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INFLUENCE OF POLYMER AND AGED BINDER ON THE PHYSICAL AND RHEOLOGICAL PROPERTIES

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ABSTRACT

This research paper presents laboratory investigation on the physical and rheological properties of asphalt binder modified with Ethylene-vinyl acetate (EVA) and Aged binder in different duration. Six different concentrations (0%, 1%, 2%, 3%, 4%, and 5% by weight of base asphalt) of Ethylene-vinyl acetate (EVA) was selected to blend with 80/100 penetration grade asphalt binder. six aging duration (0 min, 45 min, 85 min, 125 min, 165 min and 205 min) by using 80/100 penetration grade asphalt binder with rolling thin film oven were selected to prepare the aged binders. The EVA modified asphalt binders as well as Aged binders was subjected to short term aging process by means of Rolling Thin Film Oven Test (RTFOT) in order to investigate the influence of the addition of EVA and aged binder in the asphalt binder properties after aging. Bituminous binder properties were investigated by both physical and rheological methods. In general, the physical test results demonstrated prominent increment in softening point; viscosity and decrement in penetration for both EVA modified asphalt binders and aged binders as compared to non-modified and non-aged binder. This study adopts a time sweep (TS) test method to study the fatigue phenomenon under control strain mode using a dynamic shear rheometer (DSR). Fatigue life of asphalt binder is defined using the traditional approach based on number of cycles required to cause to cause failure and reduction in stiffness. Temperature sweep test by using a dynamic shear rheometer (DSR) is used to predict the asphalt grade after aging and after adding Ethylene-vinyl acetate (EVA).

Keywords: asphalt; Aging, ethylene-vinyl acetate, DSR, rheological property, physical properties, RTFO aged binder.

INTRODUCTION

The durability of asphaltic concrete is greatly influenced by the environmental changes during the year between hot and cold temperatures and between day and night. High temperatures can soften the bitumen and consequently reduce the stiffness of asphaltic concrete making the mix more susceptible to rutting. On the other hand, low temperature can increase the stiffness of bitumen and reduce the flexibility of the asphaltic concrete, hence, inducing fatigue failure. As a result, cracking of the pavement surface may develop which adversely affects the performance of the asphaltic concrete. Thus, high temperature stiffness and low temperature flexibility are important properties in bituminous mixtures respectively to avert rutting and cracking (Roberts *et al.*, 1990).

Traditionally, conventional binders, such as binder with 100 penetration grade (100 pen.) and 60 penetrations grades (60 pen.), were used in road pavement construction. However, increased axle loading, and braking power of vehicles in recent years required the durability and strength of the binder to resist rutting, fatigue, and cracking tendencies of road pavements. One means of achieving this is to modify the bitumen with polymers (Zhang *et al.* 2013). The addition of polymers, chains of repeated small molecules, to asphalt has been shown to improve performance. Pavement with polymer modification exhibits greater resistance to rutting and thermal cracking, and decreases fatigue damage, stripping, and temperature susceptibility. Polymers that are used for asphalt modification can be grouped into three main categories: thermoplastic elastomers, plastomers and reactive polymers. Thermoplastic elastomers are obviously able to confer good elastic properties on thermo modified binder; while plastomers and reactive polymers are added to improve rigidity, and reduce deformations under load. Belonging to the first category, styrene-butadiene-styrene block (SBS) copolymers are probably the most frequently used asphalt modifiers for paving applications (Zhang *et al.* 2010; Peiliang *et al*. 2013) Examples of the plastomeric types of polymers were studied since asphalt modifications are polyethylene (PE), and ethylene-butyl acrylate (EBA) random copolymers (Karim *et al.* 2012; Moatasim *et al.* 2011; Zhang *et al*. 2013; Esmaeil *et al.* 2011). Due to its low compatibility with asphalt, PE is not widely used for paving applications, and thus ethylene copoly measure preferred. Recently, reactive polymers have been introduced as asphalt modifiers. Their “reactivity” is due to the presence of functional groups supposedly able to bond with asphalt molecules. Polarity of the polymer can enhance its solubility and compatibility with base bitumen. Polar groups present in the polymer molecules can react with the polar constituents of bitumen. Subsequently, phase separation is prevented, which in turn enhances the materials consistency, and decreases oxidative ageing (Pllacco *et al.* 2005; Kim *et al*. 2011; Edwards *et al*. 2007; Merusi and Giuliani 2011). Among polar polymers, a very limited number of studies discuss the fundamental properties of modified bitumen’s with acrylate polymers. Most frequently used acrylates as bitumen modifying agents in road applications are ethylene vinyl acetate (EVA) glyceryl methacrylate (EA) terpolymer, ethylene butyl acrylate (EBA) copolymer, etc. (Fawcettand McNally 2001; Airey, 2002; Iqbal *et al*. 2006). In this research, different molecular weights from PMMA were added to asphalt for improving the performance of

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bitumen in terms of strength, durability, and resistance to rutting.

OBJECTIVE OF THE STUDY

Compare between EVA modified binder and RTFO aged binder by using physical and rheological binder test results.

MATERIALS AND METHODS

Asphalt binder

Most agencies would normally specify a higher Performance Grade (PG) asphalt binder, such as a PG 76-22 instead of the 80/100 penetration grade for highway construction projects. Since the performance of the modification and aging were of concern in this study, the commonly used 80/100 penetration grade soft binder was intentionally selected. This is to make sure there are no additional properties came from additives if modified binders such as 60/70 and PG 76-22 were used.

Ethylene-vinyl acetate (EVA)

Ethylene-vinyl acetate (EVA), also known as polyethylene-vinyl acetate (PEVA), is the copolymer of ethylene and vinyl acetate other names Poly (ethylene-vinyl acetate); Poly (ethylene-co-vinyl acetate); Polyethylene-vinyl acetate copolymer. The material has good clarity and gloss Figure-1, low-temperature toughness, stress-crack resistance, hot-melt adhesive waterproof properties, and resistance to Ultraviolet (UV) radiation.

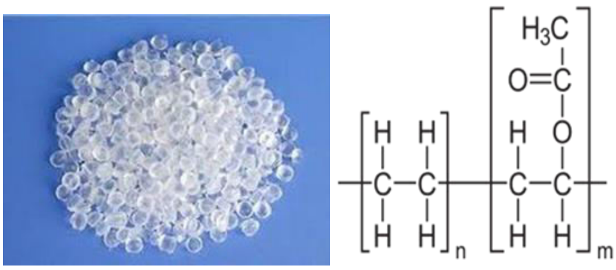

Figure-1. A close-up picture of open celled and chemical composition of ethylene-vinyl acetate (EVA).

