The impact of using Polymer Modified Bitumen in Asphalt mixs

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Abstract

The economic growth of any country relies on many factors, such as natural resources, technology, manpower, regulations, and infrastructure. Infrastructure is essential for country development. Road networks are part of the infrastructure of any country. The presence of a reliable road network will facilitate the shipping of goods, which will save time and money and contribute to economic growth. A road network is considered reliable when it reduces the journey time, provides the best routes, properly covers a country or area, reduces the delay of public transportation, contributes to economic growth, and ensures a smooth ride. Building a high-quality road pavement that meets the needs of road users and ensures smooth riding requires good planning, design, and construction of the pavement.

The construction of durable pavement can be attained through the collaboration of reliable design, selecting high-quality and suitable raw materials, appropriate asphalt mix design, and the implementation of proper construction methods in compliance with local and international standards. The need for a pavement with a longer service life that can bear high traffic loads with fewer repair requirements has become essential nowadays. Therefore, polymer-modified bitumen has been used to improve the asphalt mix properties and produce a pavement with a higher service load and higher durability. This paper will briefly review flexible pavement and focus on reviewing the different aspects of polymer-modified bitumen (PMB). Moreover, this paper will compare the properties of PMB with ordinary bitumen. The properties of the bitumen and asphalt mixes furnished in this paper have been determined by conducting the required tests at qualified labs. All test procedures and methods are in compliance with international standards.

Keywords: modified bitumen, Conventional bitumen, durability, PMB, traffic loads.

1. Introduction

Asphalt pavement, or flexible pavement, is widely used in the construction of roads. Flexible pavement dominates the road construction industry. The wide use of asphalt pavement is a result of the unique characteristics of the pavement that can't be found in rigid pavements. Well-constructed asphalt pavements offer road users smooth riding. Furthermore, asphalt pavements are cheaper than concrete pavements. However, asphalt pavements are deteriorating faster than concrete pavement, which prompts the need for periodic maintenance to avoid expensive repairs of the pavement. The nature and features of asphalt pavement, combined with weather conditions and traffic loads, can result in asphalt pavement deterioration. Asphalt pavement can be subjected to various defects such as cracks, rutting, aging, fatigue, asphalt bleeding, and pot holes. The periodic repair and maintenance of roads, especially main roads, can result in traffic jams and inconvenience for road users in the event of the closure of a road or part of it. Moreover, the cost of repairing or replacing defective roads burdens governments around the world. Therefore, the use of polymer-modified bitumen has increased recently in an attempt to increase the service life of roads and reduce maintenance and repair requirements.

This paper will briefly study the asphalt mixtures produced by the use of polymer modified bitumen. Also, this paper will discuss the properties of polymer modified bitumen and what distinguishes PMB from ordinary bitumen. The following points will be discussed:

- Bitumen modified asphalt: a short introduction of PMB
- Grades of bitumen modified asphalt
- Uses of bitumen modified asphalt
- Properties of bitumen modified asphalt and ordinary bitumen
- Mixing and laying of bitumen modified asphalt
- Marshall method of mix design: Marshall properties for bitumen modified asphalt and ordinary bitumen

2. Polymer modified bitumen

The PMB has been used to improve the durability of asphalt pavement, increase its service life, and reduce the need for maintenance and repair [8]. The main application of PMP asphalt mixes are roads subjected to high traffic loads and high rate of breaking force such as Roundabout, bends and intersections. The PMB is a bituminous binder mixed with a specific amount of polymer. The polymer is added to the bitumen binder to enhance its properties. The addition of polymers can improve bitumen elastic recovery, increase softening points, increase cohesive strength, and improve ductility. Furthermore, modifying bitumen reduces the temperature susceptibility of bitumen binder [5]. Adding polymers to bitumen binder increases the bitumen stiffness at high temperatures, thus reducing the rutting or deformation at high temperatures. On the other hand, the resistance of bitumen binder to low temperatures also improved, which prevented excessive deformation of the pavement [5]. In general, PMB will improve the performance of asphalt mixtures, which will reduce the need for maintenance and repair of asphalt roads.

