PROC. INTERNAT. CONF. SCI. ENGIN.
Volume 4, February 2021
Page 205-211

ISSN 1504607797
E-ISSN 1505707533

The Evaluation of Polymer-Modified BNA-Blend

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Abstract. Asphalt roads are the lifeblood of people who live in the desert regions in Libya, where the environment there considered the hottest and arid region in the world. So, this harsh environment damages the asphalt road and make it unsafe. High temperature and wheel loads are essential factors that damage the asphalt road. Rutting is one criterion for the failure of this asphalt mixture, which disturbs passengers and increases the maintenance costs of asphalt pavement. This research evaluated the physical and rheological characteristics of BNA-Blend modified with elastomeric polymers. Five types of polymers used, namely, NR (Latex), EVA, SBS, and EPDM at five percentages (2, 4, 6, 8, & 10%) of each kind of polymers. The fluorescent microscopy images show homogenized for NR, EVA, and SBS mixtures, except the EPDM mixture. The physical properties of these polymer-modified BNA-Blend have measured through experimental tests as penetration, softening point, and ductility test, and viscosity test to measure rheological properties. Besides, the influence of the homogeneity of polymer-modified BNA-Blend has investigated. The fluorescent microscopy images show homogenized for NR, EVA, and SBS mixtures, except the EPDM mixture. The rheology test result of polymer changed BNA-Blend increases the softening point, viscosity and decreases the penetration.

Keywords: Asphalt binder, polymer-modified BNA-Blend, NR, SBS, EVA, EBDM, physical, rheological.

Abbreviations: BNA (Buton Natural Asphalt), NR (Natural Rubber), EVA (Ethylene-Vinyl Acetate), SBS (Styrene-Butadiene-Styrene), EPDM (Ethylene Propylene Diene Monomer).

Running title: The evaluation of polymer.

INTRODUCTION

Asphalt roads are the only land transport system in Libya, and it is the lifeblood of people who live in desert areas. The desert covers 95% of the area of Libya. Which is considered one of the aridest and hottest regions during the summer. This harsh environment damages the asphalt road and makes it unsafe. The temperature in the Libyan desert in June is around 42 to 48 °C. The primary function of the roads is to connect cities, towns, and villages as much as possible throughout the country. It requires periodic maintenance at a high cost. Therefore, researchers are trying to find alternatives to conventional asphalt to increase the estimated life of the asphalt pavement and reduce maintenance costs (Salem, Uzelac, Crvenkovic, & Matic, 2014a). The structural capacity of the asphalt pavement layers depends on many factors, including its temperature (Salem, Uzelac, Crvenkovic, & Matic, 2014b). Therefore, the temperature is a significant factor that affects the performance and life span of the pavement.

Rutting is the most common pavement problem in Libya. Where Libyan roads expected life design is 20 years, although these roads do not last long due to rapid, permanent deformation (rutting) and cut down the service life. This permanent deformation happens in the first five years of the service life of asphalt pavement. While the air temperature up to 48 °C in the summer days. It is working to raise the temperature of asphalt pavement to over 70 °C "abnormally high temperature" (Roffa, 2002; Salem, Uzelac, & Matic, 2014).

The mechanism of rutting occurs in the asphalt pavement can explain in this method: at higher temperatures, the asphalt binder becomes less viscous, it produces a less rigid pavement that can be susceptible to lateral movement attributable to traffic loads, this type of rutting called plastic flow; it characterized by deformation in the wheel path under traffic load. When a load applied to asphalt concrete, a small but permanent deformation occurs, the accumulated deformations produce a rut depth that causes a lower level of comfort and hazardous conditions to traffic, Traffic densities, heavy loads, slow traffic, and high temperatures are the main factors that contribute to this process.