Blending of asphalt binder and ethylene-vinyl acetate (EVA)

The weight of Ethylene-vinyl acetate (EVA) with asphalt binder was calculated based on the percentage by the weight of the asphalt binder. The five blends were prepared by blending the EVA with the neat asphalt binder in aluminium can; the aluminium can was placed in a container that was filled with fine material in order to prevent heat lost via the conductivity of aluminium can outer layer. The whole system was then placed on a hot plate to provide uniform heating. A mechanical mixer module IKA Labortechnik, RW 20 DZM.n was used to blend the EVA and asphalt binder at established mixing temperatures (The appropriate mixing temperatures were determined following ASTM D3381 using the rotational viscometer) as depicted in Figure-2 Four thousand grams of the asphalt were heated to fluid condition and poured into a 4000 ml spherical flask, which was then placed in a heating mantle. Upon reaching 165 °C a required amount of EVA copolymer (1%, 2%, 3%, 4%, and 5% by asphalt weight) was added to the asphalt slowly, to prevent the polymer particles from possible agglomeration. Mixing was performed using mechanical mixer (500 rpm) for 5 minutes in order to avoid air bubbles and splashing, after which the speed was lowered to 300 rpm. Mixing was continued for 3 hours. When blended was completed, the blended blends were divided for testing to penetration at 25 °C, softening point, ductility at 25°C according to ASTM D5, ASTM D36 and ASTM D113, and make of DSR specimens respectively.

Figure-2. Blending process of asphalt binder EVA blend.

Preparation of blown asphalt binder with different aging duration

Rolling Thin Film Oven (RTFO) is used to simulate short-term aging of asphalt binder during HMA production and construction. The 80/100 penetration asphalt binder's samples were subjected to short-term aging by artificially conditioning them in the laboratory via the Rolling Thin-Film Oven (RTFO) in accordance with the procedures outlined in AASHTO T 240/ASTM D2872. For preparation of laboratory blown asphalt binder the following procedure was followed: A total of five hundred grams of the 80/100 penetration asphalt binder was prepared by using Rolling Thin Film Oven at 163°C. Rotation and air flow were at 15 ±0.2 rpm and 4000 ±200 ml/min (0.004 ± 0.0002 m^3) respectively. The samples were then aged in the RTFO oven for five different duration of (45, 85, 125, 165, and 205) minutes. The bottles containing the aged binder were then removed and then emptied into a suitable container and set aside for physical and rheological properties testing.

Aging of neat, EVA modified and time aged asphalt binder

The ten asphalt binder blends (EVA modified, laboratory prepared Blown (Time aged) asphalt binder) plus the neat asphalt binder (NAB) as control sample were aged through an accelerated aging process; asphalt binder blends were first aged by the Rolling Thin Film Oven Test (RTFO) in accordance with ASTM D2872 to simulate the short-term aging conditions. The Pressure Aging Vessel

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(PAV) was used after Rolling Thin Film Oven Test (RTFO) in accordance with ASTM D6521 to simulate the changes in physical and chemical properties that occur in asphalt binder as a result of long term, in-service oxidative aging in the field.

Experimental plan: property characterization of unmodified, EVA modified, and blown (time aged) asphalt binder

To achieve the objective of this study, Table-1 was developed in order to notice all tests done for Unmodified, EVA Modified and Blown (Time Aged) asphalt binder also Table-2 explain the asphalt binder and blends labelling and abbreviations used in this study:

Table-1. Unmodified, modified and aged asphalt binder testing program.

Mastic characteristic	Response variable	Aging	Test method
1. Workability	Viscosity Penetration Softening point	Unaged Unaged Unaged	Rotational Viscometer (RV) Penetration (AASHTO T49) Ring and Ball (AASHTO T53)
2. Rutting	SHRP Rutting Parameter(G*/sinδ)	Unaged and RTFO aged	Dynamic Shear Rheometer (DSR)
	Temperature Steps	Unaged	DSR
3. Fatigue	SHRP Fatigue Parameter (G*.sinδ)	PAV aged	DSR
	Fatigue life(Time sweep test)	RTFO aged	DSR

Table-2. Asphalt binder and blends labeling and abbreviations used in this study.

Binder/mastic type	Abbreviation
Neat Asphalt Binder	MB-80E0
EVA Modified Binder @ 1%	MB-80E1
EVA Modified Binder @ 2%	MB-80E2
EVA Modified Binder @ 3%	MB-80E3
EVA Modified Binder @ 4%	MB-80E4
EVA Modified Binder @ 5%	MB-80E5
Blown Asphalt; Time Aged Binder @ 45 Minutes	AB-80-45
Blown Asphalt; Time Aged Binder @ 85 Minutes	AB-80-85
Blown Asphalt; Time Aged Binder @ 125 Minutes	AB-80-125
Blown Asphalt; Time Aged Binder @ 165 Minutes	AB-80-165
Blown Asphalt; Time Aged Binder @ 205 Minutes	AB-80-205

RESULTS AND DISCUSSIONS

Physical tests

Figure-3 shows Penetration and Softening Pont test result for neat, EVA modified Binder and RTFO Aged Binder (Blown Asphalt binder prepared in the lab at five different aging durations). Before and after (RTFO) Short term aging. For this figure we can note that with the increase of EVA percentage and aging duration the value of Penetration decrease before and after RTFO test. Also we can note a increase in softening point value with the increase in both EVA percentage and Age duration. On other hand, Figure-3. Shows that Aged binder in five different duration has a higher value in Penetration and softening point as compared with EVA modified binder before RTFO test but has different behaviour after RTFO test.