Bitumen is modified by the blending of bitumen binder with a predetermined amount of polymer. Elastomers, or plastomers, are the polymeric additives used to produce PMB. Studies and practical experience have proved that styrenic block copolymers greatly improve the performance of bitumen binder. Styrenic block copolymer is a thermoplastic rubber or elastomer. Therefore, styrene-butadiene-styrene (SBS) has been widely used to improve the properties of bitumen binder. Commonly, the amount of polymeric additive added to bitumen binder varies from 3% to 4% of the bitumen weight [5]. In this paper, performance-grade bitumen PG82-22 has been tested, and results are presented. The polymer used to modify the bitumen binder studied in this paper is SBS. PMB has various grades for different applications. The PMP grades are defined by two numbers. For example, PG82-22 and 82 represent the highest design temperature for the pavement in Celsius. While -22 represents the lowest design temperature for the pavement in Celsius.

3. Grades of bitumen modified asphalt

Penetration and viscosity are the two properties that have been used to classify the bitumen. The penetration property of bitumen measures the hardness of bitumen, while the viscosity determines the consistency of bitumen. The PG grading system is a completely different classification system. The PG system classifies the bitumen based on performance at different temperatures. For example, PG82-22 can perform well at temperatures less than 82 °C and greater than -22 °C. 82 °C represents the average highest temperature of pavement for 7 consecutive days. The second number expresses the average lowest temperature of pavement for 7 consecutive days [2]. PG82-22 is suitable for UAE weather as it can perform well in hot and cold weather.

The PG grading system is not limited to PMB but is also used to classify unmodified bitumen binder. The distinguishing of PMB can be done by summing the high and low-performing temperatures of the grades. For PMB, the total will be greater than 92. The total for PG82-22 is 104, which means it is a modified bitumen.

4. Uses of Polymer modified Bitumen

The PMB has primarily been used in road construction. Also, it has been found to be good as a waterproofing material and corrosion resistance material of steel pipes coated with PMB. Bitumen binder is a temperature-sensitive material that softens at high temperatures and stiffens at low temperatures. Therefore, the correct use of polymers will enhance the bitumen properties and reduce the temperature sensitivity. However, the use of PMB for all types of pavement may not be cost-effective. The engineer should balance between the cost and benefits of using PMB. It is feasible to use ordinary bitumen binder for roads subjected to low traffic volume. These roads will not be subjected to excessive loading cycles; thus, an asphalt mixture made with unmodified bitumen will be enough. Despite the importance of bitumen in pavement mixtures, the proper selection and proportioning of asphalt mixture ingredients such as bitumen, aggregate, etc. is a very important factor in producing durable pavement.

5. Properties of Polymer Modified Bitumen and Conventional bitumen binder

Table No. 01 contains the properties test results for different grades of bitumen binders. Penetration is a property that determines the consistency and hardness of bitumen. The penetration for the modified bitumen PG82-22 is less than that of bitumen (40/50) and bitumen (60/70), which indicates that modified bitumen possesses a higher consistency and hardness. The softening point is another property tested in the lab. The softening point property defines the temperature at which bitumen softens and flows. The modified bitumen softening point is 88 °C, while the bitumen 40/50 and bitumen 60/70 softening points are 53.40 °C and 49 °C, respectively. The higher softening point reflects the higher resistance to bitumen softening and flow, which means higher resistance to deformation and rutting. The softening point of PG82-22 confirms the ability of pavement to perform at temperatures equal to or less than 82 °C. The flash point defines the lowest bitumen temperature that causes the bitumen vapor to ignite for 5 seconds when an ignition source is introduced [1]. The flash point for PG82-22 and bitumen 40/50 is approximately equal.

Table 1

Property	Bitumen (40/50)	Bitumen (60/70)	PG 82-22	Method
Penetration (0.1 mm)	46	64	43	ASTM D5
Softening point (C°)	53.40	49	88	ASTM D36
Flash point (C°)	348	289	345	ASTM T48

Table No. 02 displays the test results of various properties for three samples of modified bitumen, PG82-22. The rotational viscosity of PMB is used to determine the bitumen viscosity and ability to flow by rotating the material at a specific temperature [6]. The rotational viscosity is important for choosing the mixing and compaction temperatures of asphalt mixes, which ensure appropriate coating of bitumen on aggregates and better performance of the asphalt mixture. The result of the testing of all samples lies within the required value (maximum 3 Pa according to ASTM D 6373).

