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EVALUATION THE EFFECT OF WASTE LOW-DENSITY POLYTHLENE AND CRUMBRUBBER ON PHYSICAL PROPERTIES OF ASPHALT

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Abstract: Nowadays, Polymer Modified Binder (PMB) is necessary due to its valuable characteristics on asphalt pavement layers with increase in traffic volume and loads. However, current trend in asphalt modification is prefer the waste and by product materials for ensuring the sustainability and cost effectiveness. Therefore, to analyze the effect of waste Crumb Rubber Modifier (CRM) and waste Low-Density Polyethylene (LDPE) on the asphalt binders' physical properties, CRM/LDPE modified asphalts with different contents were prepared and investigated in this study. Measured physical characteristics were softening point, penetration, ductility and viscosity tests. Conversions of CRM and waste LDPE to functional materials have been introduced in this research study as a practical approach to improve the asphalt binder's physical properties. CRM and LDPE in the form of fine having a particle size under 250 um were used as additives to liquid asphalt, individually and collectively by weight of virgin asphalt, i.e., (5.0%, 15.0% and 25.0% of CRM) and (2.5. %, 5.0%, 7.5% and 10.0% of LDPE), after mixed with CRM and LDPE, the asphalts showed decrease in penetration, increase in softening point and rotational viscosity. This referring that both intermediate and high temperature rheological characteristics of the asphalts have been improved by the modification of waste CRM and LDPE, because that mean the stiffness of asphalt binder increases when changing these characteristics and Thus, the asphalt mixture will become more stiff and resistant to possible failures, the Physical properties of the CRM or LDPE modified asphalts are largely dependent on the waste CRM or LDPE content, and many other enhanced characteristics of the mechanical aspect can be targeted using the composite of both CRM and LDPE. However, such result confirms the validity of waste polymer in modifying the asphalt binder.

Keywords: *asphalt physical properties; Low-density Polyethylene; Ground Tire Rubber; Polymer modified asphalt.*

1. Introduction

Modifications of asphalt aim to enhance both the life time and performance of pavements, Thereby they provide advantage for both the environment and economic sectors[1]. Polymer modified bitumen's (PMBs) are mixture of polymer with asphalt by means of two main common approaches, the first one is the mechanical mixing, the second one is chemical reactions[2]. Comparing PMBs with virgin asphalt, PMBs increase toughness when temperature is high and boost the flexibility when it is low [2,3]. As a result, the new pavement mixture will keep its formation against the heavy trucks at high temperature, and during the low temperature days it will have high resistance against cracking. For all the mentioned reasons, the PMBs have been widely adopted for road pavements[3]. Despite that asphalt cement extremely influenced by temperature, it can be less gluy or viscous as well as softer when the temperature is high. As a result asphalt cement will cause a negative impact on the asphalt mixture's deformation[4][5].We need to perform asphalt cement modification to

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enhance several properties of it. Using high temperature, the stiffness can be increased of the hot mix asphalt, and that lead to performance improvement of the asphalt mixture. One additional advantage of increasing the hot mix asphalt stiffness at high temperature is reducing the rutting. By choosing a proper asphalt modifier, the service life of the pavement can be increased[6]. Previous studies were concluded that the behavior of modified asphalt cement with Crumb Rubber Modifier(CRM) is enhanced [7][8]. Back in 1960, Charles McDonald used rubber as asphalt modifier in road constructions, he added crumb rubber to the asphalt mixtures to enhance the pavement performance [9][7]. As indicated in many studies, the viscoelastic moduli and viscosity can be increased at high in-service temperatures by adding ground tire rubber to bitumen. The added rubber can reduce the storage and loss moduli at low temperatures. Both behaviors will result in a more flexible binder in this temperature range [10][11]. This bitumen shows developed mechanical characteristics which improve the resistance to both fatigue cracking and rutting. After adding rubber, the asphalt shows increased elastic and viscosity properties at high temperatures, thus allowing it to be more resistance to permanent deformations. In addition to that, it was found that low temperatures stiffness of asphalt was decreased by adding rubber, that improved the flexibility to resist low temperature fracture [12][13]. On other side, Polyethylene is also used as asphalt modifier. Appiah et al [14] reported that by using recycled plastic contains predominantly of polypropylene and low-density polyethylene into pure bituminous concrete mixture will increase its durability and service life. The modified asphalt concrete with low density polythene shows resistance to deformation compared to the unmodified mixes. Other authors stated that the use of waste polyethylene as modifier for asphalt binder, the waste polyethylene scattered in asphalt shows relatively small particles with homogeneous allocation [15][16]. Ductility, softening point and penetration were all remarkably improved compared with the ordinary polymer modified asphalt. The obtained modified asphalt has low temperature anti-cracking behavior, deformation resistance and magnificent high temperature stability. Very limited studies used CMR and PE collectively as asphalt binder modifiers, and almost they considered in roofing applications. Both rubber and Waste PE (WPE) were mixed to change the oil asphalt to improve the asphalt's performance, the whole performance of Asphalt-WPE-RU system was excellent compared with asphalt-WPE system [7][16][17]. In this research two types of polymers were used, waste Low density polyethylene (LDPE) and CRM as asphalt modifier, to sustain the knowledge about such comprising in paving industry. Waste LDPE proposed with different percentage (i.e. 2.5, 5, 7.5, and 10) % by weight of the total asphalt cement and CRM with (5, 15 and 25) % by weight of total asphalt cement to improve the properties of asphalt mixture.