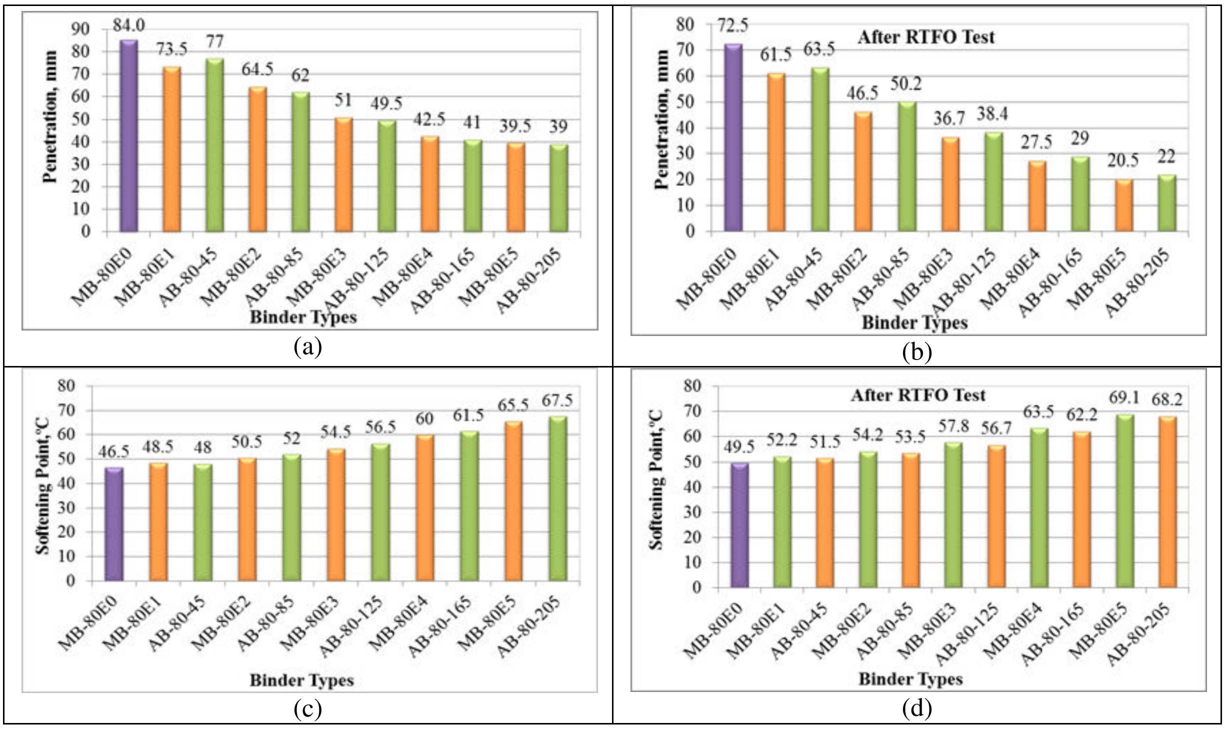

Figure-3. (a-b-c-d). Penetration and softening point of the modified asphalts and aged binder in different duration (a) Penetration before RTFO, (b) softening point before RTFO, c) penetration after short term aging, and (d) softening point after short term aging.

Table-3. Summary of physical properties for EVA modified binder and RTFO aged asphalt binder at different time.

Asphalt type	Retained penetration (RP), (%)	Increment in softening point (ISP), (°C)	Penetration index (PI) (%)	
			unaged	RTFO aged
MB-80E0	85.80	3.00	-0.83486	-0.41618
MB-80E1	83.67	3.70	-0.64981	-0.16388
MB-80E2	76.74	3.70	-0.46512	-0.23133
MB-80E3	71.96	3.30	-0.09218	-0.13726
MB-80E4	64.71	3.50	0.63090	0.33771
MB-80E5	51.90	3.60	1.47912	0.69529
AB-80-0	85.80	3.00	-0.83486	-0.41618
AB-80-45	82.47	3.50	-0.66175	-0.39440
AB-80-85	80.97	1.50	-0.19184	-0.35775
AB-80-125	77.58	0.20	0.27572	-0.26501
AB-80-165	70.73	0.70	0.83672	0.21268
AB-80-205	56.41	0.70	1.79285	0.68725

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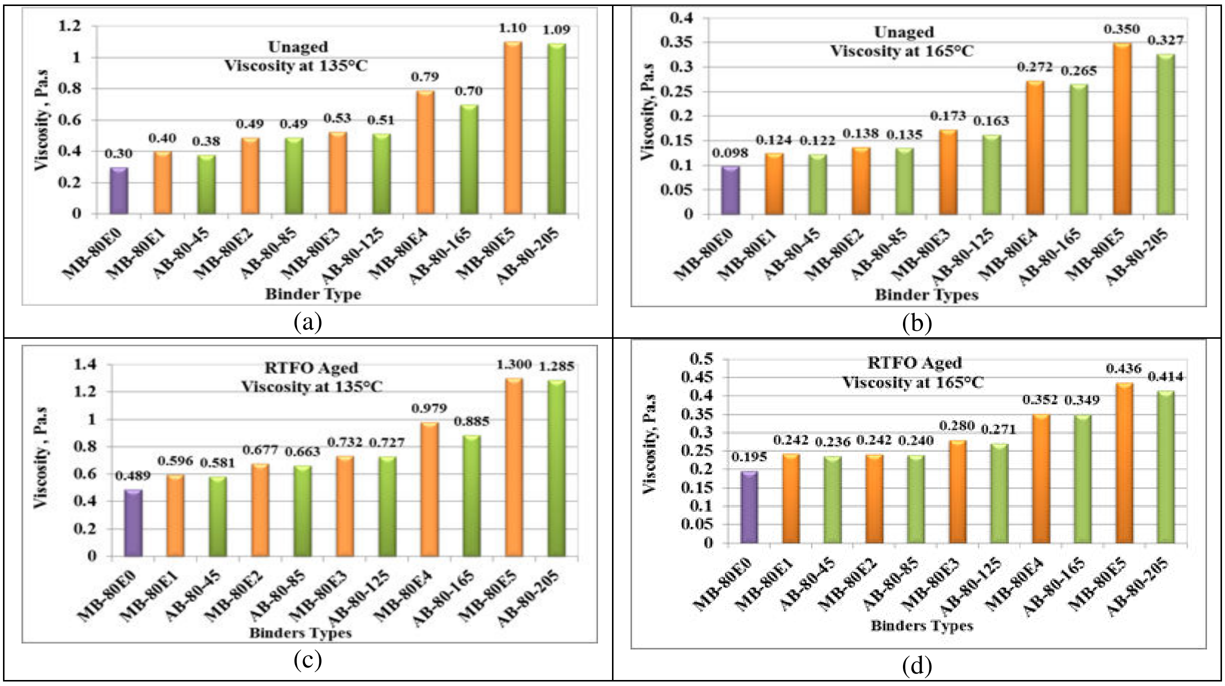

Figure-4. (a-b-c-d). Viscosity at 135°C and 165°C of the modified asphalts and blown (time aged) binder in different duration (a)Viscosity before RTFO @ 135°C, (b) Viscosity before RTFO @ 165°C, c) Viscosity after RTFO @ 135°C and d) Viscosity after RTFO @ 165°C.

