Asphalt + 12% of CR with 0.5 mm for particle size
E3	Asphalt + 18% of CR with 0.5 mm for particle size
F1	Asphalt + 6% of CR with 0.425 mm for particle size
F2	Asphalt + 12% of CR with 0.425 mm for particle size
F3	Asphalt + 18% of CR with 0.425 mm for particle size

Binders Testing

Both pure asphalt cement and modified binders in different proportions will be tested according to the details mentioned in Table 3.

ANALYSIS OF RESULTS

Viscosity

The first test methods for characterizing performance grade of asphalt binder are rotational viscometer. The viscosity results of the base and CRM binders' are illustrated in Figure (1).

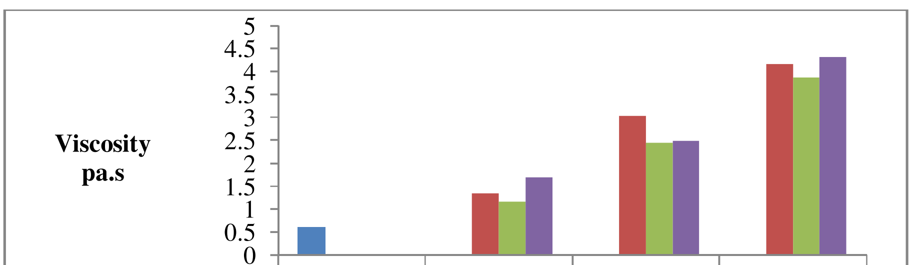
Results presented in figure (1) indicate that the asphalt cement modified had a higher viscosity than the conventional asphalt cement without modifier. Can conclude that the addition of crumb rubber to the binder significantly increases the viscosity of the binder.

Through figure (1) can note that asphalt cement modified with (CR) has highest viscosity from the pure asphalt cement. Also, the ratio of 6% and 12 % revealed lower viscosity than that of 18% for crumb rubber while Fine – sized for (CR) achieves the highest value for modified asphalt viscosity at the ratio 6% and 18%. Coarse – sized for (CR) achieves the highest value for modified asphalt viscosity at the ratio 12%.

Table 3. Binders Testing Program

Item	*Equipment*	*Purpose*	*Performance Parameter*	*Specification*
1	Rolling Thin Film Oven (RTFO)	Simulate binder aging (hardening) during HMA production and construction	Resistance to aging (durability) during construction	AASHTO T240
2	Pressure Aging Vessel (PAV)	Simulate binder aging (hardening) during HMA service life	Resistance to aging (durability) during service life	AASHTO R28
3	Rotational Viscometer (RV)	Measure binder properties at high construction temperatures	Handling and Pumping	AASHTO T316
Item	*Equipment*	*Purpose*	*Performance Parameter*	*Specification*
4	Dynamic Shear Rheometer (DSR)	Measure binder properties at high and intermediate service temperatures	Resistance to permanent deformation (rutting) and fatigue cracking	AASHTO T315
5	Bending Beam Rheometer (BBR)	Measure binder properties at low service temperatures	Resistance to thermal cracking	AASHTO T313
6	Direct Tension Tester (DTT)	Measure binder properties at low service temperatures	Resistance to thermal cracking	AASHTO T314

The viscosity resulting from the addition of 18% CR into base asphalt cement considered undesirable because they cause the mixture system clogged As mentioned in the previous study [3]. Additionally, the viscosity of the CRM binders significantly increased with increasing crumb rubber content. The size of the crumb rubber particles also influenced the viscosity of CRM binders. Generally, the finer crumb rubber produced binders with greater viscosity.



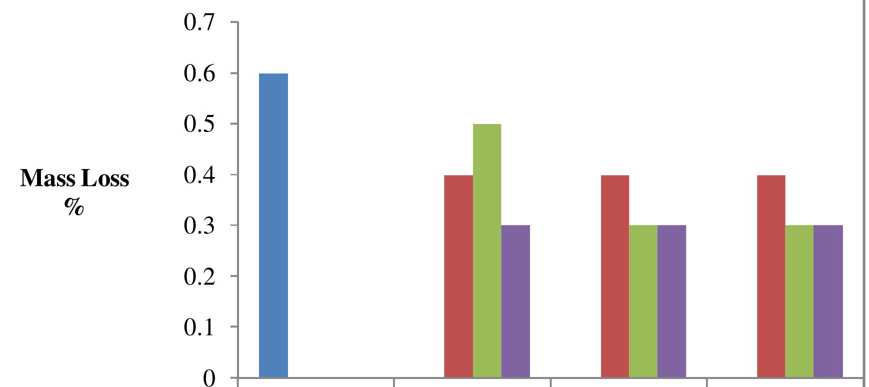
	0%	6%	12%	18%
pure	0.616			
coarse particle size		1.342	3.038	4.156
medium particle size		1.168	2.449	3.863
fine particle size		1.683	2.481	4.302