The natural rock asphalt is a sedimentary rock containing high hydrocarbon substances. The natural rock asphalt with a deposit of approximately 60,991,554.38 tons (24,352,833.07 barrel oil equivalent) occurs in the southern area of Buton Island, Indonesia (Chairuddin, Wihardi Tjaronge, Ramli, & Patanduk, 2016). Buton natural asphalt (BNA) blend is a type of modification asphalt, which made of 80% Petroleum asphalt 60/70 and 20% rock asphalt Buton Natural extraction. The addition of BNA lowered the penetration, ductility, and fire point, but increased the softening point. Adding a certain percentage of BNA produced an asphalt mixture that was more resistant to the effects of increased temperature (Hadiwardoyo, Sinaga, & Fikri, 2013).

BNA-Blend binder has better property values than asphalt 60/70 Pen binder and meets the specifications as modified asphalt according to the requirements of Bina Marga. Asphalt BNA Blend has a specific gravity of 1.091 and a softening point of 55 °C, higher than asphalt 60/70 Pen, which has a specific gravity of 1.0375 and a softening point of 48.5 °C (Fatmawati, Hario Setiadji, & Kusharjoko, 2013).

Polymer modified asphalt binder is more stable under heavy loads, braking and accelerating forces and shows increased resistance to permanent deformation in hot temperature. It resisted fatigue loads and having better adhesion between aggregates and binders (Hidayah, 2016).

This study objective is to develop the physical properties of the BNA-Blend binder by using additives as elastic polymers as Natural Rubber Latex (NR), Ethylene-Vinyl Acetate (EVA), Styrene-Butadiene-Styrene (SBS), and Ethylene Propylene Diene Monomer (M-class) rubber(EPDM) to reduce the sensitivity to temperature change by reducing the viscosity and increase the penetration value and softening point temperature to resist the permanent deformation (rutting). So that makes the new binder more suitable for high temperature, which exposed in hot and arid regions As well as to increase the service life of the pavement and to reduce the cost of maintenance of asphalt pavements. This new binder referred to as Polymer Modified BNA-Blend. This research aims:

1. To determine the physical properties of polymer modified BNA-Blend binder by tests such as (penetration, softening point, ductility, and specific gravity);
2. To determine the rheological properties of polymer modified BNA-Blend binder by viscosity test;
3. To investigate the homogeneity of the mixture and the possibility of mixing polymers with BNA-Blend binder;
4. To determine the best type of polymer modified BNA-Blend binder to use for pavement in a hot and arid region.

MATERIALS AND METHODS

A. Materials.

1) BNA-Blend

Buton Natural Asphalt Blend (BNA Blend) is the name of the product from PT. Performa Alam Lestari to improv of BNA-Blend, especially for Exclusive Project such as Circuit, Airport as well as Heavy Traffic. BNA-Blend is a result of asphalt binder material mixing additive 20% BNA with 80% Asphalt 60/70 pen.

2) NR

Liquid natural rubber (NR or Latex) used in this study from Indonesia, and the NR contains roughly 60 percent solid rubber. The laboratory tests for engineering properties of both binders and asphalt concrete mixtures in this research, 9 % concentrated NR was the suggested appropriate proportion in blending with asphalt cement. Such percentage also showed performance by resisting fatigue and permanent deformation approximately three times better than Asphalt 60/70 pen. Moreover, it requires less optimum binder content than Asphalt 60/70 pen, which may help in reducing construction capital and long-term maintenance cost for road pavement (Tuniwroawit, Lavansiri, & Phromsorn, 2005).

3) EVA

Levapren® (EVA) used in this study from LANXESS. It is a highly sophisticated material that offers an impressive range of new characteristics. Due to its outstanding compatibility with several fillers and polymers and its low viscosity. This rubber can also help to improve the property profile of other polymers significantly(LANXESS, 2017). EVA considered one of the principal elastomers used in road construction in order to improve the workability of the asphalt during construction and its deformation resistance in service.

Haddadi (Haddadi, Ghorbel, & Laradi, 2008) showed that EVA provides the modification of bitumen throughout the crystallization of rigid three-dimensional networks within the bitumen resulting in considerable changes of the physical, chemical, and morphological properties of the bitumen. The effect of the base bitumen type on the polymer compatibility and the degree of modification also outlined.