2. Materials

Control asphalt cement Pen. (40-50) was adopted for this study and its physical characteristics are listed in Table 1, specimens were tested at the National Center for Construction Laboratories and research (NCCRL) in Baghdad. CRM was brought from tires factory in Al-Najaf / governorate which is a black granule (size 250 micron or less), specific gravity (1.13), and this type is recycled from used tires. The waste LDPE in this study was brought from (Al Tobji) factories in Baghdad City, which is a waste green granule (the particle size is less than half a centimeter), density (0.918)g/cm³ as shown in Fig. 1 used for producing plastic belts for recycling used. Crumb rubber as shown in Fig. 2 is the recycled rubber obtained by mechanical shearing or grinding of tires into small coarse crumb rubber. CRM can be defined as a sustainable product resulted from scrap rubber that is pulverized and crushed into different mesh sizes. The process of modifying asphalt binders with CRM&LDPE through a wet process.

Table 1: Physical Properties of Asphalt Cement

Property	ASTM Designation	Test result	SCRB specification
Penetration at 25 ^{O}C,100 gm,5 sec. (0.1 mm)	D-5	47	(40-50)
Ductility at 25 ^{O}C, 5 cm/min. (cm)	D-113	>100	>100
Flash point (Cleveland open cup), (^{O}C)	D-92	245	Min.232
Softening point, (^{O}C)	D-36	52	-----------
%Solubility in trichloroethylene	D-2042	99.2	Min. 99%
Specific gravity at 25 ^{O}C	D-70	1.04	-------

Figure1. Waste Low Density Polyethylene

Figure2. Crumb Rubber Modifier

3. Sample Preparation

Three CRM concentrations (5%, 15%, and 25%) and four LDPE concentrations (2.5%, 5%, 7.5%, and 10%), in relation to the weight of neat asphalt cement, were selected. Using the mechanical shearing process, the modified asphalts were produced using different CRM and LDPE concentrations. The modifier Asphalt binders were prepared in the laboratory with a wet process by blending the (40-50 grade) virgin binder with the CRM as a single pure modifier and with admixture of CRM/LDPE. Preparation method was developed in the laboratory to maximize the rheological properties and to minimize the asphalt degradation. The asphalt was heated to become a fluid in an iron container. One important point is using the appropriate temperature to maintain the mixing quality. Number of constraints need to be considered when working with polymer-modified asphalt and choosing the mixing temperature. These vital factors are mentioned below:

1) The use of high temperature to ensure the following:
    - the binder has suitable fluidity to provide uniform aggregate coating during mixing

- The result mix discharge does not cool to below 85ºC during laying and compaction as stated by [21]

2) The use of low temperature to ensure the following

    - Polymer in the modified binder does not degrade,
    - Accelerated hardening of the asphalt in the modified binder does not take place due to exposure to heat and air.

A mechanical mixer was manufactured with high shear mixing force, and used to mix both the virgin binder and CRM/LDPE. In this work, the blending temperature was in the range of (170ºC) to (180ºC), the virgin binder temperature was raised to (180°C) with an independent temperature controller, This temperatures (170 to 180) were selected after several attempts to obtain a homogeneous blend so that the reaction between the CRM and the asphalt binder is reacted and the virgin asphalt binder is heated to a high temperature of 180, due to the effect of the CRM when added it will cause reduction of the asphalt binder temperature when first added to the hot asphalt binder. When reaching the desired temperature, the mixing started with the shear mixer at mixing speed up to 3500 rpm. The certain amount of polymers (CRM and LDPE) was then gradually added into asphalt binder to prevent any sudden drop in temperature, which was monitored during the whole mixing process. The mixer and the heating system are shown in Fig. 3.

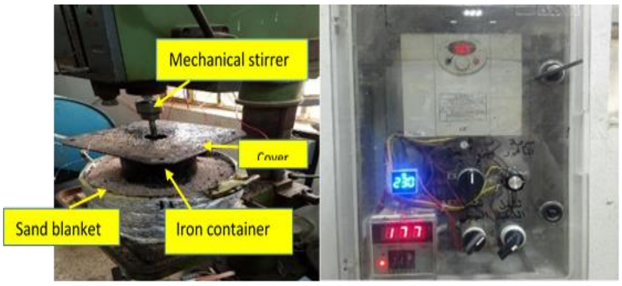

Figure 3. Shear Mixer and Heating System

4. Testing

Laboratory test results often give a picture that reflects the performance of the asphalt mixtures in an actual pavement. Bitumen holds complex physical properties, and in order to explain these properties correctly, we need to perform many tests to represent a vast range of operating conditions like loading rate, temperature, strain and stress. To prevent dealing with this situation, equations and empirical tests were formulated to describe the rheological properties and mechanical behavior of bitumen. Four tests were used to identify the significant of introducing CRM/LDPE on the neat asphalt binder, including Penetration test at 25ºC, ductility test at 25 ºC, softening point test and rotational viscosities, the asphalts' physical characteristics were identified according to ASTM D5, ASTM D113, ASTM D36, and ASTM D4402, respectively. In this research work Temperature susceptibility (TS) is identified also. TS is defined as the change in stiffness, consistency and the viscosity as a function of temperature. Temperature susceptibility which is the measure of asphalt behavior deviation from Newtonian to non-Newtonian. For road construction, asphalt typically holds amount between +1 and -1, while the asphalt with amount fewer than -2 shows Newtonian behavior and can be break at lower value and those more than +2 are less fragile, showing high elastic characteristics under higher stress[18]. The PI can be used to characterize the rheological type and can be determined from the following equation, it's one of the best-known equations is that describing the temperature susceptibility of a bitumen:

$$\frac{20-PI}{10+PI}=5\times\left(\frac{\log 800-\log penettation}{T_{R\&B}-T}\right) \quad (1)$$

where T is penetration temperature (normally taken at 25 ºC), TR&B is ring-and-ball softening point temperature (ºC) and the penetration value of 800 dmm represents the penetration at softening point temperature for bitumen. Assuming that the penetration temperature will be 25 ºC, so the equation above can be rearranged to calculate the PI of the asphalt binder as following:

$$PI \; \frac{1952-500\log pen-20SP}{50\log pen-SP-120} \quad (2)$$

5. Methodology

The following methods were used to identify the significant of the comprising waste CMR and LDPE on the physical properties of the asphalt binder:

- Identifying the physical properties of the neat asphalt binder for the purpose of comparison with modified asphalt binder which has been processed by waste materials
- Identifying the variation in physical properties of modified asphalt due to incorporating of polymers (i.e. waste CRM and LDPE)
- Identifying the ideal percentages of CRM according to ASTM D 6114
- Identifying the effect of mixing time on viscosity modified asphalt binder

6. Results and Discussion

6.1 Penetration Test

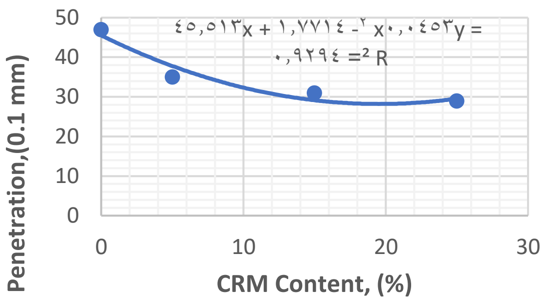

Figure 4. Relationship between Penetration and CRM Content

The results of penetration test are presented in Fig. 4 indicate that the physical properties of modified asphalt binder were changing dramatically when added the CRM. This indicates that the mixing process with the CRM lead to an increase in hardness due to stiffening of binder, as a result of absorption of some bitumen oils by rubber which increases the viscosity of asphalt binder. On the other hand, when mixing both polymer and asphalt, it forms a multiphase system, and it has great amount of non-absorbed asphalt by the polymer and that mean when these two polymeric materials are simultaneously added into bitumen interesting types of morphology and dispersion are happened. For example rubber particles became larger in volume. This clearly differentiates rubber particles from those of LDPE. In spite of rubber swelling the formed polymer network remains unchanged in bitumen medium. As a result, the consistency will increase of the modified binder by the construction of a more complicated form internally. By analyzing Fig. 4, it shows that penetration in all cases continued to decrease when increasing the percentage of CRM, but in nonequivalent rates. However, as the dose percentage of additives was (5%), we can clearly see a semi-sharp decline in the rate of change in penetration (penetration reduces by 26% as compared to unmodified asphalt binder). While a steady decrease in a slower rate of penetration was dominant with higher CRM (34% and 38% when increasing the percentage of CRM to 15% and 25%, respectively). CRM can have big impact on the blended asphalt due two characteristics, namely, a good dispersion has been achieved through the small size of CRM particle, to add on that, because of the small particles in size used CRM (250 micron or less), which represent each unit mass of polymer has large surface area. The asphalt's penetration results confirm the swelling of the Crumb Rubber and rapid dissolution is completed, by increase in hardness of the modified asphalt. The penetration test is a means of classification of asphalt binder rather than a measure of quality[18]. Thus, the 15% was taken as a control percentage of CRM according previous recommendation that It has been found that at least 15 % rubber by weight of the total blend is usually necessary to provide acceptable properties of asphalt-rubber that the reason of using of 15% CRM and that supported by ASTM D 6114 [22].The effects of LDPE on penetration of modified binder comprising 15% CRM are shown in Fig. 5. Used CRM/LDEP as admixture additives are 15:2.5, 15:5, 15:7.5 and 15:10 of the asphalt binder.

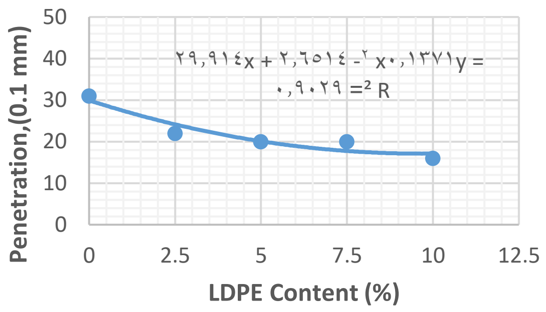

Figure 5. Relationship between Penetration and LDPE Content for modified binder with 15%CRM

From Fig. 5 it can be observed that penetration in all cases continued to decrease when admixture of LDPE increases. regardless the findings, considering the tiny concentration of LDPE (2.5%) which exceedingly achieved an early differentiation in penetration by reduction the penetration point by 29% as compared to modified asphalt binder with 15% CRM. It worth mentioned that the increase rate in penetration due to LDPE comprising is increase slightly with higher LDPE dosages, they are 37%, 37% and 48% for modified binder comprising 5%,7.5% and 10% of LDPE, respectively, as compared to binder comprising 15% CMR. These results indicate that the asphalt binder becomes hard. Similarly, it seemed that the increasing value of LDPE provide stiffness effects on the mixture of SRM/LDPE, and that will lead to dropping in penetration comparing to the flexibility effects of CRM.

6.2 Softening Point

According to ASTM D-36/ 2014, the softening point to all samples (or ring and bell test) was followed as shown in Fig. 6.