Figure 1. Rotational viscometer test columns for asphalt cement modified by crumb rubber

Short - Term Aged Binder (RTFO Aging)

The second test method for characterizing performance grade of asphalt binder is rolling thin film oven. The mass loss results from testing the base and CRM binders with the rolling thin film oven (RTFO) at 163c is illustrated in Figure (2).

Results presented in figure (2) indicate that the asphalt cement modified had a lower mass loss than the conventional asphalt cement without modifier. Through figure (2) can note that pure asphalt cement has highest mass loss from asphalt cement modifier with (CR). Also, lower mass loss is achieved through the addition of 6% from the CR with fine - sized and the addition of 12% and 18% from the CR with medium and fine sized to asphalt cement.



	0%	6%	12%	18%
pure	0.6			
coarse particle size		0.4	0.4	0.4
medium particle size		0.5	0.3	0.3
fine particle size		0.3	0.3	0.3

Crumb Rubber %

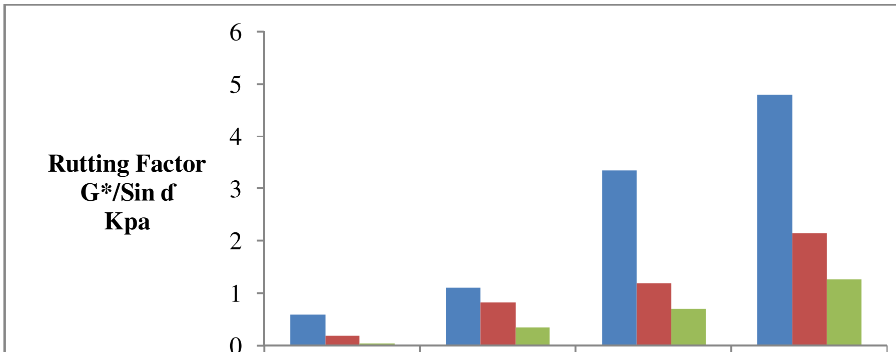
Figure 2. Mass loss columns for aged asphalt cement modified by crumb rubber

Dynamic Shear Rheometer

The third test method for characterizing performance grade of asphalt binder is dynamic shear rheometer. The rutting factor, (G*/sin d) results from testing the base and CRM binders with the dynamic shear rheometer (DSR) at 64, 70 and 76 ^{o}C are illustrated in Figures (3) and (4).

Note from the charts it has been used the largest size of CR based on previous studies, which states that coarser materials are more resistant to flow than finer particles. Where the size of the CRM did not show the same trend with the binder G* as with the viscosity as seen when comparing the G* results with the viscosity [7] [8] because coarser rubber produced a modified binder with high shear modules [9].

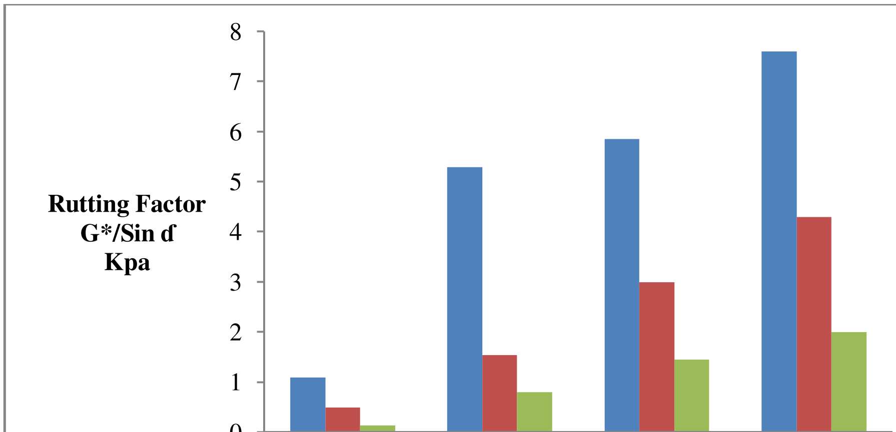
Figures (3) and (4) show the effect of rubber content on the rutting factor as a function of permanent deformation for unaged and aged asphalt binder at blending time equal 60 minute. Three temperatures were used with the larger size for modifier to determine the rutting resistance for unaged and aged asphalt binder. It is evident from these results that the addition of crumb rubber to an asphalt binder has a significant impact on the binder's high temperature performance.