4) SBS

Poly (Styrene-Butadiene-Styrene) (SBS) used in this study is Thermoplastic Rubber from LG 501 Thermoplastic. It used as a modifying agent for polymer-modified asphalt to increase the performance mixtures. The performance of SBS-modified asphalt improves with an increase in SBS concentration (Hanyu, Ueno, Kasahara, & Saito, 2005).

5) EPDM

Ethylene propylene diene monomer (EPDM) elastomer used in this study from LANXESS. Ghoreishi (Ghoreishi, Koosha, & Nasirizadeh, 2018) concluded that small amounts of the EPDM can profoundly enhance the viscoelastic behavior of the bitumen at elevated temperatures, lowest penetration degree, highest softening point, and lowest temperature susceptibility and has the potential to have a better performance in warm areas.

B. Asphalt binder modification.

This study performed by experimental research; The polymer mixed with BNA-Blend according to the appropriate mixing method for each type of polymer to obtain the desired homogeneous mixture and get the most benefit from the polymer in the mixture. Four types of polymers used as a modifier (NR, EVA, SBS, and EPDM) for the production of the new binder separately. Asphalt heated in less than 190℃, and then add the polymer according to the required ratio to asphalt with a stirring speed range from 1400 rpm until 3600 rpm for a minimum time of 3 hours to ensure all the particle of polymer melted and mixed well with the asphalt and reach homogeneity. Four kinds of polymers with five different mixing ratios (2, 4, 6, 8.and 10%) for 20 types of polymer-modified BNA-Blend binder rate. The homogeneity of the mixture was confirmed using a fluorescent microscope. Some laboratory experiments, such as (Penetration test, softening point test, Ductility test, Specific gravity test, and Viscosity test) carried out to determine the physical and rheological properties of the binder and the asphalt mixture.

RESULTS AND DISCUSSION

1) **Penetration test.**

This test method penetration test, according to (ASTM D5)to the determination of the cohesion bituminous materials. Penetration value is the cohesion of bituminous material. Higher values of penetration indicate a softer cohesion (D5 ASTM, 2013). Where table 1 shows the results of the penetration value for each type of bitumen.

Table 1. Penetration value for each type of bitumen.

Asphalt Binder Type	Polymer Addition Rate %					
	0%	**2%**	**4%**	**6%**	**8%**	**10%**
NR + BNA-Blend	55.3	60.2	56.2	54.6	42.4	35.8
EVA + BNA-Blend	55.3	52.1	43.7	38.3	31.7	-
SBS + BNA-Blend	55.3	47.5	44.7	37.1	28	20.8
EPDM + BNA-Blend	55.3	50.40	42	33.4	26.6	-

Through the figure 1, the relationship between the ratio of polymers and the value of penetration observed that the EPDM modified BNA-blend and SBS modified BNA-blend responded quickly to the rate of increase in polymers, Which leads to reduces the penetration value by up to 63.86% and 62.35% respectively at a rate of 10% polymers, This percentage is the highest compared to the other types of polymers used in this research. NR modified BNA-blend gives less response to the penetration compared with other types of polymers. The penetration value for this type of asphalt binder has decreased to approximately 35.3% at 10% NR compared with the penetration value of BNA-blend. AVE modified BNA-blend, SBS modified BNA-blend, EPDM modified BNA-blend gave quick response to penetration resistance.

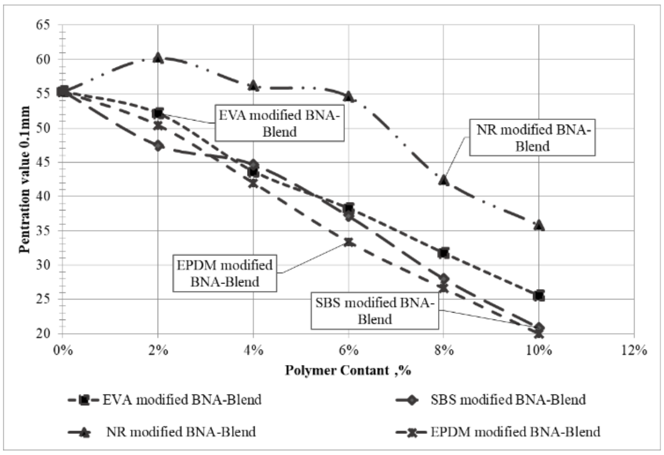

Figure 1. Typical correlations between the penetration value of some polymers used as modifiers and their concentration in the BNA-blend.