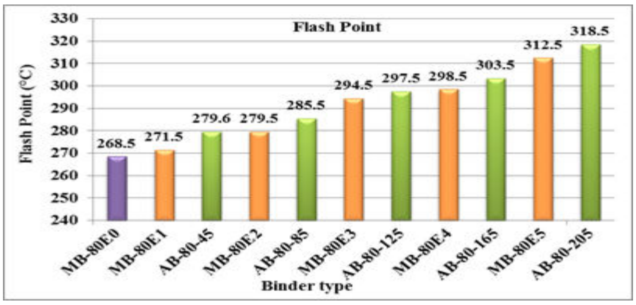

Figure-5. Flash point for EVA modified binder and blown (time aged) binder at five different durations.

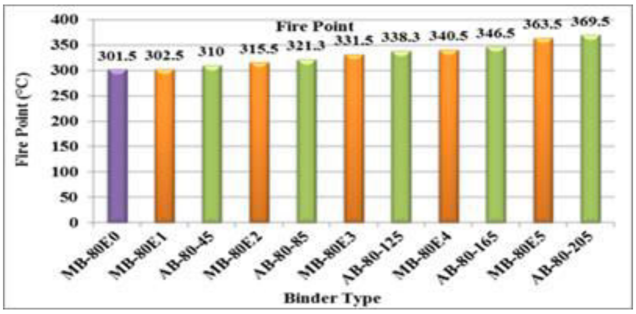

Figure-6. Fire point for EVA modified binder and blown (time aged) binder at five different durations.

Rheological properties of ethylene-vinyl acetate (EVA) and blown (time aged) asphalt binder

The fundamental rheological properties of the un-aged, short term (RTFO-aged), and long term (PAV aged) asphalt binder, EVA, and laboratory prepared blown (time aged) asphalt binder were measured in terms of complex modulus (G*), phase angle (δ), temperature sweep test on both un-aged and short term aged (RTFO) state. Also, the EVA and laboratory prepared blown (time aged) asphalt binder were tested in fatigue performance on RTFO-aged specimens using dynamic shear rheometers (DSR).

A. Temperature sweep test at high temperature

In this test G* (complex modulus) and δ (phase angle) of all un- aged EVA modified binder at five different proportion and laboratory prepared blown asphalt binder at five different durations blends were measured over a temperature range between 40°C and 82°C using DSR to investigate the effect of adding EVA and time aging at five different durations in terms of rutting. Based on the Superpave specification, G*/sin δ represents the asphalt binder resistance to permanent deformation (rutting). A stiff and elastic binder could contribute better to rutting resistance therefore increasing G* or decreasing sinδ would lead to more rutting resistance. It is recommended a minimum value of 1.0 kPa for G*/sin δ to ensure that asphalt binder could resist well against permanent deformation at designed performance grade temperature. As a result 1.0 kPa was selected as failure temperature criteria in this test. Figures 7 and 8 shows failure temperature for EVA Modified binder and laboratory prepared asphalt binder at five different durations.

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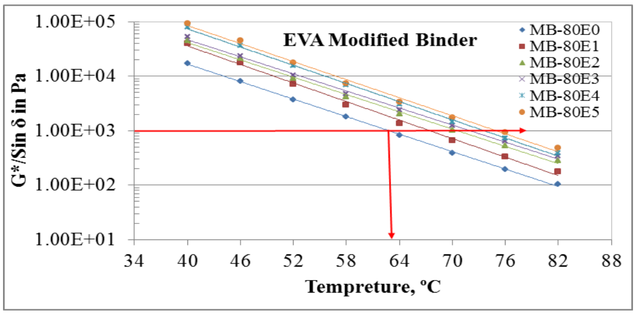

Figure-7. Temperature sweep test for EVA modified binder.

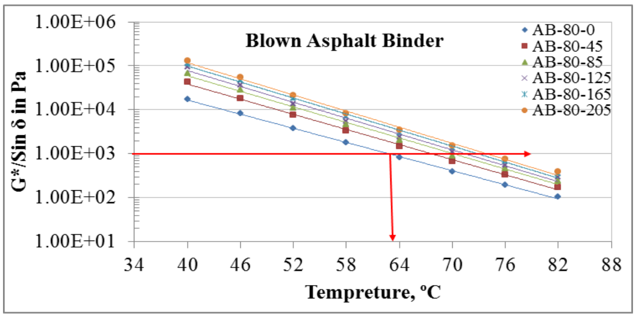

Figure-8. Temperature sweep test for blown asphalt at five different time aging duration.

Temperature sweep test on RTFO aged binder were carried out for EVA modified binder at five different proportions and laboratory prepared asphalt binder at five different time durations as shown in Figures 9 and 10. It is recommended a minimum value of 2.2 kPa for /sin δ to ensure that asphalt binder could resist well against permanent deformation at designed performance grade temperature. As a result 2.2 kPa was selected as failure temperature criteria in this test.

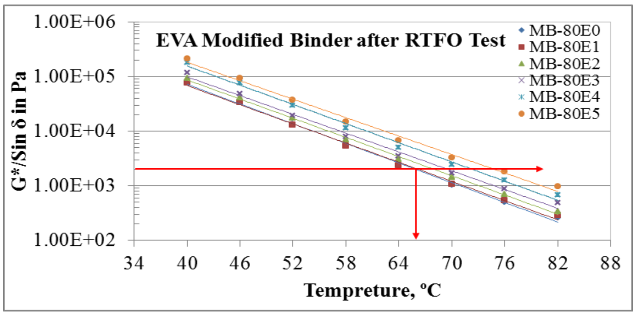

Figure-9. Temperature sweep test on RTFO aged for EVA modified binder.

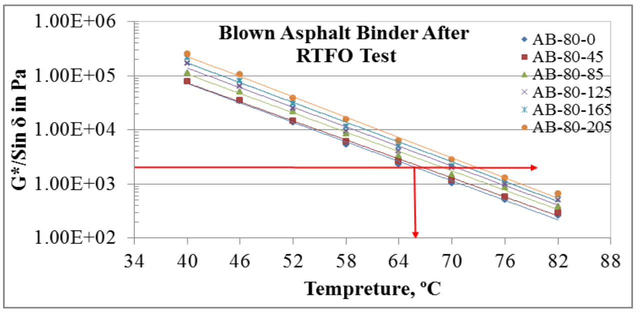

Figure-10. Temperature sweep test on RTFO aged blown asphalt binder.