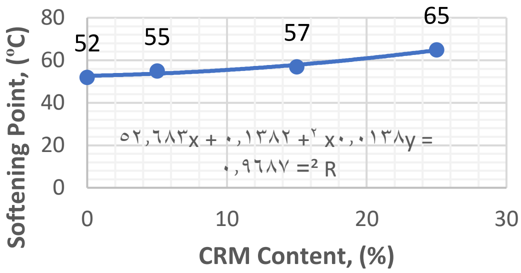

Figure 6. Relationship between Softening Point and CRM Content

The results of softening point test in Fig. 6 depict the effect of CRM on softening point of asphalt binder. It can be observed with 5.0% concentration of CRM an increase in softening point is recognized in comparison to the virgin asphalt (0.0% additions). The softening point of the modified asphalt was increased profoundly in proportion to the increment percentage of the CRM over 5.0%. As example, it is increased from the starting softening point of virgin asphalt of 52°C to 57°C at 15.0%, and eventually hit 65°C at 25.0% of single CRM pure addition. This huge elevation in softening point with increment in CRM concentrations is due to the instability in the thermodynamic properties of the internal structure, and as a result it will effect on the softening point of the virgin asphalt. That represents the relation between the permanent deformation and the excellent performance. Also, it should be noted that the increasing of CRM usually attended with the decreasing in penetration, on the other hand softening point is usually increased that means an opposite relationship between two empirical tests as shown in Fig. 7. When the relationship is inverse as shown in the Figure below that supports the results presented because it corresponds to the researches and literatures of others in the concept of changing the physical and rheological linker on this type of manner.

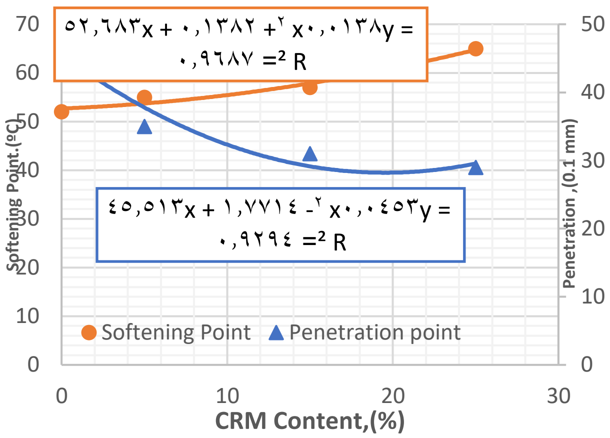

Figure 7. Relationship between Softening Point Test & Penetration Test of Modified Binder comprising CRM

The analysis of tests results shows that the polymerized asphalt mix had a higher softening point than the neat asphalt binder. Based on previous studies, all percentages of polymeric materials may improve the mixture, but to varying degrees, and sometimes the high increase in additives may increase the hardness of asphalt binder and give undesirable negative results, but generally it may be concluded that the polymerized asphalt binder will enhance the performance of mixture when used in combined with aggregate and other components of mixture and would be less susceptible to plastic deformation. Generally, by using rubber we are increasing the elasticity of HMA[23], as a result the asphalt mixture will show improvement against cracking. However, as expected, better results in the softening point were revealed when using CRM modified asphalt. Many researchers [23, 24] stated that may relate to the similarities in the chemical characteristics between the asphalt and CRM, as both are hydrocarbons materials. Hydrocarbons materials provide strong bonding and high attraction among the molecules of both asphalt binder and CRM powder. Other factors that provide the strong bonding is the softness and the tiny particle sizes of the rubber particles (<0.25 mm), that provides high surface area in the mixture of CRM and asphalt binder and that supported by [25]. Three advantages can be received from this final modified product, these are resistance to permanent deformation (cracking and rutting), resistance to fatigue and to temperature.

On the other side, the blending of LDPE with asphalt comprising 15% CRM as additives with ratio of 2.5:15, 5:15, 7.5:15 and 10:15 were characterized for softening point. It can be seen a considerable variation was obviously attained with increase in LDPE introduction. The four additions influence the softening point of the modified asphalt binder as shown in Fig. 8.

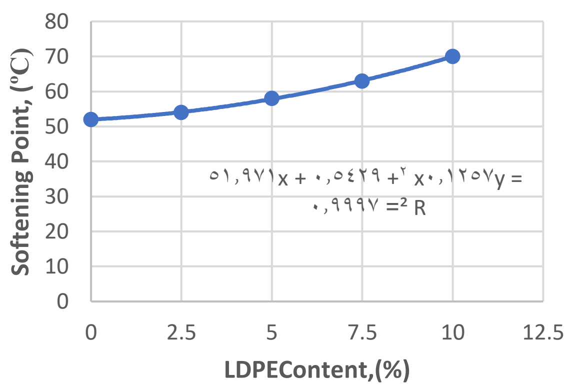

Figure 8. Relationship between Softening Point and LDPE Content for modified binder with 15%CRM

The analysis of Fig. 8 shows that the softening point was increased in the modified asphalt proportionally with the increment percentage of the additions. We can see clearly that the softening point of the modified asphalt was grown remarkably with the increment percentage of the additions more than 5.0% of LDPE. As example, it is increased from starting softening point of neat asphalt binder equaled to 52°C to 54 °C at (2.5%:15%), then 58°C, 63 °C at (5%:15%), (7.5%:15%) and finally reached 70°C at (10%:15%) of LDPE/ CRM additives. This large rise in softening point with the growth in LDPE amount is a consequence of the inner construction generated from LDPE. However, the softness and size of the small particle rubber powder (<0.25mm) are considerable factor to the bonding between asphalt and CRM since provides better results in concern to softening point, as show in in Fig. 4 above. When the softening point of admixture of LDPE: CRM is lower than the test results for single pure of 15% CRM which is related to the similarities in the chemical characteristics between both asphalt binder and CRM. Fig. 9 show the relationships between softening point and contents of an admixture of LDPE: CRM, and a single pure 15% of CRM.