1. Softening point test.

The ring and ball softening point test according to (ASTM D36) standards measure the temperature at which asphalt reaches a certain softness. This method covers the determination of the softening point of bitumen in the range from 30 to 157 °C using the ring-and-ball apparatus immersed in distilled water (30 to 80 °C) and glycerin (above 80 to 157 °C) (D36 ASTM, 2014). Table 4.6 shows the results of the softening point temperature for each type of asphalt.

Table 2. Softening point value for each type of bitumen.

Asphalt Binder Type	Polymer Addition Rate %					
	0%	**2%**	**4%**	**6%**	**8%**	**10%**
NR + BNA-Blend	49.5	52.1	54	55.6	59.8	61.9
EVA + BNA-Blend	49.5	52.8	58.3	59.3	63.0	68.0
SBS + BNA-Blend	49.5	55.4	68.0	82.8	91.0	94.1
EPDM + BNA-Blend	49.5	56.2	63.3	71.0	77.3	82.0

Figure 2 prepared to compare the temperature of the softening point for all types of asphalt modified with polymers. The results have proven that SBS is one of the best kind of polymers to increase the softening point temperature of the asphalt binder, at the rate of SBS 10%, the softening point temperature of SBS modified BNA-blend increases to approximately 94.1 °C. equivalent to 90.1% compared with pure BNA-blend. In the second rank, it observed that the polymer type EPDM, where the softening point temperature has increased by 65.7 %, which is equivalent to 81°C, and it is considered the second-best type of polymer used in this research in terms of increasing the temperature of the softening point. Polymer type EVA, which gives a reasonable rate in increasing the softening point temperature by up to 37.4%, which is approximately 68 °C, it is considered in the third rank of polymer compared with other types of polymers used. In the fourth rank, it observed that the polymer type NR at 10% gave a slight increase in the temperature of the softening point 31.3% equivalent to 61.9 ° C.

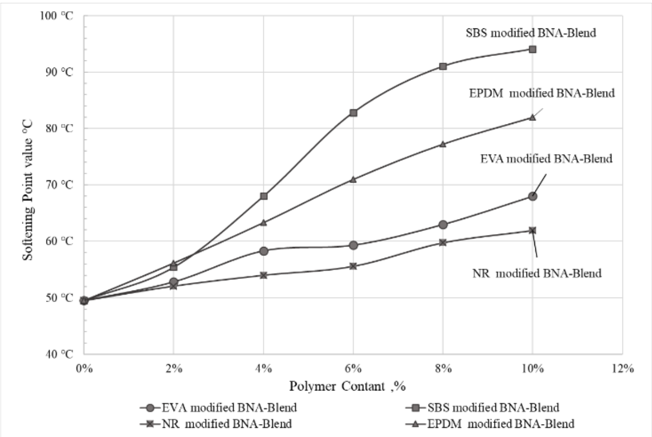

Figure 2. Typical correlations between the Softening point value of some polymers used as modifiers and their concentration in the BNA-blend.

2) Ductility test.

The ductility of asphalt binder is its property to elongate under traffic load without getting cracked in road construction works. The ductility test, according (ASTM D113) to measures the distance in centimeters to which it elongates before breaking. Generally considered that asphalt with a very low ductility would have poor adhesive properties and thus poor performance in service (ASTM, 2007). Where figure 4.13 ductility test of bitumen machine.