The dynamic shear rheometer test was conducted to determine the dynamic modulus G and the phasing angle δ for PG82-22 binder samples. The test is performed on three types of samples unconditioned binder, RTFOT and PAV-conditioned binder. The RTFOT condition the bitumen sample to replicate the short-term again, while the PAV stimulates the long-term aging of asphalt [1]. The complex shear modulus evaluates the stiffness and resistance of asphalt binder to deformation. It is also used to determine the elasticity and stiffness of asphalt binder, which is an important factor in assessing the performance of asphalt pavements. The test conducted at a temperature of 82 °C and a frequency of 10 rad/s. The results of the DSR presented in Table No. 02 are within the specified limits according to ASTM D6373. The creep stiffness property was determined by the use of the bending beam rheometer test. The cracking of asphalt at low-term pavement is related to creep stiffness. The obtained test results evaluate the performance of asphalt pavement at low temperatures. All tests conducted on modified bitumen (PG82-22) and listed in Table No. 02 confirm the compliance of the tested modified bitumen with ASTM D 6373 [1].

Table 2

Property	Sample 01	Sample 02	Sample 03	Requirement-ASTM D 6373	Method
Rotational viscosity @135 C°	1.475 Pa.S	1.775 Pa.S	1.749 Pa.S	Max 3 pa.s	AASHTO T316
Dynamic Shear Ratio, $G^*/\sin\delta$ at 82°C at 10 rad/s	1.51 kPa	1.412 kPa	1.433 kPa	Min 1 Kpa	AASHTO T315
Dynamic Shear Ratio, $G^*/\sin\delta$ (after RTFOT[1]) at 82°C at 10 rad/s,	2.55 kPa	2.49 kPa	2.51 kPa	Min 2.2 Kpa	AASHTO T315
Dynamic Shear Ratio, G*sinsin δ (After PAV[2])at 34°C at 10 rad/s,	1240 kPa	1479.6 kPa	1469.1 kPa	Max 5000 Kpa	AASHTO T315
RTFOT Mass loss	0.014	0.06	0.05	Max 0.60%	AASHTO T240
Creep stiffness	174 0.375	153.19 0.313	152.11 0.3108	Max 300 Mpa Min 0.3	AASHTO 313
Elastic recovery @25 C° , 10 cm after RTFOT	80	90	89	Min 75%	AASHTO T301

[1]RTFOT: Rolling Thin-Film Oven Test.

[2]PAV: Pressure Aging Vessel.

6. Mixing and compaction temperatures of bitumen modified asphalt

The mixing of asphalt should be performed at a specific temperature known as the mixing temperature. The use of the correct temperature significantly impacts the properties of the asphalt mixture. Likewise, the asphalt mixture should be laid and compacted at a predetermined temperature. The unmodified bitumen equiviscous method has been used to determine the mixing and compaction temperatures. In this method, the viscosity is determined at two test temperatures to create a relationship between temperature and viscosity. For unmodified binder, the mixing temperature corresponds to a viscosity range of 0.17±0.02 pa.s, while the compaction temperature corresponds to a viscosity range of 0.28±0.03 pa.s [3]. The mixing and compaction temperatures have been determined through lab testing for unmodified bitumen grades 40/50 and 60/70. The mixing and compaction temperatures for bitumen grades 40/50 were 150 to 156 °C and 140 to 145 °C, respectively.

The use of the equiviscous method to find out the mixing and compaction temperatures of modified bitumen may result in high temperatures. High temperatures may adversely affect the quality of the asphalt mixture. The

Asphalt Institute recommends the use of mixing and compaction temperatures recommended by the modified bitumen supplier. In our case, the modified bitumen (PG82-22) supplier recommends mixing and compaction temperatures of 160 to 170 °C and 150 to 160 °C, respectively. Clearly, the mixing and compaction temperatures for PG82-22 are higher. NCHRP Report 648 recommends the use of DSR Phase Angle or DSR Steady Shear Flow tests to determine the mixing and compaction temperatures for modified binder. The selected mixing and compaction temperatures shall be suitable; using lower or higher temperatures may adversely impact the asphalt mixture and result in low workability, increase stiffness, aging of asphalt, lower performance, and reduce the durability of road pavement.