	0%	6%	12%	18%
Temperature = 64 c	0.6	1.1	3.35	4.8
Temperature = 70 c	0.2	0.825	1.2	2.15
Temperature = 76 c	0.05	0.34	0.7	1.27

Crumb Rubber %

Figure 3. Rutting factor columns for unaged asphalt cement modified by crumb rubber



	0%	6%	12%	18%
Temperature = 64 c	1.1	5.3	5.85	7.6
Temperature = 70 c	0.5	1.55	3	4.3
Temperature = 76 c	0.14	0.8	1.45	2

Crumb Rubber %

Figure 4. Rutting factor columns for aged asphalt cement modified by crumb rubber

Also, It has been shown that the addition of crumb rubber to asphalt binder increases the high temperature stiffness (G*) of the binders. Thus, the rutting factor (G*/sin d) increases with the addition of CR into the pure asphalt cement. Also, the rutting factor increases with increasing the modifier content of the CR. It is mean that the permanent deformation will decrease with increasing modifier content in both unaged and aged asphalt binder. The reason for this is due to the interaction of crumb rubber with base binders. Due to this interaction, there are noticeable changes in the viscosity, physical and rheological properties of the rubberised bitumen binder, leading to high resistance of rutting of pavements [10] [11].

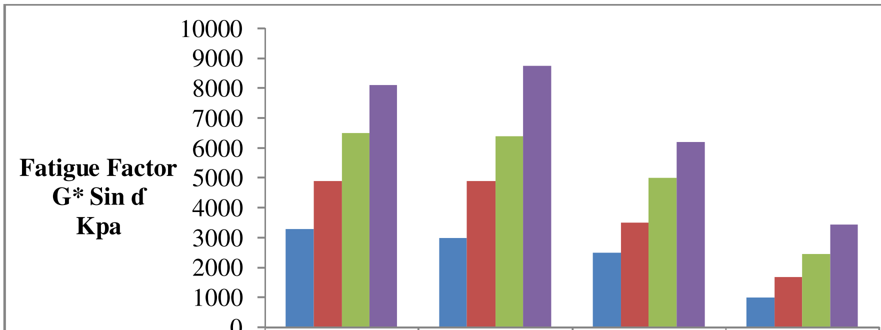
In addition the absorption of the light binder fraction by the crumb rubber (interaction) was not the sole cause of the increases in viscosity and G*. There was another factor, which was the result of the rubber particles acting as filler within the binder [8]. The interaction is swelling of the rubber particles caused by the absorption of light fractions into these particles and stiffening of the residual binder phase [7] [10] [12] [13]. The rubber particles are constricted in their movement into the binder matrix to move about due to the swelling process which limits the free space between the rubber particles [7]. The rubber particles may also suffer some form of degradation when they are mixed with bitumen at high temperatures for prolonged periods of time [13] [14] [15].

Long-Term Aged Binder (PAV Aging)

Fatigue Cracking Properties at Intermediate Temperature

After PAV aging , the fatigue resistance parameters, G*sin ƌ values, of the control and CRM binders were measured using the DSR at 13 , 16 , 19 and 22 C and the results are illustrated in figure (5).

Figures (5) show the effect of rubber content on the fatigue factor as a function of fatigue cracking for aged asphalt binder. Four temperatures were used with the larger size for modifier to determine the fatigue resistance for aged asphalt binder. It is evident from these results that the addition of crumb rubber to an asphalt binder has a significant impact on the binder's intermediate temperature performance. Also, It has been shown that the addition of crumb rubber to asphalt binder decreases the fatigue factor (G*sinƌ) of the binders. Thus, the fatigue resistance increases. Blending crumb rubber into an asphalt binder is believed to improve its elastic and energy absorption properties which are directly related to the binder resistance to cracking and rutting failures [16]. Also, the fatigue factor decreases with increasing the modifier content for each of the CR. It is mean that fatigue cracking will decrease with increasing modifier content in aged asphalt binder.