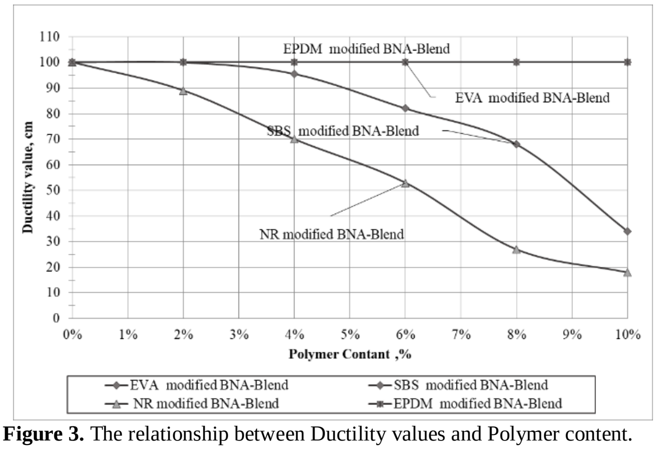

Figure 3. The relationship between Ductility values and Polymer content.

Noted that from figure 3, both of the mixture EVA modified BNA-Blend and EPDM modified BNA-Blend are still maintaining a ductility value up to 100 cm, Although the polymer content increased to 10%. Moreover, Reduction in the ductility value for two other mixtures, SBS modified BNA-Blend and NR modified BNA-Blend. Whereas, the low ductility value is an indication of low coherence in the asphalt binder, which leads to the occurrence of cracks in the asphalt concrete in cold areas. Where this research studies the possibility of using modified asphalt with polymers in hot regions, so, It does not depend on this mainly on these results.

3) Penetration Index

Asphalt binder is only a minor component of asphalt mixes. However, it has a crucial part to play in providing viscoelasticity and acting in a durable binder. Mostly, the performance of the asphalt binder achieved if specific properties controlled, namely rheology, cohesion, adhesion, and durability. The primary or routine rheological properties are penetration, softening point, and viscosity. The temperature susceptibility usually described as the change of primary or routine rheological properties of asphalt binders with temperature. Pfeiffer and Van Dormaal (Pfeiffer & Van Doormaal, 1936) defined the temperature susceptibility of asphalt as the Penetration Index. The following equation calculates the penetration Index value.

$$PI = \frac{1952\text{-}500 \text{ Log Pen-}20(SP)}{50 \text{ Log Pen-}(SP)\text{-}120}$$

Where:

Pen = Penetration. SP = Softening Point

The value of Penetration Index ranges from -3 for highly temperature susceptible asphalt to about + 7 for profoundly blown low temperature likely (high PI) asphalt (Affandi, 2009). Figure 5 shows the relationship between Penetration Index values and Polymer content for each type of Polymer Modified BNA-Blend.

Table 3. Penetration index value for each type of bitumen.

Asphalt Binder Type	Polymer Addition Rate %					
	0%	2%	4%	6%	8%	10%
NR + BNA- Blend	-1.1	-0.2	0.0	0.3	0.6	0.6
EVA + BNA- Blend	-1.1	-0.4	0.4	0.3	0.5	0.9
SBS + BNA- Blend	-1.1	-0.1	2.2	3.9	4.3	4.0
EPDM + BNA-Blend	-1.1	0.2	1.2	2.0	2.4	2.5

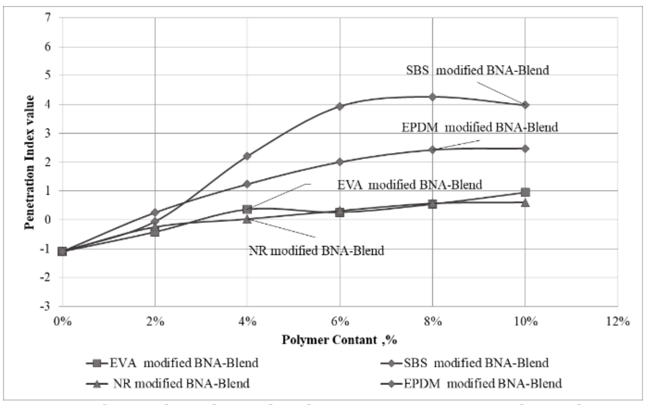

Figure 4. Shows the relationship between Penetration Index values and Polymer content.

