Development of a Polymer Modified Flexible Pavement Material for Sustainable Pavement System

Sami A. Osman*
Assistant Professor, Department of Transportation Engineering College of Engineering, University of Dammam, Kingdom of Saudi Arabia,
sakhair@uod.edu.sa

Muhammad Saleem
Associate Professor, Department of Basic Engineering, College of Engineering, University of Dammam, Kingdom of Saudi Arabia, mssharif@uod.edu.sa

Rana Sajid Khan
Lecturer, Department of Transportation Engineering, College of Engineering, University of Dammam, Kingdom of Saudi Arabia,
rmSajid@uod.edu.sa

Muhamad Abid
Lecturer, Basic Engineering Department, College of Engineering, University of Dammam, Kingdom of Saudi Arabia,
maakhan@uod.edu.sa

Abstract

In Kingdom of Saudi Arabia (KSA) number of vehicles increased dramatically with an annual growth rate of 5 to 6%. This increase in number of vehicles lead to heavy traffic loads which lead to structural problems for the layer of the pavement. There has been a huge amount of investment in road infrastructure. Accordingly, road network is facing different problems in different aspects such as bituminous materials, loading and design method. A detailed experimentation has been carried out to investigate and evaluate the binder, aggregate and mixture composition, air void, materials characterization and improving pavement performance by using five different types of polymers with different concentrations. Several mixes were tested using Marshal tests. Dynamic shear Rheometer used to characterize bitumen and modified bitumen. Results show that use of plastomer polymers types (e.g. Polybilt-101, EE2) to modify the asphalt binder by improving their physical and rheological properties to meet the performance requirements is effective. It is possible to use different types of polymers (LDPE and HDPE) and different percentage of polymer concentration to achieve the performance requirements (e.g. PG 70 can be achieved by using 3% of EE2 or 4% of Polybilt).. It can concluded that the asphalt 60/70 pen grade which is used today in eastern province, KSA, meets the performance requirements to resist the main distress of flexible pavement. The asphalt binder behavior affects the performance of asphaltic concrete mixes. However, there are several important characteristics of asphalt binder (e.g. the adhesion of .asphalt binder to aggregate) should be evaluated besides modification of asphalt binders

.**Keywords**: Asphalt;asphalt mixture; polymers; modified asphalt

1. Introduction

Cracking in road can occurs at an intermediate and low temperatures, and permanent deformation can occurs at high temperatures. These are the most serious distresses for the flexible pavements. These distresses are reducing the pavement life; in addition to increasing maintenance cost (KACST, 1993). Permanent deformation is important type of distresses and the principle class of this type is rutting. Rutting occurs in the flexible pavements when vehicles loads cause shear stresses which are more than the shear strength of the materials used to construct the pavement so that it depends on the vehicular loads and the visco-elastic properties of the bitumen. This means bitumens are required to have high stiffness at high temperature to resist rutting. The bitumen behavior affects by its chemical composition. The atoms in molecules and its type of structures are the affecting factors to the bitumen behavior, therefore, it is more necessary than the total amount of each element. On the other hand, the study of chemical properties is more complicated, this is why the physical and rheological properties are used to characterize the asphalt binder because they are easy to understand in addition, they give indication about the chemical components (http:// www. new-technologies.org, 2016). The fast increase in the number of vehicles in KSA and associated loads lead to development of different problems to the layered structure of the pavement. This means the existing design approaches need to be reviewed for effectiveness specifically the methods which depend on empirical analysis of loads. The performance of flexible pavement affected mainly as material properties, vehicles loads, environment and methods of construction. Most of the design methods based on the field tests and experience gained from the American Association of State Highway Officials (AASHTO). The new approaches for the pavement design are based on the analysis of stresses and strains or deflection to calculate the permanent deformation and pavement fatigues using multilayers system (AASHTO, 2010). The tensile strains under the bituminous layers can leading to fatigue cracking and rutting due to strain at top of subgrade layer. Saeed and Ali explore the uses of fibers in asphalt mixtures. They said that use of fibers as an additives materials is not a new phenomenon, bitumen-fiber material have been used since 1950. Today in developed countries most of concrete used in construction industry are improved by additives (Saeed et al., 2008). Extensive research works are undergoing using different fibers and asphalt binder (Vikas and Shweta, 2006; Hossam et al. 2005). It can be concluded that they affect the performance of asphalt mixes. Any addition of fiber can lead to significant changes to mixture properties, even more investigation and experimental works are required to prove their effects (Pyeong et al. 2010). Extensive research has been conducted or in progress all over the world including costly accelerated dynamic field testing to replace or modernize the existing conventional design methods. The dynamic-response parameters are needed as fundamental inputs to modern evaluation and mechanistic design of pavements. These properties will also allow characterization and comparative studies of available conventional, marginal and treated highway materials. The results of laboratory test, related with the theoretical predictions, will permit comparison with actual pavement performance available from field measurements. The findings from such studies will ultimately lead to adoption and use of new or improved materials based on satisfactory performance (Preston, 1997).