7. Marshall method of mix design

The Marshall method of mix design is a common laboratory method used to obtain the optimum bitumen content for a predetermined aggregate gradation. The optimum bitumen content is acquired through conducting various tests to determine the volumetric and strength properties of tested samples. Five different bitumen contents will be tested for the selected aggregate gradation. Three identical samples will be prepared for each bitumen content, and the test results for each bitumen content will be the average of three samples [3].

The preparation of Marshall samples includes the preparation of aggregates, mixing the aggregates and bitumen, and the compaction of specimens at Marshall mold. The aggregates should be dried and combined to conform to the required grade. Abu Dhabi specification (ADQCC) furnishes the suitable aggregate gradation in tables for different asphaltic concrete mixes. The mixing of aggregate and bitumen in the lab should proceed when the mixing temperature is achieved. Appropriate mixing, whether by mechanical mixer or manually, is essential to producing a homogenous mixture. The specimen will be compacted by the compaction hammer; the number of blows is determined by the type of road and traffic, according to the Asphalt Institute. Abu Dhabi specification (ADQCC) fixes the number of blows at 75 for all road types and different asphaltic concrete mixes, as furnished in Table No. 3.

Table 3 [9]

Properties	Bituminous base course			Bituminous binder course	Bituminous wearing course		
Type/category of road	Parking lots, minor roads, driveways, etc. (light, traffic volume)	Sector roads (medium traffic volume)	Main roads, highways, truck roads, etc. (heavy traffic volume)	All roads categories	Parking lots, minor roads, driveways, etc. (light, traffic volume)	Sector roads (medium traffic volume)	Main roads, highways, truck roads, etc. (heavy traffic volume)
Penetration grade of bitumen*	60/70	40/50 or 60/70	40/50 or 60/70	60/70 or 40/50	60/70	40/50 or 60/70	40/50 or PG
Number of compaction blows each end of specimen by freely held Marshall hammer	75	75	75	75	75	75	75
Stability (Marshall) minimum kg	1000	1100	1200	1300	1400	1500	1600
Flow (Marshall) mm	2 - 4	2 - 4	2 - 4	2 - 4	2 - 4	2 - 4	2 - 4
Stiffness minimum kg/mm (minimum)	400	400	500	500	450	450	550
❖ Percent air voids in mix	3 - 5	4 - 7	5 - 7	5 - 7	3 - 5	4 - 7	5 - 7
❖ Percent voids in mineral aggregate (VMA), % minimum	11	13	13	13	13	14	**14.5**
❖ Percent voids filled with	60-75	55-70	50-65	50-70	60-75	55-70	50-65

To investigate the impact of using modified bitumen on Marshall properties. Marshall samples have been prepared for conventional bitumen grades 40/50 and for modified bitumen grades PG82-22. Similar aggregate gradation has been used to prepare the Marshall samples to study the changes in Marshal properties.

Table 4

Seive size		Combined Grading
Inc	mm	
¾”	19	100
½”	12.5	81
3/8”	9.5	73
No 4	4.75	54
No 8	2.36	36
No16	1.18	25
No 30	0.60	17
No 50	0.30	12
No 100	0.15	18
No 200	0.072	3.8

8. Marshal properties of bitumen modified asphalt

Prepared Marshall samples were tested to determine the volumetric and stability properties of the prepared specimens. The stability properties of the specimen were determined by conducting stability and flow tests. While volumetric testing and analysis aim to determine a set of important properties such as voids in mix, void-filled bitumen (VFB), and voids in mineral aggregate (VMA), The Marshall intent is to determine the bitumen content that achieves specific strength and volumetric features of an asphalt mix.

9.1 Marshal flow and Stability

Stability tests measure the maximum load resisted by the Marshall specimen. The stability test was conducted by subjecting the asphalt specimen to a constant loading rate of 51 mm per minute. The maximum load or stability is obtained when the asphalt specimen fails. The flow of an asphalt mix is the deformation of the asphalt specimen measured during the stability test [3]. The maximum flow or deformation occurs at peak load. Abu Dhabi specification (ADQCC) specifies the minimum requirements of stability and flow for different asphaltic concrete mixes, as presented in Table No. 3.