Figures 7 to 10 shows that, regardless aging state (un-aged or RTFO aged) the EVA modified asphalt has the highest stiffness modulus (G* value) at the lower end of the temperature domain and a high stiffness modulus at higher temperatures compared to the neat asphalt and laboratory prepared blown asphalt regardless EVA content and blown asphalt aging time. This indicates the improved (reduced) temperature susceptibility of the EVA modified asphalt resulting in both increased flexibility at lower temperatures and increased hardness at high temperatures. Similar results were seen for the blown asphalt but with less stiffness. This may be due to the fact that EVE modified asphalt deformation resistance (G* Blend / G* Bitumen) and modulus of elasticity (storage shear modulus, G´, (G´ Blend / G´ Bitumen)) as well as the values of G* is higher than those of the laboratory prepared blown asphalt binder used in this study.

The SHRP researchers considered rutting as a stress controlled cyclic loading phenomenon in determining the rutting parameter, at a reference high temperature of 58°C at which rutting is believed to be important, the performance and ranking of the asphalt binder and EVA and laboratory prepared blown (time aged) asphalt binder were presented in Table-4 with higher values of G*/sin δ (behaves more like elastic solid) values indicated superior rutting resistance.

It can be seen from Table-4 that the modification percent and aging time duration influenced the rheological properties of asphalt binder differently. In fact, Table-4 showed that the EVA modification and the blown asphalt have different effects on the same asphalt binder due to the EVA properties and physical chemical reactions between the two materials.

The EVA modified asphalt binder showed a relatively consistent increase in G* and decrease in sin δ regardless the content. Also the phase angle was increased numerically of the EVA modified asphalt binder specimen compared to the blown asphalt regardless the content. This is due to the fact that, as the blown asphalt accumulates distress the elasticity decreases (more viscous), resulting in a numerically increasing the phase angle and makes the asphalt binder less resistant to permanent deformation.

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Table-4. Ranking of un-aged EVA and blown asphalt at reference temperature of 58 °C.

Blend type	Rutting parameter G*/sinδ (kPa)	Ranking	Rutting parameter G*/sinδ (kPa) for RTFO aged binder	Ranking
MB-80E0	1777.97	6	5372.4	6
MB-80E1	3003.7	5	5372.15	5
MB-80E2	4140	4	6890.75	4
MB-80E3	4809.9	3	7843.26	3
MB-80E4	6980.6	2	11558.89	2
MB-80E5	7316.2	1	14946.57	1
AB-80-0	1777.97	6	5373.4	6
AB-80-45	3304.14	5	6104	5
AB-80-85	4638.95	4	8446.35	4
AB-80-125	5487.48	3	9439.88	3
AB-80-165	7040.26	2	11630	2
AB-80-205	8286.09	1	15323	1

The test results showed that the complex modulus (G*) increases with the increase of EVA content/blown asphalt aging time. This is consistent with the results of viscosity, softening point, and penetration testing of which showed that, EVA at given proportion has caused the highest stiffening effect. Laboratory prepared blown asphalt ranks second regardless aging time duration. This kind of behaviour is expected since the higher the EVA percentage the stiffer the mix (less free asphalt).

Using the hypothesis that increase in rutting parameter (G*/sin δ) will correspond to improved rutting resistance. The EVA show more pronounced increase in G* and decrease in sin δ, which improved temperature susceptibility followed by blown asphalt which indicated a general trend that, for given EVA content caused the most stiffening and superior performance. This results demonstrates that complex modulus (G*) alone is not sufficient to characterize asphalt binder/or mastic, phase angle (δ) is also need.

B. Sustenance measurement of original, modified asphalt blends, and blown asphalt in different duration using time sweep test at low temperature

Time sweep test protocol was similar to asphalt fatigue testing method for the asphalt binder using DSR. This test was ideal to observe how asphalt binder changes over time. This test was carried out on RTFO aged samples with diameter of 8 mm and thickness of 2 mm. the requirement temperature was 20°C with the frequency of 10 Hz. The results of time sweep test are shown in Figures 11 and 12.

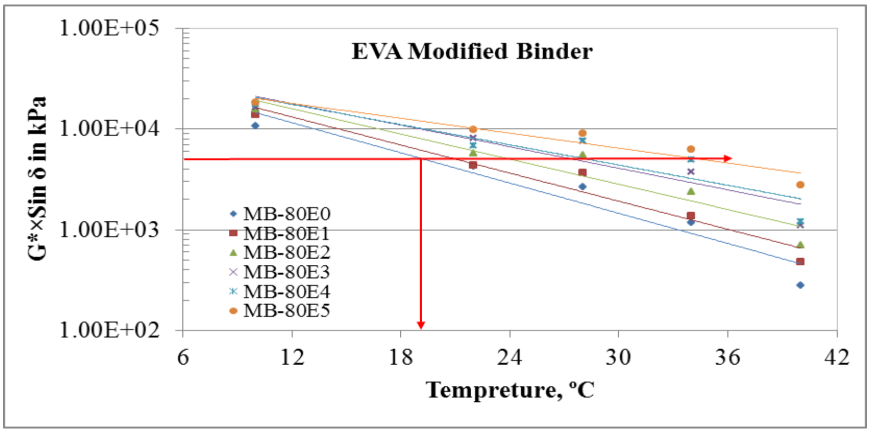

Figure-11. Time sweep test for EVA modified binder at five different proportion.

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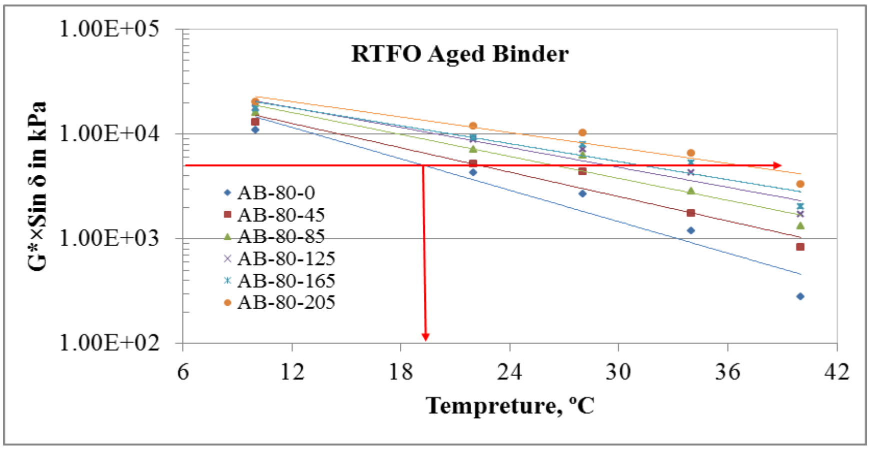

Figure-12. Time sweep test for blown asphalt binder at five different aging time duration.