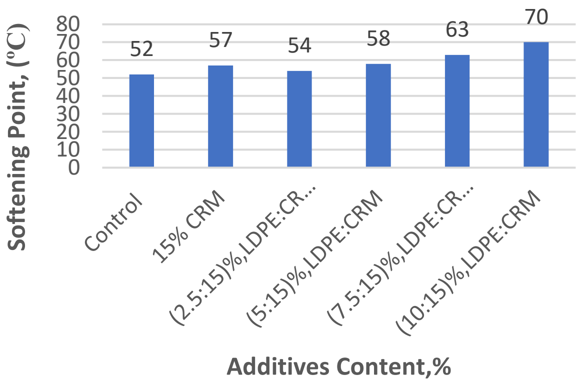

Figure 9. Relationship between Softening Point and Additives Content

Outstandingly, as observed in the modified asphalt, a tight relation in terms of their effect on the softening point when adding LDPE and CRM in a ratio of 7.5:15 as a mixture additive to the virgin asphalt as shown in Figure 9. On the other hand, in the mixture of both LDPE/CRM, when increasing the amount of LDPE from 5:15 to 7.5:15, the modified asphalt's softening point was increased. That was also the same case happened with increasing the LDPE: CRM mixture ratio from 7.5:15 to 10:15. The low amount of LDPE is reducing the softening point value as compared to a single pure 15% CRM, exactly for the ratio 2.5:15 of LDPE. which may be attributed to high attraction and strong bonding among the molecules of both LDPE powder and asphalt binder also the presence of CRM seemed to be the accountable for increasing the softening point of the modified asphalt due to small particle sizes of the rubber powder that will participate to the bonding between asphalt binder and CRM due to its high surface area. In conclusion, the final modified product will show more resistance in terms of deformation (both cracking and rutting).

6.3 Viscosity

The asphalt samples' viscosity characteristics were determined by a rotational viscometer following ASTMD-4402. The viscosity properties for the virgin asphalt and modified one (CRM and a mixture of CRM/LDPE) was measured by equipment. The test results of viscosity for modified asphalt binder show in Table 2.

Table 2. Viscosity as a function of different quantities of CRM

Asphalt Binder Type	% Additives	Viscosity, (Pa. Sec)		
		@ 135 ºC	@ 165 ºC	@ 175 ºC
Control	0	0.775	0.156	0.094
CRM,5	5	1.190	0.240	0.155
CRM,15	15	1.425	0.301	0.193
CRM,25	25	-	3.760	2.663

The results are represented in Fig. 10, which shows the increment in viscosity of the modified asphalt blend alongside the different percentage of composite single pure CRM that increase related to the additions in a higher manner compared to the virgin asphalt binder.

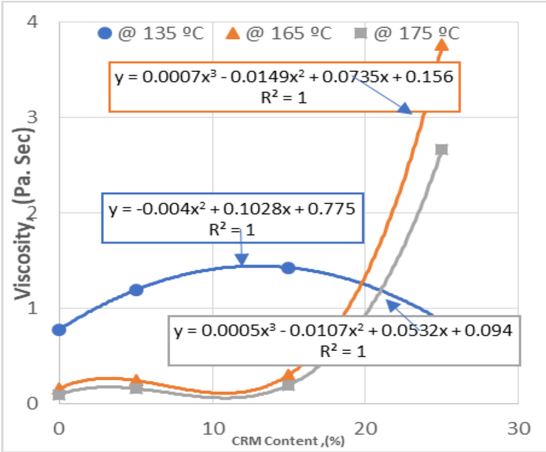

Figure 10. The relationship between Viscosity & CRM Content at different Temp. Test

As shown in Figure 10, the variation in viscosity was revealed in the single pure CRM modified asphalt. In addition to that, in the same Figure it can be seen the effect on the final asphalt's viscosity varied by 25% regarding the effect of single pure CRM additions because the high percentage of CRM increases the absorption of materials with a small molecular weight and therefore will increase the density and it well known from the above Figure we note that the higher temperature the less viscosity and the greater the proportion of additives the greater the viscosity. It is noticed that the percentage of increase in the viscosity is 35% when the CRM content is 5%, and then increase to 46% at CRM content 15% (as compared to control asphalt binder for temp. test 135 ºC) .it should be noted that the viscosity decreases when the temperature of test increase and that represents the fact related in the behavior of asphalt binder. Similarly, the viscosity increases 35%, 48% and 95% for CRM content 5%, 15% and 25% respectively (as compared to control asphalt binder for temp. test 165 ºC). As the observation, the final modified asphalt's viscosity was affected by single pure CRM and it is apparent at 25% of additive. Asphalt change its behavior according to the temperature and load applied to it, that is why it is identified as thermo-viscos-elastic material. In high temperature it shows some viscous behavior, while when the temperature is low it reveals some elastic behavior. To determine the viscosity of modified asphalt binder by different percentage of LDPE in addition to the presence of 15% CRM, Rotational Viscometer used according to the ASTM D 4402–06, test results represented in Table 3. For years, asphalt mix design procedures have used equiviscous temperature ranges for selecting laboratory mixing and compaction temperatures. The purpose of using equiviscous mixing and compaction temperatures in laboratory mix design procedures is to normalize the effect of asphalt binder stiffness on mixture volumetric properties, that represents the reason for selecting the two temperatures (135 and 165 ºC). The readings show viscosity increment of the added mixtures with the modified asphalt blend. Admixtures of 15% CRM: LDPE additives of ratios of 15: 2.5, 15: 5, 15: 7.5 and 15:10 respectively, were increased as shown in Fig. 11 than the neat asphalt binder.