Fatigue of mixtures can be assessed reasonably satisfactorily in a number of ways and such tests are now routinely carried out in many countries as part of a mixture design process. However, the relative importance of the different mixture components is not well understood, nor is the real relationship between fatigue in laboratory tests and that in the road pavement. Currently several factors, such as temperature and moisture are considered in the different modeling techniques applied for paving mixtures and flexible pavements. However, in regions where hot climate prevails, like in KSA, the following two main factors ought to be accounted for when investigating for the permanent deformation and fatigue cracking:

a. Environmental effects, basically high temperature during most of the year, and

b. Use of the materials available in the project area.

The primary methods of modeling and analysis include elastic, viscoelsticity, elasto-plasticity, visco-plasticity and finite element. The most important parameters used in these analytical methods are the resilient modulus and the complex modulus (Qi and Witczak, 1998). Asphalt binder is complex materials due to heterogeneous structure. Many researches carried out worldwide to understand its behavior. Recently research works carrying out to simulate fatigue cracking and permanent deformation through models of materials [Lee et al. 2000; Lytton, 1993; and Park, 1996). There is an obvious difference between the relatively uniform stress conditions present in a pure binder specimen and the highly variable stresses present in the binder around numerous filler particles. The analysis demands innovative thinking (Osman, 2005). Permanent deformation or rutting and fatigue cracking are the main distresses facing the flexible pavement. Polymer modification has been proven to be an effective way to improve bitumen properties to some extent by many researchers and has been used widely in practice (Nahal et al 2014, Zhu et al 2014)

Abdulaziz**,** 2001 conducted a research that stated; that the fatigue cracking and rutting in the shape of longitudinal depression are the main distresses in KSA in spite other failure modes. Due to heavily trucked highways and overweight of trucks pressure of tire rutting is almost the dominant distresses in Eastern province. So to overcome these problems asphalt mixture materials, design and method of construction should be changed to obtain high quality pavement (Abdulaziz, 2001). Some researchers have found that adding polymers to asphalt may increase the product price by between 60 and 100% owing to following reasons (Al-Dubeeb et al. 1998).

Price of polymer and content of polymer can decrease, Pavement cycle cost increase by 10 folds, Most used polymer in asphalt modification is Styrene ButyleStyrene and crumbed tire rubber. Fig. 3 shows temperature zoning map and performance Grade (PG) binder That can be used in Kingdom of Saudi Arab.

2. Materials and Methods

Asphalt grade 60/70 Pen was used in this research collected from Ras-Tanora refinery. Fifty liters of asphalt were collected and distributed into small containers after heating to avoid repeating of heating samples which may change the characteristics of asphalt binder. Polymers samples were collected from three sources: SABIC polymers: two types of High Density Polyethylene (HDPE); HDPE M80064 and HDPE M200056, one type of Linear Low Density Polyethylene (LDPE), Exxon Chemical (EE2) and Eastman Polybilt Polymer (PB-101).

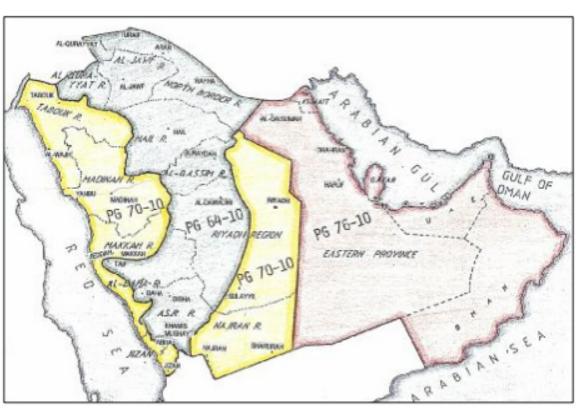

Fig. 1. Temperature Zoning Map and binder PG for the Kingdom of Saudi Arabia (Hamad, 1996).