	0%	6%	12%	18%
Temperature = 22 c	3300	3000	2500	1000
Temperature = 19 c	4900	4900	3500	1700
Temperature = 16 c	6500	6400	5000	2450
Temperature = 13 c	8100	8750	6200	3450

Crumb Rubber %

Figure 5. Fatigue factor columns for aged asphalt cement modified by crumb rubber

Cracking Properties at Low Temperature

The fourth test method for characterizing performance grade of asphalt binder is bending beam rheometer. From the BBR tests at -12 and -18 C, the shrinkage resistance parameters, stiffness and m-value, of the control and CRM binders were calculated in fig. (6) (7) (8) and (9).

Figures (6) (7) (8) and (9) show the effect of rubber content and particle size of rubber on the stiffness and m-value as a function of low temperature cracking for aged asphalt binder.

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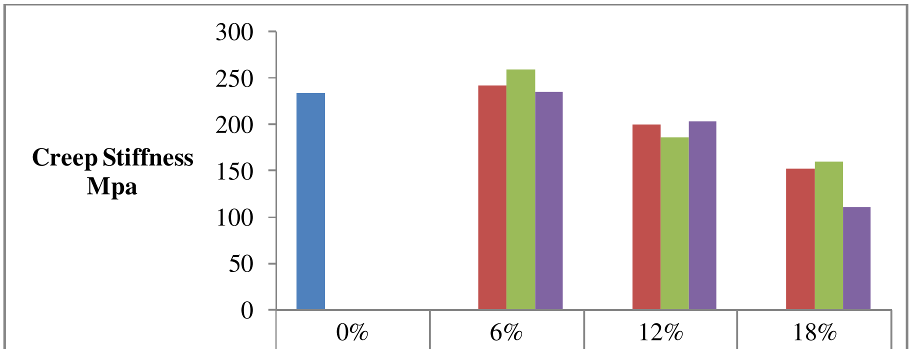
Two temperatures were used with three sizes for modifier to determine the low temperature cracking resistance for aged asphalt binder. It is evident from these results that the addition of crumb rubber to an asphalt binder has a significant impact on the binder's low temperature performance.

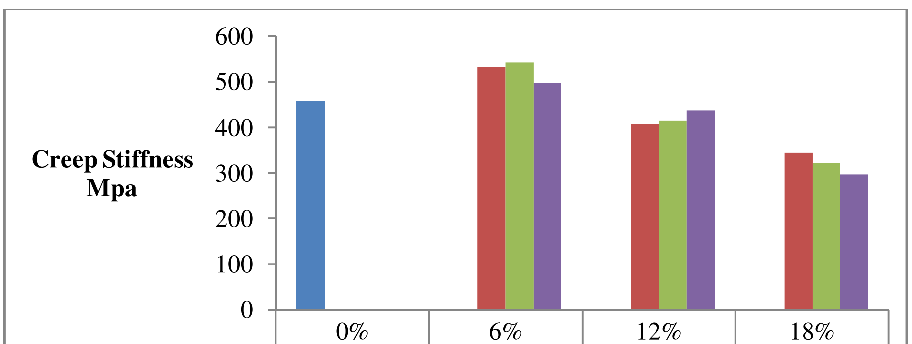
Also, it has been shown that the addition of crumb rubber to asphalt binder decreases the stiffness and increases m-value of the binders. Where that addition of crumb rubber to bitumen decreases the elastic and viscous moduli at low temperatures and, therefore, it causes an increase in binder flexibility.

Furthermore, it can be deduced that the thermal susceptibility of the binder is clearly reduced as a consequence of rubber addition. Consequently, enhanced resistance to low-temperature should be expected in the resulting asphalt rubber mixtures [13] [16].Also , Can be seen from the results that have been obtained from this study that increase the amount of rubber lead to continuous decrease in stiffness and continuous increase in m – value , Thus , the thermal cracking resistance of asphalt binder increases.