Table 3. Viscosity as A function of Different Quantities of CRM: LDPE

Asphalt Binder Type	% Additives	Viscosity, (Pa. Sec) @ 135 ºC	@ 165 ºC	@ 175 ºC
Control	0	0.775	0.156	0.094
CRM: LDPE	15:2.5	3.545	0.669	0.523
CRM: LDPE	15:5	6.958	1.300	0.808
CRM: LDPE	15:7.5	15.680	5.913	3.665
CRM: LDPE	15:10	16.000	9.175	7.567

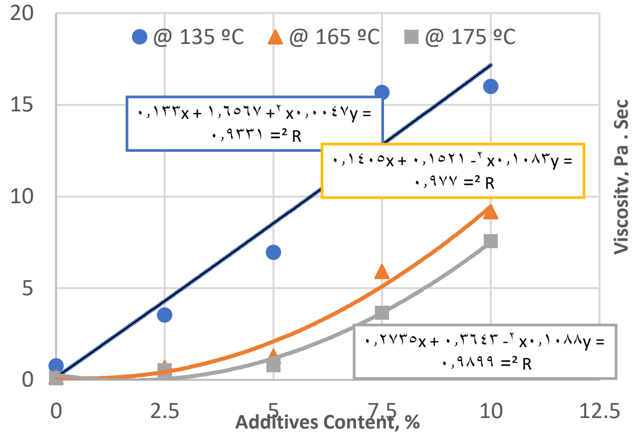

Figure 11. The relationship between Viscosity & LDPE Content at different Temp. Test

The analysis of Fig. 11 show that the mixture of CRM: LDPE in ratios of 15:2.5 and 15:5, when virgin asphalt is blended with them under the experimental conditions, the viscosity was less varied by both, at 165 ºC and 175 ºC which was apparent at the admixture of CRM: LDPE in ratio 15: 7.5. As an increment of 15:10 of the percentage of the mixture additions (of ratio). The following increase in the percentage of the added mixtures to the neat asphalt has led to make a clear contrast with a lower rate especially by the CRM: LDPE in a proportion of 15:2.5. The viscosity of the composite single pure CRM added to the modified asphalt blend, and the mixtures of CRM: LDPE additions in all ratios were collected as in Fig. 12 and 13.

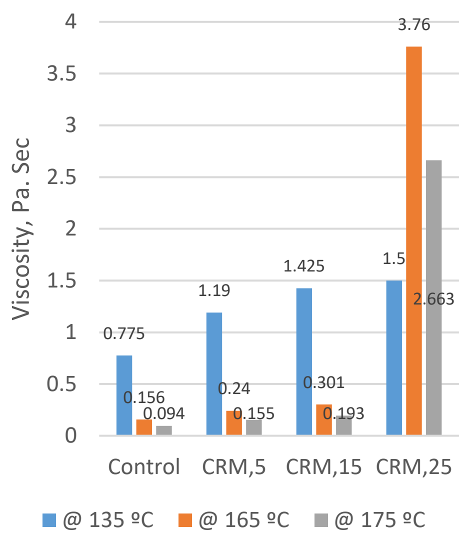

Figure 12. Viscosity as a Function of Different Quantities of Single Pure CRM

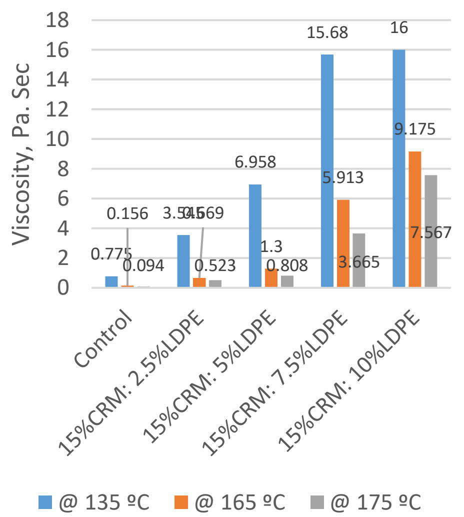

Figure 13. Viscosity as a Function of Different Quantities of Admixture of CRM: LDPE

It seems that the increment in CRM value with the added mixture is somehow accountable for decreasing the viscosity of the final modified asphalt result, suggesting that the CRM is the main factor for having the perfect acceptable viscosity results. Due to the melting point of LDPE equal 122°C, and that is less than the reaction temperature of the asphalt which is 180 ± 2°C, LDPE soak up some of the melted asphalt's oil. That will result in releasing some low molecular weight fraction to the bitumen, and that will effect on the polymer modified asphalt by increasing its viscosity. By the time it cools a tougher mixture is resulted, and that is important to get harder material, so the viscosity was increased for the modified asphalt binder.