For our study case, Marshal stability and flow determined for asphalt mixes made from Two different bitumen types (PG82-22, unmodified bitumen 40/50). Table no:05 list results for stability and flow tests. The bitumen content for both mixes is 3.80%. we can notice that the stability is higher by 9.0% for asphalt mix made with modified bitumen PG82-22 according to conducted tests.

Figure 1

The conducted test report shows an increase in the stability of asphalt mixtures made with modified bitumen (PG82-22), which supports the anticipated improvement in performance and strength for asphalt mixes made with modified bitumen.

Table 5

Asphalt mix	Property	Sample 01	Sample 02	Sample 03
Wearing course-40/50	Stability **Average= 1773 Kgs**	1752 Kgs	1794 Kgs	1773 Kgs
	Flow **Average= 2.83 mm**	2.80 mm	2.90 mm	2.80 mm
Wearing course-PG82-22	Stability **Average= 1935 Kgs**	1900 Kgs	1963 Kgs	1942 Kgs
	Flow **Average= 3.10 mm**	3.0 mm	3.20 mm	3.10 mm

9.2 Volumetric properties of asphalt mixture

The compaction of asphalt mixes in the field is essential for producing a smooth surface, proper compaction determines the reliability of constructed roads. Furthermore, sufficient compaction will play a pivotal role in producing a durable pavement that can sustain traffic loads without excessive deformation or cracking. Another important volumetric property is the in-place air. The designer of pavement should address the in-place air void requirement in asphalt mix design. The presence of optimum air content in asphalt mixes is essential for the better performance of asphalt mixes. In-place air voids allow for a slight compaction of asphalt pavement under traffic loads, which ensures the flexibility of the pavement and improves the performance of constructed roads.

9.2.1 Marshal density (Gmb)

The bulk density (Gmb) for a Marshall specimen was determined according to ASTM D2726. Determining the asphalt bulk density in the lab under ideal compaction effort is essential to extracting the reference Marshall density. The measured lab density is the reference for determining the degree of compaction at the site. Therefore, the determination of Gmb for asphalt mixtures under controlled conditions is crucial for measuring the effectiveness of field compaction. Furthermore, the determination of Gmb is important to determine the in-place air void for asphalt mixes.

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The bulk density for prepared asphalt mixes is listed in Table No. 6. It is obvious that the type of bitumen doesn't significantly impact the bulk density of asphalt mixes.

Table 6

Asphalt mix	Property	Sample 01	Sample 02	Sample 03
Wearing course-40/50	Bulk density (Gmb) **Avg=2.560 g/cc**	2.568 g/cc	2.572 g/cc	2.565 g/cc
Wearing course-PG82-22	Bulk density (Gmb) **Avg=2.539 g/cc**	2.535 g/cc	2.542 g/cc	2.539 g/cc

9.2.2 Maximum theoretical specific gravity of asphalt mixture (Gmm)

The Gmm represents the density of an asphalt mixture, excluding the air voids. ASTM D2041 provides the procedure for determining the Gmm for a loose asphalt mixture. The determination of Gmm is essential for determining the air voids in a compacted asphalt mixture. Moreover, it is used to determine the amount of bitumen absorbed by the aggregates in the asphalt mixture.

Table No. 7 displays the maximum specific gravity of the studied asphalt mixture. We can notice that the value of Gmm is similar, with a minor difference. This finding confirms that the use of modified bitumen doesn't impact the volumetric characteristics of asphalt mixtures.