The increment of failure temperature is very important to improving the high performance of asphalt binder. It will help to reduce the high temperature deformation and rutting damage of asphalt pavement. Table-5 shows the Failure Temperature and PG- Grading for EVA Modified binder at five different proportions and laboratory prepared blown asphalt binder at five different temperatures.

Table-5. Failure temperature and PG- grading of EVA modified binder and blown asphalt binder.

Binder type	Failure temperature (°C)			Temperature high and low PG - grading
	Un-aged	RTFO aged short term aging	PAV aged Long term aging	
MB-80E0	62.9	65.5	18.7	PG-58-19
MB-80E1	68.0	66.8	20.5	PG-64-22
MB-80E2	70.2	68.0	23.5	PG-64-25
MB-80E3	73.0	70.2	26.7	PG-70-28
MB-80E4	74.2	72.0	28.2	PG-70-31
MB-80E5	75.5	75.0	34	PG-70-34
AB-80-0	62.9	65.5	18.7	PG-58-19
AB-80-45	67.7	66.5	21.7	PG-64-22
AB-80-85	70.0	69.5	25.7	PG-64-28
AB-80E125	72.0	70.1	29.0	PG-70-31
AB-80-165	73.0	71.2	30.5	PG-70-31
AB-80-205	74.5	73.8	35.0	PG-70-37

The DSR Superpave EVA modified and blown asphalt binder properties test results in Table-4.8 indicated that the (MB-80E3, MB-80E4, MB-80E5, AB-80E125, AB-80E165, and AB-80-205) increased the high temperature stiffness by three grades and (MB-80E1, MB-80E2, AB-80-45, and AB-80-85) increased by two grades higher than the base asphalt binder. A general trend was observed that, the EVA modified asphalt was performed higher than that observed for the laboratory prepared blown asphalt.

The results of temperature steps tests on the EVA modified and Blown asphalt indicated that, the percent drop in rutting parameter cross the temperature domain (46 -82° C) of blown asphalt binder was greater than the EVA modified asphalt binder regardless EVA content and aging time. The drop in rutting parameter (G*/sinδ) and failure temperature of blown asphalt compared to the EVA modified asphalt binder was not significant.

Figure-13 shows the increment of failure temperature of EVA Modified binder at five different proportions. The increment of failure temperature at 5% EVA was 20.03, 14.50, and 81.82°C for the three states (un-aged, RTFO aged, and PAV aged) compared to neat asphalt binder.

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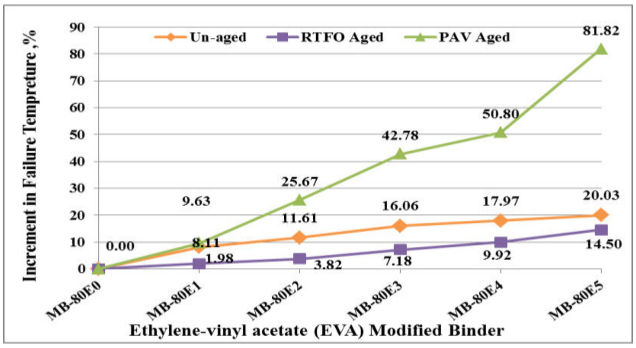

Figure-13. Increment in failure temperature for EVA modified asphalt binder.

Figure-14 shows the increment of failure temperature of and laboratory prepared blown asphalt binder at five different aging times. The increment of failure temperature at 205 minutes aging time was 18.44, 12.67, and 87.17°C for the three states (un-aged, RTFO aged, and PAV aged) compared to neat asphalt binder. Comparing the EVA modified and blown asphalt one can say that EVA modified perform better than blown asphalt accept for PAV aged state.

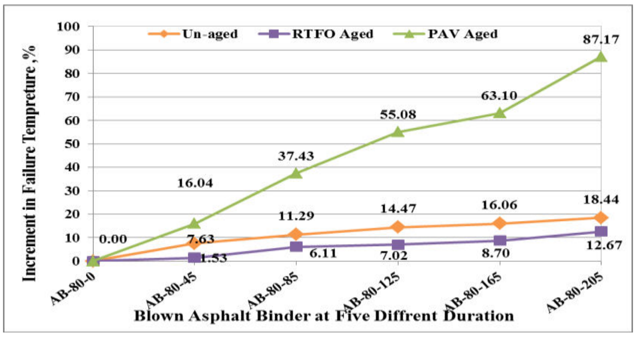

Figure-14. Increments in failure temperature for blown asphalt binder.

C. Fatigue parameter (G*. sinδ)

The rheological properties of the PAV-aged asphalt binder and asphalt blends were measured in terms of complex modulus G*, and phase angle δ (viscoelastic balance of rheological behaviour) using parallel plate geometries of 8 mm diameter with 2 mm gap. The fatigue parameter (G*.sinδ) were then determined at a loading frequency of 1.59Hz (10rad/s) in control strain mode (γ = 1%), since fatigue cracking was considered a strain controlled phenomenon, at a reference intermediate temperature of 20°C at which fatigue cracking is believed to be important. The fatigue parameter was chosen (G*.sinδ) to reflect the energy dissipated per load cycle (Anderson and Kennedy, 1993).

The SHRP specification prescribed a relationship whereby a reduction in G*·sin δ at 10 rads/sec corresponds to improved fatigue resistance. Using the hypothesis that a reduction in G*·sin δ will correspond to improved fatigue resistance, the fatigue parameters and the ranking of the ten asphalt blends were calculated and graphically presented in Figure-15.

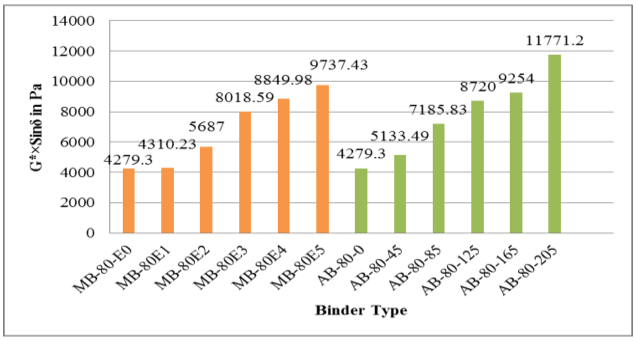

Figure-15. Fatigue parameter (G*. sin δ) of PAV-aged asphalt binder and asphalt blends at 20 °C, 1.59Hz, and strain level of 1%.