6.3.1 Effect of Blending Time on Viscosity

CRM and LDPE modified binders were produced in the laboratory using three blending times (15, 30, and 45 minutes) for each percent content of polymers, and after each blending time, the modified asphalt binder tested by Rotational Viscometer (RV) to determine the viscosity to select the optimum blending time. Fig. 14 show the variation of viscosity for 15% CRM blended with neat asphalt binder in different times. It is noted from Fig. 14 that at 30 minute of blending time, the viscosity of modified asphalt binder reduces, and at 45 minute the reduction of viscosity is lower reduction as compared with the viscosity at 30 minute of blending time. This was considered to be a 30-minute blending time in this study and represents the required time for completing reaction between the rubber particles and the asphalt binder.

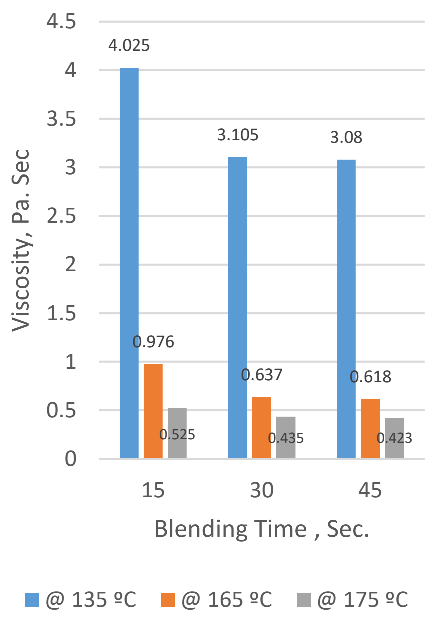

Figure 14.Viscosity and Blending Time

The art of good asphalt modification is in trying to make the overall binder behaves more like the polymer while maintaining good workability in the end-use application. When the polymer is blended into the asphalt it is dispersed either as discrete particles or as a three-dimensional network in the asphalt. The challenge is to form and maintain the desirable network consistently in different asphalt types and for prolonged periods in hot storage. Some polymers form networks under correct conditions due to their structure while other polymers need chemical cross-linking to form a network. The reaction process of rubber particles in asphalt cement is time dependent. Higher temperatures result in quicker reaction and may result in greater amounts of swelling, [19]. It has high dependency on the blending temperature and blending shear rate. It was found that blending for long time is uneconomical and detrimental to rheological characteristics of the modified binder. By monitoring the decreasing in consistency of the PMA, that can be done by measuring the viscosity at regular time duration while it is in the blending process (for example every 20 minutes), then we can identify the blending time for a specific polymer type. Once the viscosity shows stability and does not reveal a significant change with time, the blending process can be halted[20].

7. Ductility

The ductility of an asphalt cement provides measure of homogeneity properties of bituminous materials and may be used to measure ductility for specification requirements. For neat asphalt, ductility is an indicator of how flexible the behavior of bitumen under various temperatures. The results of ductility presented through Fig. 15, it illustrates that decreases of ductility are observed and affected deeply when CRM is added into the neat asphalt binder.

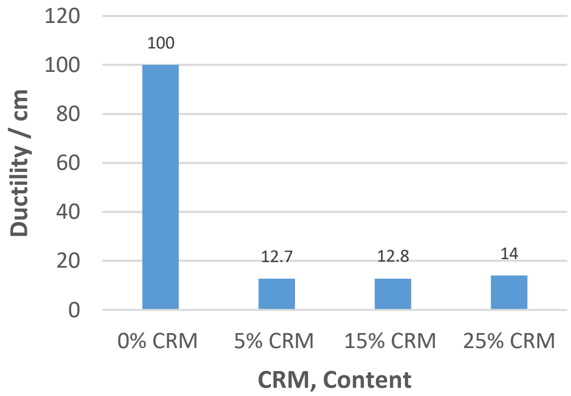

Figure 15. Ductility of Asphalt Binder with Different CRM Contents

However, though the ductility has a reverse relation with increasing CRM concentration, its change over CRM contents does not follow a single direction: when small part of CRM is mixed with the asphalt binder, the ductility decreased sharply, then with the increasing ease of CRM content the ductility begins to rise slowly. At higher CRM content (25%), the ductility increases continuously as CRM content increases. This could be a result of swelling effect of the added CRM. At low CRM, the amount of the free aromatics and some other low molecular composites become less, and that make the asphalt less ductile as well. However, when the CRM content continues to increase, the rubber particles can form interconnections, which makes the asphalt binder less stiff and yield increased ductility or the presence of CRM introduces more elasticity, consequently resulting in ductility increment. In general the ductility decreases due to the absorption of lower molecular weight by CRM and that cause the increase in stiffness of asphalt cement thus reduces the ductility and that support by several researchers [23, 24, 26]. Similarly, decrease of ductility is observed as shown in Fig. 16 when CRM and LDPE are added into the neat asphalts. Nevertheless, there is a fixed decreasing behavior of ductility with LDPE concentration increment with or without the availability of CRM.

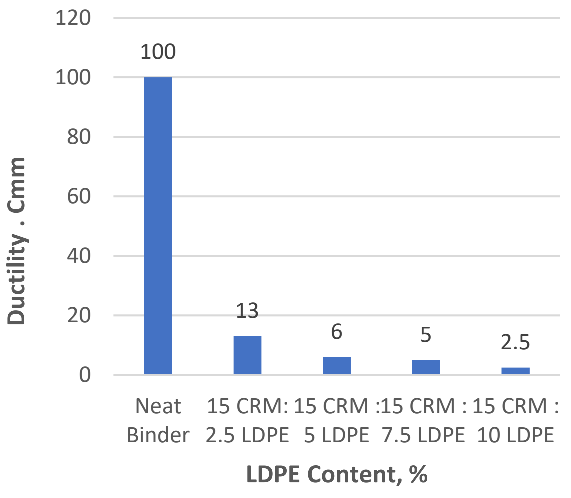

Figure 16. Ductility of Asphalt Binder with Different LDPE Contents

Although, when increasing the content of CRM, interconnections are formed by the rubber particles, which decrease the asphalt's stiffness and then increment in ductility; but when LDPE content increases and the percent of CRM is constant at 15%, the ductility continuous to reduce especially at high LDPE content, the LDPE may have already formed a network throughout the asphalt, and the added 15% of CRM not effect on the elasticity of admixture , consequently resulting in decreased ductility.