2.1 Preparation of polymer and asphalt blend

Five polymers were used in this research, individual polymer blended with asphalt grade 60/70 Pen. To insure homogeneity of the product the heating temperature and blending time had been followed as per manufacture's recommendation. Of course experience playing a major role in defining the polymer concentration of the selected types. The specified percentage of each polymer was used to produce the Polymer Modified Bitumen. Aggregate from different sizes were blended by trial and error to achieve the aggregate skeleton as per specifications (MOM &RA – KSA, 2011). Marshal mixture design was used to evaluate the asphalt mixture. Aggregate mixture was heated to160-180°C. Bitumen also heated to 170°C.

2.2 Asphalt Mixture Design

Asphalt mix is designed using different polymers types. A control mix was designed using the specifications of Ministry of Transport in Eastern Province. Asphalt mixes sample were prepared (see Fig. 2):

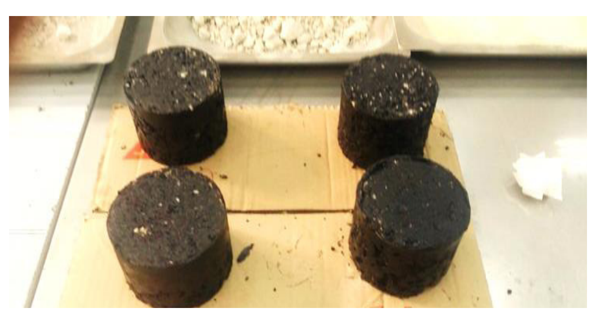

Fig. 2.Samples of control mix, mix1

Mix 1: Control mix as used in eastern province specifications, KSA without using asphalt modifier 3 samples per bitumen content by weight has been used.

Mix 2: Modified Asphalt with HDPE M80064 polymer 3 samples per bitumen content.

Mix 3: Modified Asphalt with LLDPE M200024 polymer 5 samples with bitumen content.

Mix 4: Modified Asphalt with HDPE Polybilt polymer 5 samples with bitumen content.

Mix 5: Modified Asphalt with HDPE EE2 polymer 5 samples with bitumen content.

3. Results and Discussions

3.1 Aggregate Testing Results

Aggregate is a mix of granular particles with different sizes and shapes produced by mechanical crushing of natural or industrial stones. Samples of coarse and fine crushed aggregates materials were obtained from Abu Mean company. Cement filler was used in asphalt mixture as a filler material. Coarse aggregates were evaluated using different methods such as: abrasion test, impact value, crushing value, gradation, water absorption and specific gravity, angularity, flakiness index and elongation. Finer materials were evaluated by using sieve analyses, specific gravity and absorption. Table 1 presents the specific gravity and other properties of the aggregate samples. Table 1 presents the results of physical properties of the asphaltic materials.

3.2 Testing of Asphalt Binders

The total numbers of asphalt binders tested are five including the neat (un-aged) asphalt binder 60/70 pen grade and four modified binder. Two percentages of polymer contents for each types is used to achieve different PG grades. Series of testing was established to get the physical and consistency properties

Table 1. Properties of aggregate used in asphaltic concrete

Test	Test used	Aggregate size			
		3/4"	3/8"	Crushed sand	Filler
Magnesium Sulphate soundness loss, %	ASTM C88-05	10	10	11	-
Los Angles Abrasion Value, %	AASHTO T-96 ASTM C 131	29.2	29.5	-	-
Aggregate Impact Value	BS 812-112	11.2	11.2	-	-
Specific gravity for Bulk	AASHTO T85	2.572	2.25	2.636	2.673
Specific gravity for Saturated Surface Dry		2.627	2.28	2.684	
Apparent Specific Gravity		2.72	2.34	2.777	
Absorption of Water, %		2.1	1.74	2.0	-
Flakiness index,%	ASTM D4791-05	4.8	31	-	-
Elongation index,%	ASTM D4791-05	2.5	21.3	-	-
Clay content, %	AASHTO T-112	0.20		0.17	
Coating and stripping, %, min.	AASHTO T-182	95			
Liquid Limit	ASTM D4318	-	-	N.L	N.L
Plastic Limit	ASTM D4318	-	-	N.P	N.P