The DSR results of PAV aged blends in Figure 4.20 showed that all the blends demonstrated G*sin δ value far below the maximum requirement of 5000 kPa. During the life of pavement, work can be dissipated in several ways such as cracking and crack propagation which contribute to pavement distress. The lower amount of energy dissipated, the lower the amount of fatigue cracking to occur. Since G*. sin δ may lead to the less likelihood of fatigue cracking. Based on this judgment and the results of the DSR for PAV aged blends it seems that MB-80E1 with G^*.sin δ of 4310.23 Pa has the best performance and MB-80E5 with G^*.sin δ of 9737.43 Pa has the poorest performance of fatigue cracking for EVA modified binder while AB-80-45 with G^*.sin δ of 5133.49 Pa has the best performance and AB-80-205 with G^*.sin δ of 11771.2 Pa has the poorest performance of fatigue cracking for blown lab prepare binder.

In the situation of lack of flexibility, repeated traffic loads cause fatigue (alligator) cracking which is counted as an important deterioration mode for HMA pavements (Abo-Qudais and Shatnawi, 2007), G*.sinδ values at 10 rads/s and at medium temperatures is considered as a numerical indicator of fatigue resistance (Airey, 2004; AlKhateeb *et al*., 2009), Lower G*.sin δ values are favourable for better fatigue performance.

The reduced values of (G*.sin δ) are beneficial in improving the binder fatigue resistance and extending its fatigue life. The G*·sin δ values in Figure-4.20 indicated that, the blown asphalt exhibited more brittleness at low temperature and after been aged in PAV vessel (long term aging) compared to the EVA modified binder, this could be due to the complexity of the asphalt binder and the interaction between the constituent. Interestingly, as can be seen from Figure-4.20 the lower the EVA content and lower aging time durations the better are the aging characteristics of the modified binder compared to the unaged counterpart with respect to fatigue (G*.sinδ, and permanent deformation (G*/sinδ and component G'/G''). Also, Figure-4.20 indicated that, the proprietary (MB-80E0 and AB-80-0) should have far superior fatigue performance compared to the EVA modified binder and laboratory blended blown asphalt which indicated a general trend that, for the given combinations and EVA

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modified binder perform better than the laboratory blended blown asphalt

In general, results show that decreasing asphalt binder aging time and EVA content improved the fatigue performance. This is expected and in harmony with literature like that Gandhi (2008) reported that some binders which were produced at lower mixing and compaction temperatures than usual showed better fatigue cracking performance.

D. Fatigue performance (Time sweep test)

In this study, time sweep test was performed on RTFO aged asphalt binder and ten asphalt binder blends to simulate the effect of mixing and compaction temperature. The testing was conducted at 20°C, a strain level of 1%, which is small enough to develop linear fatigue damage (within viscoelastic range) and not to cause any nonlinear damage, was selected and applied to each 8 mm diameter and 2 mm thick DSR specimen with constant loading frequency of 10Hz to determine the fatigue life of the neat asphalt binder and the asphalt blends. The number of cycles to failure (fatigue life) was determined from a set of complex modulus (G*) versus time in seconds plots, the fatigue life is defined as the number of load repetitions to specimen failure or 50% of initial G*.

The initial stiffness (G_i*) is the value of the complex modulus (G*) for the first data point of the time sweep taken at approximately 200-300 seconds, in another word the asphalt-blends reached about 300 seconds before any of them showed a significant reduction in complex modulus (G*). The time in seconds was calculated at 50% of initial G_i*, the fatigue life was then determined by multiplying the time corresponding to 50% of initial G_i* by the frequency (10 Hz). The results of time sweep test and the characteristic fatigue curves obtained from time sweep tests were shown in Figures 16, 17, and 18. Figures 16, 18 shows fatigue curves that the initial Gi* values of the ten blends were slightly different and the asphalt binder blend show different fatigue behaviour. These fatigue curves were representative of fatigue test in that there was a gradual reduction in stiffness marked by a change in the slope of the complex modulus curve, but no sudden failure, due to decreased stress as the test proceeds. As the test proceeds, damage, caused by the initiation and propagation of micro-cracks, results in a gradual reduction in the stiffness.

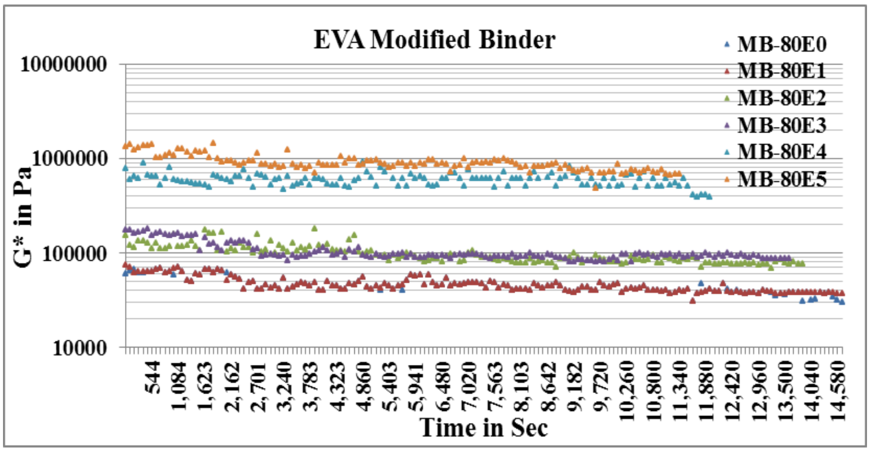

Figure-16. Isochronal plots of (G*) for EVA modified asphalt at frequency of 10 Hz and temperature of 20 °C.

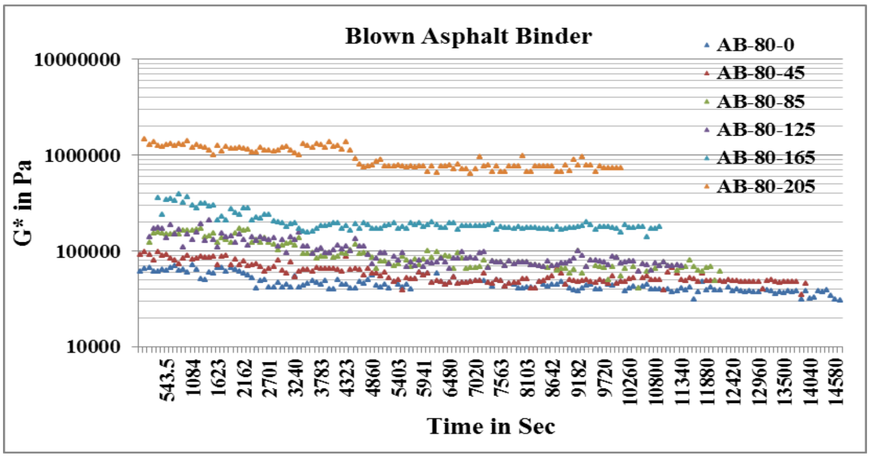

Figure-17. Isochronal plots of (G*) for blown asphalt at frequency of 10 Hz and temperature of 20 °C.