The conclusion from the results of laboratory tests and calculations for the penetration index, that polymers increase the performance of asphalt and reduce the sensitivity of asphalt binder temperature changes, and thus increase the performance of the asphalt pavement in hot regions. Where a significant increase in the penetration index value when using the type SBS polymer with a value of up to +2.2 at the content of SBS 4%, EPDM polymer increase the PI up to +2 at the content of SBS 6%, and both of EVA, NR increase the PI up to + 0.6, 0.9 at the content of EVA, NR 6% respectively. These results give a clear vision of the best types of polymers used in the modification of the asphalt binder for hot regions.

C. Rotational viscosity.

Viscosity determination of asphalt binder at elevated temperatures using a rotational viscometer. This test method, according (ASTM D4402) to measuring the apparent viscosity of hard asphalt from 100 to 260 °C using a rotational viscometer and a temperature-controlled thermal chamber for maintaining the test temperature (D ASTM, 2015). Where the device consists of a thermostatically controlled oil bath containing a sample of hot bitumen. The spindle is lowered into the asphalt binder and rotated. The torque required to turn the axis measured and converted into the viscosity of the bitumen (in Pa.s). Figure (5, 6, 7, and 8) shows the relationship between viscosity values and temperature for each type of asphalt.

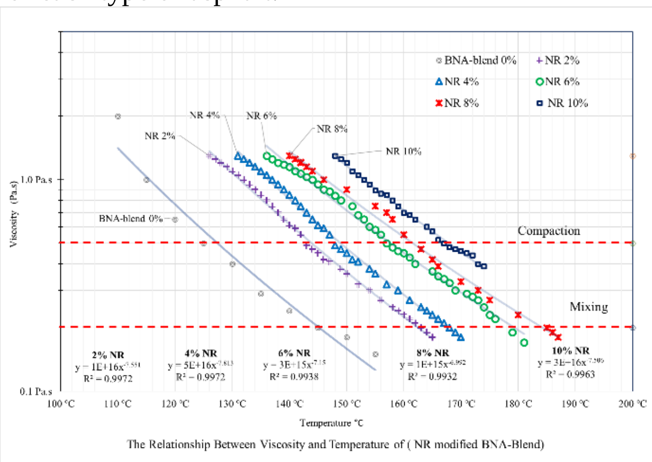

Figure 5. The Relationship Between Viscosity and Temperature of (NR modified BNA-Blend).

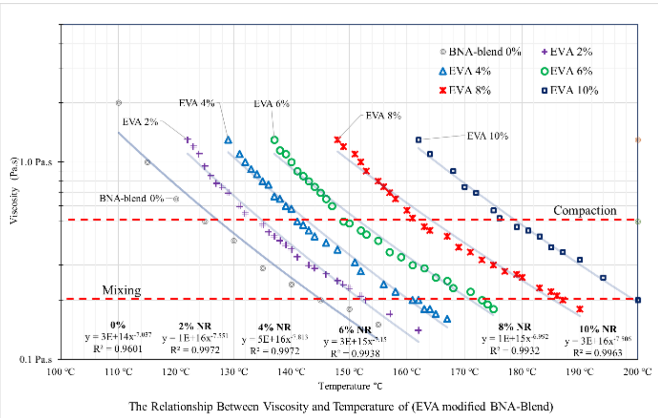

Figure 6. The Relationship Between Viscosity and Temperature of (EVA modified BNA-Blend).

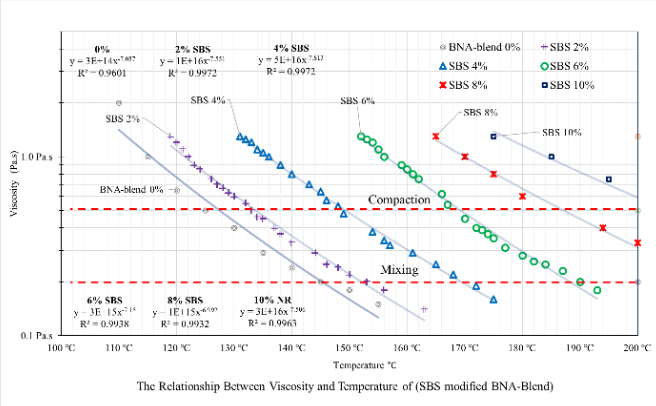

Figure 7. The Relationship Between Viscosity and Temperature of (SBS modified BNA-Blend).