in the laboratory as shown in Table 2. For each test, four samples were experimented to eliminate the percentage of error. Table 3 gives summary of binder characterization test results. Asphalt binder properties evaluated through superpave tests corresponding to different temperature range like low, medium and high as shown in Table 3. Dynamic Shear Rheometer (DSR) AASHTO TP-5 is used for properties determination at intermediate and high temperatures to evaluate both neat and modified asphalt.

Table 2. Bitumen Physical Properties Tests Results

Property	AASHTO Test	Penetration Grade 60-70	Mean test value
Penetration at 25 Degrees C, 100g, 5sec.	T-49	68	2.21
Viscosity, at 60 °C, Poise,	T-202	2750	0.96
Flash point, Cleveland Open, °C,	T-48	235	0.82
Fire point, Cleveland Open, °C,.	T-48	245	0.817
Ductility at 25 °C, 5cm per min, cm,	T-51	104	
Solubility in trichloroethylene, percent,	T-44	99	
Specific gravity		1.03	0.002
Softening Point (˚C)		49.3	0.153

The (DSR) test conducted to determine the rheological properties for aged and un-aged asphalt binder samples. The DSR test provides different parameters - at a temperature range from 22 to 40°C, and for flexural creep between -6 to -12°C as shown in table 3- as listed below:

- Complex Shear Modulus, G* = Peak Stress / Peak Strain
- Phase Angle, d (defined as the phase difference between stress and strain)
- Shear Storage Modulus, G′ = G* Cos δ
- Shear Loss Modulus, G″ = G* sin δ
- G* / sin δ

The established sequenced is followed to determine the PG grade of asphalt binder samples. Bending Beam Rheometer (BBR) test is used for the low temperature properties (creep stiffness (S) and creep

Table 3.Summary of Polymer Binder Characterization Results.

Tests	**Grade 60/70**	**EE2 4%**	**EE2 5%**	**PB 4%**	**PB 5%**
Viscosity (cP) (RV) max 3000Cp	494.25	450	425	450	837.5
Mass Loss % (RTFO) max 1%	(+) 0.344	(-) 0.037	(-) 0.034	(-) 0.01	(+) 0.020
G*/Sinδ (OB) (DSR) ≥1kPa	1.343	1.302	1.460	1.828	1.801
G*/Sinδ (RTFO) (DSR) ≥2.2kPa	3.384	2.673	3.614	3.620	3.282
G*Sinδ (PAV) (DSR)<5MPa	4.386	3.994	3.097	1.811	1.486
Stiffness (BBR)<300 MPa	167	182.5	187	102.1	50.7
m-value (BBR)≥ 0.30	0.345	0.325	0.314	0.33	0.307
PG	64-22	70-22	76-22	70-16	76-16

rate (m-value)) evaluation. Pressure Aging Vessel (PAV) (AASHTO PP-1) residue are the samples used for BBR test for both neat and modified asphalt binder. As a definition the creep rate is the slope of log loading time versus log stiffness. The Rotational Viscosity test at 135ºC performed using Rotational viscometer (RV AASHTO TP-48) is a valuable conducting test to evaluate the workability, pumping and handling for both types of binder (neat and modified). One advantage of the RV test is that the result could be used to determine the mixing and compaction temperatures based on temperature versus viscosity chart by testing the viscosity at 163 ºC. The Rolling Thin Film Oven (RTFO, ASTM D-2982) and PAV method were used to simulate the short and long term aging respectively for modified and un-modified (60/70 pen grade) asphalt binders samples. There was no need to conduct the Direct Tension Test (DDT) because of the BBR test results.

3.3 Asphalt Mixture Results

Fig. 3 to Fig 7 shows asphalt mixture properties for Marshall testing.