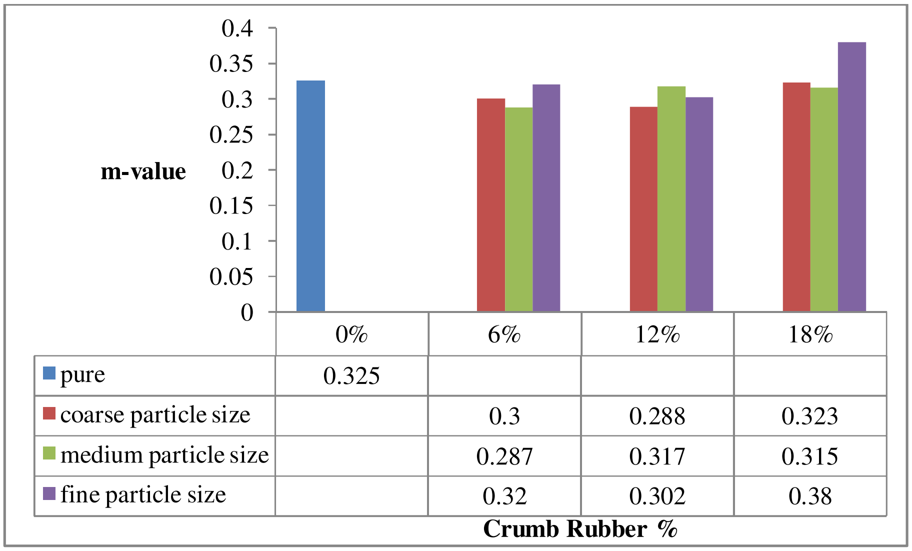
	0%	6%	12%	18%
pure	234			
coarse particle size		242	200	152
medium particle size		259	186	160
fine particle size		235	203	111

Figure 6. Creep stiffness columns for aged asphalt cement modified by crumb rubber at -12c



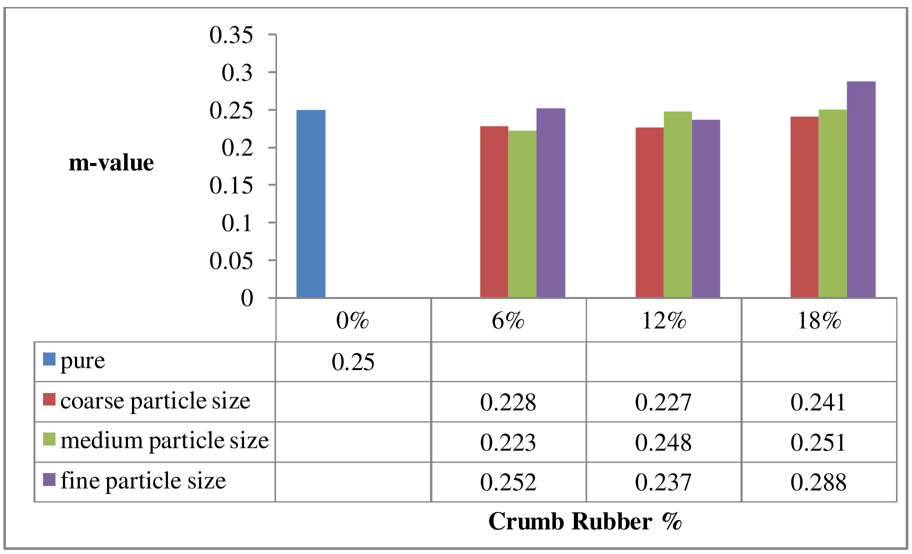
	0%	6%	12%	18%
pure	459			
coarse partcle size		533	409	345
medium particle size		543	415	323
fine particle size		498	437	297

Figure 7. Creep stiffness columns for aged asphalt cement modified by crumb rubber at -18c



	0%	6%	12%	18%
pure	0.325			
coarse particle size		0.3	0.288	0.323
medium particle size		0.287	0.317	0.315
fine particle size		0.32	0.302	0.38

Figure 8. m-value columns for aged asphalt cement modified by crumb rubber at -12c



	0%	6%	12%	18%
pure	0.25			
coarse particle size		0.228	0.227	0.241
medium particle size		0.223	0.248	0.251
fine particle size		0.252	0.237	0.288

Figure 9. m-value columns for aged asphalt cement modified by crumb rubber at -18c.