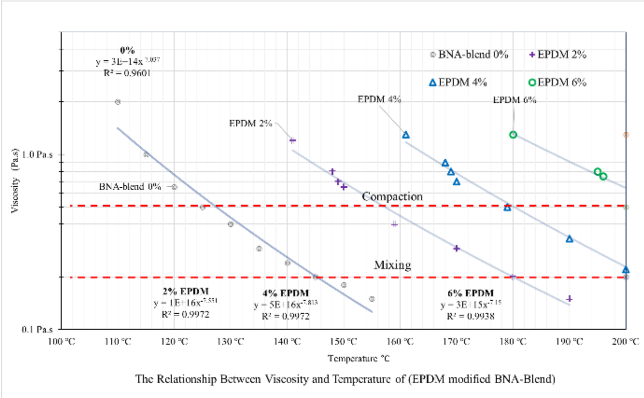

Figure 8. The Relationship Between Viscosity and Temperature of (EPDM modified BNA-Blend).

Through laboratory experiments to measure viscosity at different temperatures, the relationship between viscosity and the high temperature shown in figures 5, 6, 7, and 8 of the four types of polymers (NR, EVA, SBS, and EPDM) used in this study. It observed that with increasing polymer content, the viscosity decreases, and therefore the asphalt binder resistance to temperature increases.

Table 0.3: Mixing Temperatures of HMA.

ASPHALT BINDER TYPE	POLYMER ADDITION RATE %					
	0%	2%	4%	6%	8%	10%
NR + BNA- Blend	146	164	168	178	184	190
EVA + BNA- Blend	146	148	156	166	180	194
SBS + BNA- Blend	146	152	170	188	212	-
EPDM + BNA-Blend	146	180	200	-	-	-

Table 11: Compaction Temperatures of HMA.

ASPHALT BINDER TYPE	POLYMER ADDITION RATE %					
	0%	2%	4%	6%	8%	10%
NR + BNA- Blend	124	142	148	156	160	166
EVA + BNA- Blend	124	138	140	147	160	175
SBS + BNA- Blend	124	134	150	170	187	208
EPDM + BNA- Blend	124	158	180	208	-	-

According to the American specifications, the mixing and compaction temperature for the hot mix asphalt can determine to depend on the results of the viscosity curve at a value of 0.2 Pa.s for mixing and a value of 0.5 Pa.s for compaction. Table 4 shows the mixing temperatures for all types of asphalt, and Table 5 shows the desired compaction temperature to obtain the best results from the hot mix asphalt.

D. **Fluorescent microscope.**

Fluorescent microscopy based on the principle that the polymers swell due to the absorption of some of the constituents of the base asphalt and, subsequently, fluoresces in ultraviolet light. The asphalt-rich phase appears dark or black, while the polymer-rich period appears light or yellow-green. Thus, it is possible to know the homogeneity of the modified asphalt mixture with polymers. The fluorescent microscopy used to explore the homogeneity of the dissolved polymers in the asphalt binder. Figures 9, 10, 11, and 12) illustrate that. Where complete homogeneity observed with the appearance of fine threads representing the polymers NR, EVA, and SBS dissolved in the asphalt.