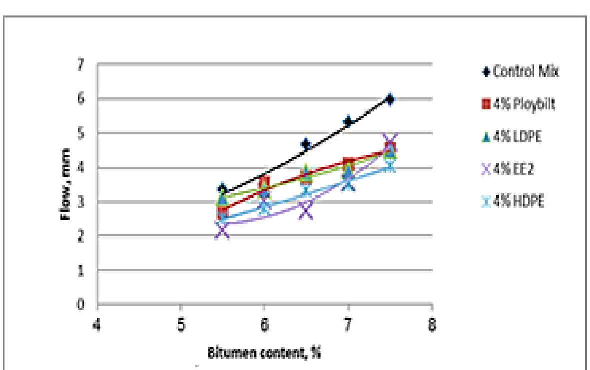

Fig.3. Bitumen contents Vs. mix stability

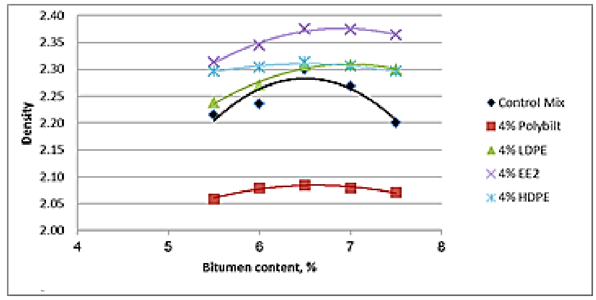

Fig. 4. Bitumen contents Vs mix density(kg/m³)

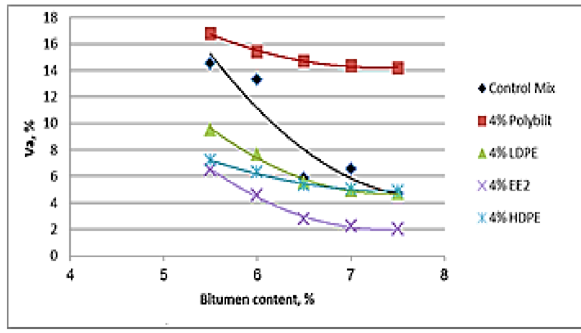

Fig. 5. Bitumen contents Vs air voids

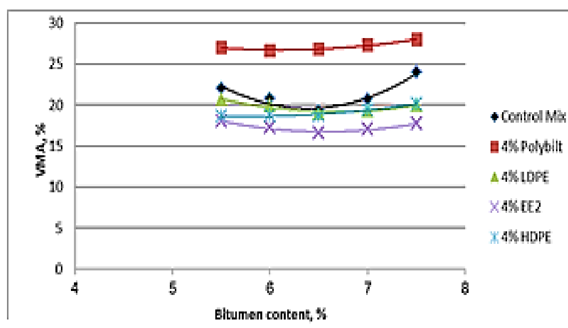

Fig. 6. Bitumen contents Vs Voids in mineral aggregate

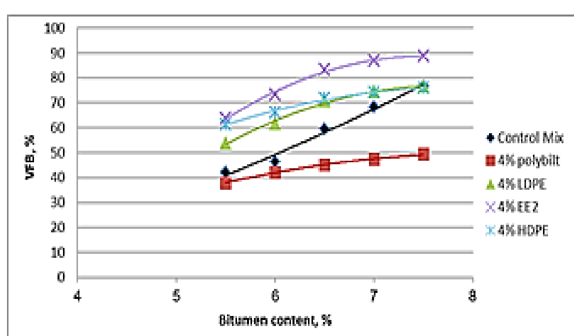

Fig. 7. Bitumen contents vs Voids filled with bitumen

3.4 Discussion

AASHTO specifications are used for sample preparation and polymer blend with provided recommendations by the manufacturer. Appropriate percentage selection of the polymer was a considerable point and this selection of the previous percentage of polymers contents based on the experience. Bitumen binder is a visco-elastic material and its properties affected by two factors - which are load time and temperature - extensive evaluation had been done using Superpave tests methods and PG grade system. The PG grade was determined to see whether it satisfies the specification requirements according to the Temperature Zoning in KSA as shown in Fig. 3 above. So that, resistance to rutting and fatigue cracking was covered. In addition to that workability, safety, pumping and handling characteristics are evaluated.