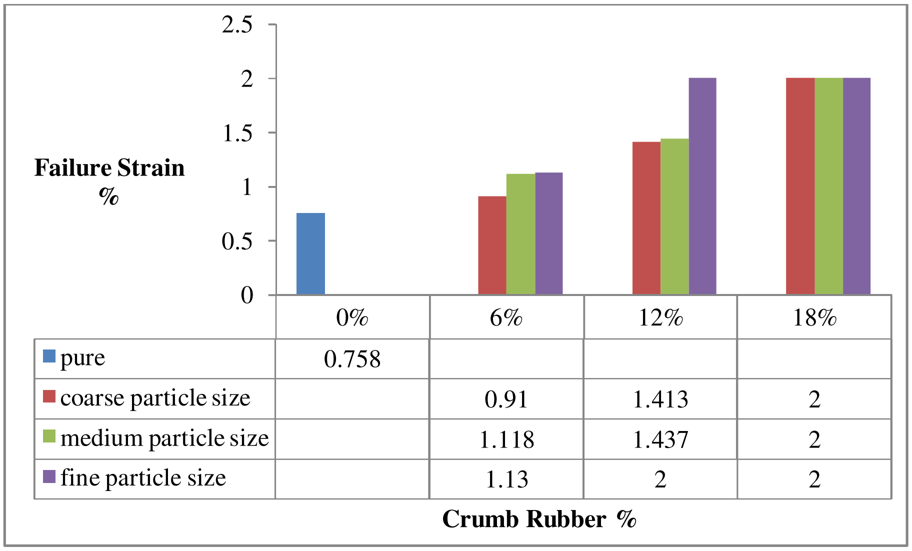
Note through schemes that the use of -12 c or -18 c as temperature test , We conclude the following: Fine–sized for (CR) achieves the lowest value for modified asphalt creep stiffness and achieves the highest m-value for modified asphalt at the ratio 18% .

The analysis of improvement in thermal cracking resistance of asphalt binder is as following:

1. The decrease in stiffness leads to smaller tensile stresses in the asphalt binder and less chance for low temperature cracking [17].
2. Binders with low m-values are slow to relax their stress as the temperature decreases, resulting in a thermal stress that builds more rapidly than that of those having a higher m-value [18]. In other words, Ahigh m-value is desirable because this means that as the temperature changes and thermal stresses accumulate, the stiffness will change relatively fast. Arelatively fast change in stiffness means that the binder will tend to shed stresses that would otherwise build up to a level where low temperature cracking would occur [19].

Changes in Failure Properties at Lowest Pavement Temperatures

The fifth test method for characterizing performance grade of asphalt binder is direct tension tester. From the DDT test at -12 C, the strain at failure of the control and CRM binders was calculated in fig. (10)



	0%	6%	12%	18%
pure	0.758			
coarse particle size		0.91	1.413	2
medium particle size		1.118	1.437	2
fine particle size		1.13	2	2

Figure 10. Failure strain columns for aged asphalt cement modified by crumb rubber at -12c

Results presented in figure (10) indicate that the asphalt cement modified had a higher strain at failure than the conventional asphalt cement without modifier. Can conclude that the addition of crumb rubber to the binder significantly increases the strain at failure of the binder because in the case of rubber particles in asphalt, at low temperatures such as the temperatures used in this study, the rubbers are much more flexible than the asphalt. It is, therefore, reasonable to expect an increase in strain tolerance as is observed in this study.

Through figure (10) can note that the ratio of 6% and 12 % revealed lower strain at failure than that of 18% for (CR) and can note from figures (10) that all sizes for (CR) achieves the highest value for strain at failure of modified asphalt at the ratio 18% while the fine – sized for (CR) achieves the highest value for strain at failure of modified asphalt at the ratio 12%. When (CR) percentage is 6% from the total weight of the mixed can note that medium and fine sizes produce convergent stain at failure values than coarse size.

CONCLUSIONS

According to the results above, it could be concluded that a desired stiffness and viscosity with high resistance for each of the permanent deformation and fatigue cracking and low temperature cracking of asphalt cement can be achieved by the modification of asphalt cement with a suitable quantity and choose the proper particle size. The properties of modified asphalt cement enhanced, by choose the proper particle size and increasing rubber content until the appropriate percent, as follows:

For asphalt modifier by crumb rubber (CR):

1. The proper particle size is fine size while the appropriate percent is 12 % from asphalt binder produces the best result for viscosity.
2. The proper particle size is fine size at 6% from asphalt binder and the proper particle size is medium and fine sizes at 12% and 18 % from asphalt binder produces the best result for mass loss.

3. The appropriate percent is 18 % from asphalt binder produces the best result for resistance of permanent deformation and fatigue cracking.
4. The proper particle size is fine size while the appropriate percent is 18 % from asphalt binder produces the best result for resistance of low temperature cracking.

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