Figure 1. Fluorescent microscopy of BNA-Blend

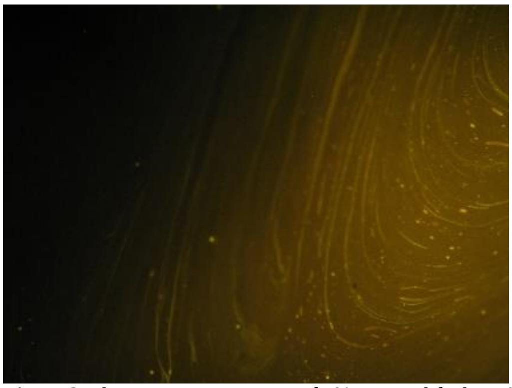

Figure 2. Fluorescent microscopy of 4% NR modified BNA-Blend

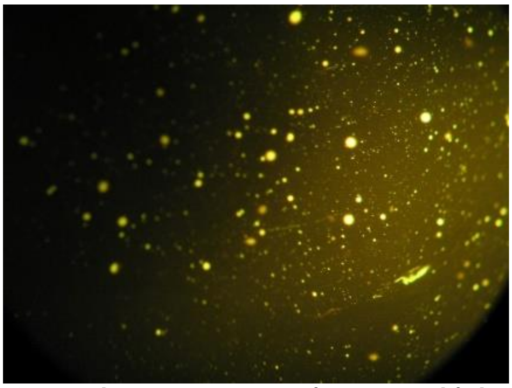

Figure 3. Fluorescent microscopy of 4% EVM modified BNA-Blend.

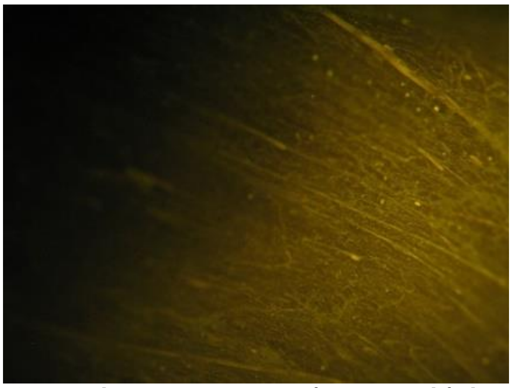

Figure 5. Fluorescent microscopy of 6% SBS modified BNA-Blend.

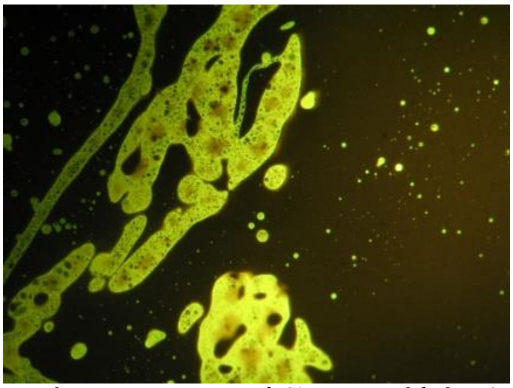

Figure 4. Fluorescent microscopy of 4% EPDM modified BNA-Blend

The results of imaging by a fluorescent microscope of EPDM modified BNA-BLEND show the heterogeneity of the mixture and the appearance of polymer molecules in yellow in a large percentage. It leads to the separation of polymer molecules and the inability to store this asphalt binder type EPDM modified BNA-BLEND.

CONCLUSIONS

It concluded from laboratory experiments and physical properties of polymer modified BNA-Blend the following:

1. All types of polymers used in this study increase the penetration value by increasing the polymer content mixed with the asphalt binder.
2. Polymers increased the temperature of the softening point by different proportions. SBS results showed the highest value of the softening temperature.
3. The results of the ductility tests for both EVA modified BNA-Blend and NR modified BNA-Blend are unacceptable, and this could be due to the presence of impurities in the asphalt ore extracted from the rock asphalt. The maximum of polymer-modified BNA-Blend is 4% SBS, 6% EPDM, up to 10% EVA, and up to 10%NR.
4. It observed that with increasing polymer content, the viscosity decreases, and therefore the asphalt binder resistance to temperature increases.
5. The results of imaging by a fluorescent microscope of EPDM modified BNA-BLEND show the heterogeneity of the mixture and the appearance of polymer molecules in yellow in a large percentage. It leads to the separation of polymer molecules and the inability to store this asphalt binder type EPDM modified BNA-BLEND.

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