Voids in mix

Voids in mix (VIM) are the air pockets between the mixture-coated aggregates in the compacted asphalt mixture. VIM can be determined by using the following equation:

$$VIM = \frac{Gmm-Gmb}{Gmm} * 100\% ----01$$

Abu Dhabi specification (ADQCC) specifies the range of air voids for different asphaltic concrete mixes, as displayed in Table No. 3. The air void requirement is mandatory. The compacted asphalt mixes must contain a specific amount of air voids as specified in the specification. Air voids are important to allow for further compaction of compacted asphalt mixtures under traffic loads, which ensures the flexibility of road pavement and positively impacts the performance and durability of asphalt pavements. Therefore, some specifications limit the degree of compaction to 101.50% of the marshal density to ensure the formation of air voids in compacted mixes. The amount of air voids should be controlled; a higher amount of air voids can result in a permeable road pavement, which can result in the ingress of harmful water and air. The VIM for asphalt mix made with modified bitumen can be calculated by using equation no. 1, the result of which is presented in table no. 7. The VIM for wearing course made with unmodified bitumen is 5.5%, while the VIM for asphalt made with modified bitumen is 6.10%.

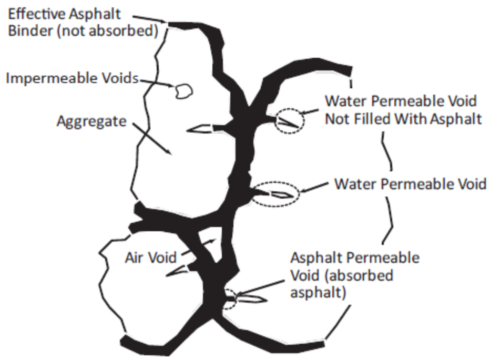

Figure 2

Voids in mineral aggregates (VMA)

Voids in mineral aggregates are the voids between aggregates, including the air pockets and the effective asphalt content. The amount of voids in mineral aggregates should be sufficient to accommodate asphalt binder and the specified in-place-air voids. Low VMA values will result in reduced VFA and VIM, which will negatively impact the asphalt mixture's performance and durability. Asphalt bleeding may happen for mixtures with low VMA. Computing the VMA can be performed by simply subtracting the volume of aggregates determined by bulk specific gravity from the bulk volume of compacted asphalt mixes [3]. Table No. 03 specifies the minimum requirement for VMA for different asphaltic concrete courses according to the Abu Dhabi specification (ADQCC). We can notice that the requirement as per Table No. 03 for VMA is more for wearing courses and for asphalt courses subjected to high volumes of traffic. The increase in VMA due to traffic volume can be interpreted as the need for a higher volume of voids to accommodate bitumen and the compaction due to traffic load. The values of VMA presented in Table No. 07 are similar, with a slight difference.

9.2.3 Voids filled with bitumen

The voids filled with bitumen in a specific asphalt mix should be balanced. Voids filled with bitumen represent the portion of voids between aggregates that are filled with bitumen binder. Low VFB can significantly reduce the bonding between aggregates. Furthermore, the harmful weather and moisture effects may cause the stripping of binder films from aggregates [8]. The low VFB will reduce asphalt pavement performance and may cause premature aging of asphalt pavement. On the other hand, high VFB will result in a tender mixture with low stability. Therefore, the engineer should ensure that VFB is within the acceptable limit to prevent any adverse effects on the constructed pavement.

Table 7

Asphalt mix	Property	Sample 01
Wearing course-40/50	Gmm	2.717 g/cc
	VIM	5.5%
	VMA	14.10%
	VFB	61.0%
Wearing course-PG82-22	Gmm	2.705 g/cc
	VIM	6.1%
	VMA	15%
	VFB	59.40%

9. Conclusion

In this paper, the strength and volumetric properties of asphalt mixes made with modified and unmodified bitumen are tested to verify the changes that occur due to incorporating modified bitumen into the asphalt mix. The test result has shown a considerable increase in the modified bitumen softening temperature. Furthermore, the marshal stability test of asphalt mixes made with modified bitumen has shown an increase of almost 9%. The use of modified bitumen (PG82-22 in this study) has shown a considerable improvement in the strength properties of asphalt mixes. The volumetric properties of tested asphalt mixes have shown no significant difference. The volumetric properties will be significantly impacted by aggregate gradation and bitumen content. The tested asphalt mixes have similar aggregate gradation and bitumen content, which explains the similar test results.

However, the use of PMB alone is not sufficient to produce a high-performance and durable mix. The production of durable asphalt mixes will depend on many factors, such as careful selection of aggregate grades, bitumen content, volumetric properties, proper manufacturing of asphalt mixes, and the proper laying and compacting of asphalt mixes.

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