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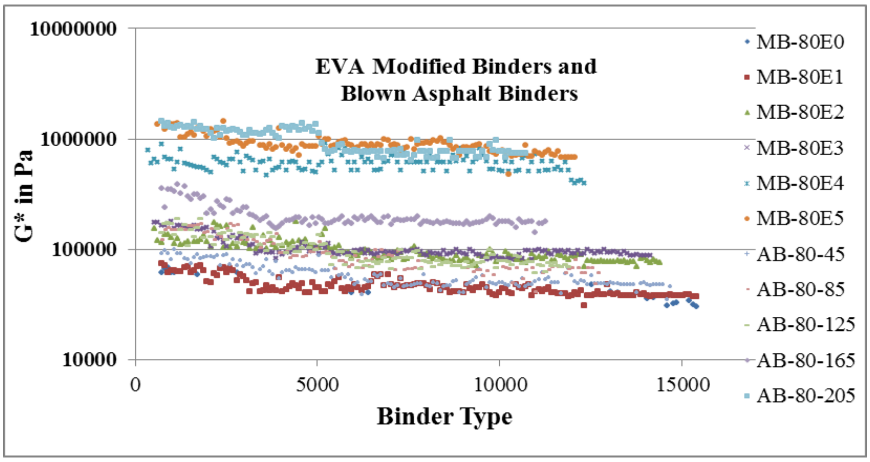

Figure-18. Isochronal plots of (G*) for EVA modified asphalt and blown asphalt at frequency of 10 Hz and temperature of 20 °C.

The results in Table-6 show that, the lower EVA content and lower aging time has a larger effect on the fatigue life while the higher EVA content and higher aging time show a smaller fatigue life dependence on type. Also, the data showed that, stiffness of EVA modified asphalt showed high resistance to fatigue after more than 12,000 cycles compared to blown asphalt. Also the blown asphalt (time aged) blends showed slight variation in fatigue life and were approximately equal. The EVA modified asphalt at 5% and blown at 205 minutes time aging duration have a fatigue life (drop in fatigue life) approximately 23.09% and 31.69% lower than the neat asphalt binder respectively.

Table-6. Fatigue performance and ranking of EVA modified asphalt and blown asphalt at frequency of 1.59 Hz and temperature of 20 °C.

Asphalt types	Initial (Gi*)Pa	50% of (Gi*)Pa	No. of Cycles @ 50% of (Gi*)	Ranking
MB-80E0	61080	30,540	15680	1
MB-80E1	74100	37,050	15390	2
MB-80E2	153080	76,540	14400	3
MB-80E3	174200	87,100	14130	4
MB-80E4	790000	295,000	12330	5
MB-80E5	1351000	675,500	12060	6
AB-80-0	61080	30,540	15680	1
AB-80-45	91680	4,5840	14670	2
AB-80-85	123020	61,510	12690	3
AB-80-125	134280	97,140	11880	4
AB-80-165	342620	171,310	11250	5
AB-80-205	1468000	734,000	10710	6

Table-7 shows the physical Properties of EVA modified binder and Blown asphalt binder prepared in the laboratory while Table-8 shows Rheological properties for these asphalt binders.

Table-7. Summery for physical properties of EVA modified asphalt and blown asphalt binder.

Blend type	Asphalt and blend properties				Penetration index (PI) (%)	
	Softening point, °C	Penetration	Viscosity, Pa.s@		unaged	RTFO aged
			135 °C	165°C		
MB-0E0	46.5	84.0	0.3	0.098	-0.83486	-0.41618
MB-0E1	48.5	73.5	0.4	0.124	-0.64981	-0.16388
MB-0E2	50.5	64.5	0.49	0.138	-0.46512	-0.23133
MB-0E3	54.5	51.0	0.53	0.173	-0.09218	-0.13726
MB-0E4	60.0	42.5	0.79	0.272	0.63090	0.33771
MB-0E5	65.5	39.5	1.1	0.350	1.47912	0.69529
AB-80-0	46.5	84.0	0.3	0.098	-0.83486	-0.41618
AB-80-45	48.0	77.0	0.38	0.122	-0.66175	-0.39440
AB-80-85	52.0	62.0	0.49	0.135	-0.19184	-0.35775
AB-80-125	56.5	49.5	0.51	0.163	0.27572	-0.26501
AB-80-165	61.5	41.0	0.7	0.265	0.83672	0.21268
AB-80-205	67.5	39.0	1.09	0.327	1.79285	0.68725

Table-8. Summery for rheological properties of EVA modified asphalt and blown asphalt binder.

Asphalt types	50% of (Gi*) Pa	No. of cycles @ 50% of (Gi*)	% Life reduction	Temperature high and low PG - grading
MB-80E0	30,540	15680	0	PG-58-19
MB-80E1	37,050	15390	1.85	PG-64-22
MB-80E2	76,540	14400	8.16	PG-64-25
MB-80E3	87,100	14130	9.89	PG-70-28
MB-80E4	295,000	12330	21.36	PG-70-31
MB-80E5	675,500	12060	23.09	PG-70-34
AB-80-0	30,540	15680	0	PG-58-19
AB-80-45	4,5840	14670	6.44	PG-64-22
AB-80-85	61,510	12690	19.07	PG-64-28
AB-80-125	97,140	11880	24.23	PG-70-31
AB-80-165	171,310	11250	28.25	PG-70-31
AB-80-205	734,000	10710	31.70	PG-70-37

CONCLUSIONS

From Table-7 we can notice that the physical properties for EVA modified binder and RTFO aged binder (Blown asphalt) that prepared in the laboratory is quite similar when we compare 1% EVA with 45min aging time, 2% EVA with 85min, 3% EVA with 125min, 4%EVA with 165min, and 5%EVA with 205 min. That gave a good initial indication that RTFO aged binder can work as EVA modified binder. Also from Table-8 can notice the same behaviour for PG - Grading at high and low temperatures.

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