8. Penetration Index

Fig. 17 and 18 demonstrates the temperature susceptibility in term of PI. For sure, in the countries with higher temperature, those type of modified asphalts should be used in road constructions.

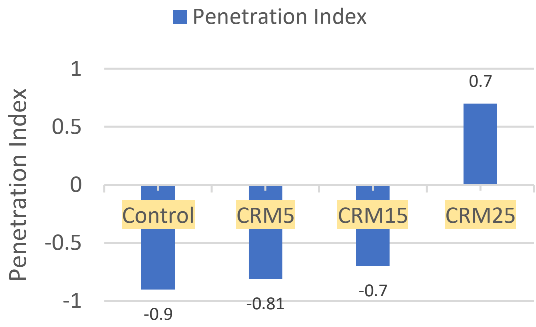

Figure 17. Penetration Index for different %CRM Modified Asphalt Binder

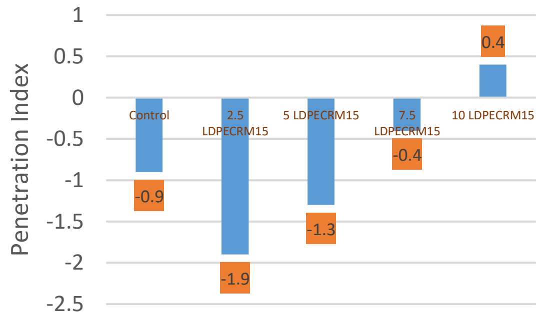

Figure 18. Penetration Index for different %LDPE Modified Asphalt Binder

Table 4 depicted the values of softening point and penetration point for different modified asphalt binder by LDPE and CRM and demonstrated a penetration index that represents the most common way to measure temperature susceptibility for asphalt binder.

Table 6. The PI values compared to the Softening point and Penetration Values

Asphalt Binder Type	% Additives	Softening Point	Penetration Point	Penetration Index
Control	0	52	47	-0.9
CRM	5	55	35	-0.81
CRM	15	57	31	-0.7
CRM	25	65	29	0.7
CRM: LDPE	15:2.5	54	22	-1.9
CRM: LDPE	15: 5	58	20	-1.3
CRM: LDPE	15:7.5	63	20	-0.4
CRM: LDPE	15:10	70	16	0.4

PI values are located between both -1 and +1 for all the high percentage of additives. Any Modified asphalt with this range of PI values would prove that it has less sensitivity toward temperature compared to the virgin asphalt, as a result the cracking process will be less in low temperatures and fewer rutting during summer time. On the other hand, it seemed that by increasing the ratio of LDPE (as a mixture of CRM), that will lead the PI to go beyond the required value for applications of pavement constructions.

9. Conclusions

With reference to the test and analysis program of this research work, the following can be concluded

1. The physical characteristics of asphalts are improved by the addition of CRM and LDPE. After mixed with CRM and LDPE the asphalts reveal increased viscosity and softening points, as well as decreasing in penetration, for instance as the dose percentage of CRM was (5%), (penetration reduces by 26% as compared to unmodified asphalt binder). While a fixed and slower rate decreasing of penetration was obvious with higher CRM (34% and 38% when increasing the percentage of CRM to 15% and 25%, respectively) and, it is increased from starting softening point of neat asphalt binder equaled to 52°C to 54 °C at (2.5%:15%), then 58°C, 63 °C at (5%:15%), (7.5%:15%) and finally reached 70°C at (10%:15%) of LDPE/ CRM additives, suggesting that the CRM/LDPE modified asphalts become more resistant to deformation and harder in the normal and high temperatures.
2. The three factors of polymers type, particle size and content are affecting significantly the characteristics of physical properties of PMB. The content is foremost factor affecting the performance of modified asphalt binder, followed by polymer type, and particle size comes last. The basic performances of asphalt modified by low polymer content, for different type of polymers (CRM & LDPE), have no significant difference, while the increasing in polymers content that improve the asphalt binder properties significantly.

3. The addition of 15.0% Crumb Rubber Modifier to asphalt binder, processed at 180 ºC for 0.5 hr., results in a stunning modification in the rheological response. The viscosity of CRM asphalt binder, in a temperature range comprised between 135ºC–175 ºC, increases with Crumb Rubber content and is clearly more viscous than the corresponding neat and processed binder. In addition to that, due to the increase in

temperature and content, flow behaviors of the modified binder become more non-Newtonian.

4. The softening point can be increased, and the high/low temperature performance can be improved for the row asphalt, when combining modification of asphalt binder by LDPE and CRM. The amount of the LDPE is more influential on the high-temperature performance, while the waste CRM can enhance the low-temperature cracking resistance.

5. The inclusion of CRM increases the stiffness of asphalt binder and in turn increases the stiffness of asphalt mixtures at intermediate temperatures (20◦C), which reduce the cracking potential of pavements at intermediate temperatures and fatigue cracking

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