Based on SHRP Superpave System the performance of asphalt binders in specified location is controlled by two factors, these are: the average seven day maximum pavement design temperature and the minimum pavement design temperature. As a result of the research, the temperature zoning of KSA which is shown in Figure 3 are identified (-10 ºC) as the minimum pavement design temperature and (70 ºC) as the maximum pavement design temperature, but the asphalt binder samples which are collected from the refinery had the minimum required G*/sin (δ) which is 1.0 KPa at 64ºC. So that, the produced asphalt binder from the refinery do not meet the performance requirements of more than 60% of KSA area. So this type of asphalt (60/70 pen Grade) can be used without modification in some locations, if the traffic condition does not require developing of PG based on Table 3, otherwise modification is required. For the other areas asphalt modification is needed to improve asphalt binder properties to satisfy the required PG grade, because 60/70 pen grade asphalt do not exhibit adequate visco-elastic properties to resist high temperature distresses in areas when the high pavement design temperature exceed 64 ºC. In this regard, two types of polymers from international producer used to modify the 60/70 pen grade asphalt binder samples from the refinery. Modification of asphalt does not mean to check the requirements at high temperature only, so that, it is important to note that, although the performance of low temperature requirement of asphalt binder in KSA (-10 ºC) is satisfied by 60/70 pen grade asphalt binder, the polymer modified binders must be evaluated for their low temperature behavior to insure that the modification does not affect their behavior at low temperatures as a tradeoff for the improvement of their behavior at high temperatures.

According to the laboratory results which were shown in Table 3 it is evident that the PG 76 could be achieved by using the same percentage of the two different types of polymers (5%) but, the low temperature is different. On the other hand, the PG 70 can be achieved by using 4% of EE2 or 4% of Polybilt. It is important to note that, the rheological properties of modified bitumen binder using two or more different types of polymers were not depending on the percentage of polymers, even they gave same high temperature properties requirement at one percent.

On the basis of the asphalt mixture results obtained, comparison can be establish in the optimum asphalt content between the control mix and the modified polymers as following:

- Target optimum asphalt content for HDPE M200056 polymer is less than Control mix
- Target optimum asphalt content for LLDPE M200024 polymer is less than Control mix
- Target optimum asphalt content for Polybilt polymer is less than Control mix
- Target optimum asphalt content for EE2 polymer is less than Control mix

4. Conclusion

Based on the above Marshal design results the following points can be concluded:

- Mixture Flow of unmodified asphalt is higher compared with all modified asphalt. Lower value of flow obtained when using EE2 polymer and HDPE.
- Low stability was obtained from unmodified mixture whereas high stability was obtained when using EE2 and HDPE polymers. Polybilt modified mixture gave lower stability compared with other modified polymers.
- EE2 modified mixture gave a higher density compared with other mixes. But a polybilt mixture gave low density than the control mix.
- Polybilt mixture gave high air voids content even higher than the control mix. The others modifiers gave lower air voids compared with control mix. Similar results were obtained for voids in mix aggregate (VMA).
- As a consequence the polybilt mixture gave lower voids filled with bitumen compared with other modifiers.
- Based on the testing results and analysis, for modified and un-modified asphalt binder, the following conclusion can be stated:
- The asphalt 60/70 Pen grade which is used today in Eastern province, KSA, meets the performance requirements to resist the main distress of flexible pavement (Fatigue cracking and permanent deformation), where the maximum temperature of pavement at the specified depth does not exceed (70 ºC) and the minimum temperature of pavement is not below (-10 ºC).
- Use of plastomer polymers types (e.g. Polybilt-101, EE2) to modify the asphalt binder by improving their physical and rheological properties to meet the performance requirements is effective.
- It is possible to use different types of polymers and different percentage of

polymer concentration to achieve the performance requirements (e.g. PG 70 can be achieved by using 3% of EE2 or 4% of Polybilt).

- The concentration and type of polymer affect the rheological properties and workability of modified asphalt binder.
- Blending and mixing of polymers produces a homogenous mix with complete dispersion within the body of asphalt binder.
- The plastomer types of polymers are easiest in processing of asphalt blend because it does not need high shear mixer and some types (e.g. Polybilt-101) can be added directly in the asphalt plant during the production of asphalt mixes.
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