Evaluation of HMA Modified with Titan Polymer

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ABSTRACT

Improving the quality of the road pavement and ensuring the safety of the drivers on the road are issues of paramount importance. Cracking and rutting are two of the most common damages that occur to asphalt pavement due to environmental effects and traffic. Utilizing a modified binder is a solution for improving the pavement's resistance to these damages and enhancing pavement durability. This study investigates the performance of Hot Mix Asphalt (HMA) modified with Titan7205 polymers and then compares it with that of a control mix of modified HMA with Styrene-Butadiene-Styrene (SBS) or crumb rubber (CR). Two percentages of Titan7205 were utilized to find out which dose provided better performance. HMA was prepared by adding polymers with different percentages (3% and 5% Titan7205, 4% SBS, and 8% CR). After preparing the samples, they were tested (unconditioned and AASHTO R30) for Dynamic Shear Rheometer (DSR) testing, Cantabro Mass Loss (CML), Tensile Strength Ratio (TSR), and Indirect Tensile Tension (IDT). The results showed that the mix with 3% of Titan7205 has a similar or better performance than the mixes with the other polymer additives utilized in this study.

Keywords-polymer; SBS; Titan 7205; Hot Mix Asphalt (HMA); crumb rubber

I. INTRODUCTION

During the last quarter of the century, road networks in the Kingdom of Saudi Arabia are growing exponentially. It is inevitable to use durable asphalt mixtures to increase pavement quality, improve drivers' protection and comfort, decrease pavement damage, and decrease maintenance costs. One of the most common damages to asphalt pavement is fatigue cracking, which occurs as a result of the daily traffic and passing load. The use of a high-quality or modified asphalt binder is a method to improve and strengthen asphalt pavement and make it more able to resist cracking and rutting. To evaluate asphalt performance, numerous mixture tests can be used.

Authors in [1, 2] conducted a study on asphalt mixtures to investigate their capability to capture damage of single and combined effects of the environment (oxidation, moisture, freeze-thaw). Different laboratory conditions were utilized, including single or combined environment effects of oxidation, moisture, and freeze thaw. Four asphalt mixtures were utilized with NMAS 12.5mm. The results showed that CML was better capture damages of environment on asphalt mixtures. Asphalt additives are commonly classified as elastomers and plastomers [3-6]. Titan additive is considered a plastomer asphalt binder additive, while CR and SBS additives are considered elastomer asphalt binder additives [3-11]. Since the '80s, bitumen has been modified by the addition of polymers that help reduce rutting and cracking, such as SBS and CR [11-13]. Also, many researchers have studied the preparation technology of bitumen using modified materials such as SBS and CR. It has been found that SBS and CR could raise high-temperature stability and possess the best aging resistance [14-16]. Authors in [17] studied the performance of bitumen and asphalt mixtures modified by CR and SBS. The test results showed that it is necessary to use twice as much CR as SBS to reach the same performance as SBS. Authors in [18] investigated the performance of asphalt mixtures modified with SBS polymer against low-temperature cracking. A Beam Rheometer (BBR) test was used with the trimmed specimens at different temperatures. The results showed that the SBS modified asphalt binder performed better in resisting low temperature cracking compared to the unmodified binder. Authors in [19] stated that SBS additive is one of the most widely used bitumen modifiers because it enhances the mixture's rutting and fatigue resistance and mitigates its susceptibility to temperature variations. Authors in [20] explored the experimental methods of polymer-modified asphalt, including SBS, with different proportions to systematically ensure the quality and requirements of construction engineering in asphalt pavement. The results showed that SBS improved the high temperature performance of asphalt and could be used to increase its compressive strength.

CR is frequently used as a modifier to improve asphalt properties such as rutting and fatigue [21, 22]. The Virginia Department of Transportation (VDOT) conducted research to see the effects of CR addition on the moisture susceptibility of asphalt mixtures [23]. Modified Lottman and the Texas Boiling Water Test were used for the evaluation of asphalt mixtures. The results showed that CR modifiers could improve asphalt mixture stripping and moisture susceptibility. CR has been used successfully for improving the mechanical characteristics of HMA mixtures, where it was observed to improve the laboratory performance of mixtures against rutting, cracking, moisture damage, and oxidation [24].

Titan materials have different effects on HMA depending on their type and properties. The Titan additive has been shown to reduce harmful emissions from road paving by approximately 82% and the amount of fuel required in a mixture by 13% [25]. Authors in [26] investigated the effect of oxidized Titan7686 polymer on the rheological and performance properties of SBS modified bitumen with 0.5% by weight control binder. Indirect tensile strength, resilient modulus, and DSR test were performed to investigate the binder characterization. The results of the modulus of elasticity test indicated that the addition of the Titan7686 polymer enhanced the response of the modified bituminous mixtures under repeated loading, while it was observed that the MR value respectively increased by 11%, 20%, and 16% at 25°C, 35°C, and 45°C compared to the SBS bitumen mixture. Also, there was an increase in the value of the TSR test compared to the SBS. On the other hand, it was observed that the complex modulus, shear modulus, and loss modulus of Titan7686 are higher than that of SBS. Authors in [27] investigated the negative effects of wax within bitumen from different sources to determine the wax content and the type of polymer that would be best for the needs of refineries in different countries [27]. Temperature performance, fatigue cracking, and rutting were evaluated using dynamic shear tests, zero shear viscosity tests, and multiple stress creep recovery tests. Titan7686 generally improved the rutting and fatigue cracking properties of waxy bitumen. Depending on the asphalt mixture materials, Titan can reduce the amount of additive required by around 30% and help reduce rutting issues. Asphalt binders play an important role in the performance of resilient sidewalks when exposed to high traffic loads and harsh environmental conditions [28]. Some tests were conducted to study the influence of the physical and rheological properties of asphalt binders using polymers, most notably SBS, Polybilt, Titan7686, and Titan7205. The results showed that adding enhancers, especially Titan7205, improved the performance of the asphalt mixtures. There is a lack of information and research on the performance of Titan7205 when used with HMA, and the current research fills this gap.

II. MATERIALS AND METHODS

Table I shows the properties of the materials used for the asphalt mix, the gradient, the bitumen ratio, and the type of additive used. In this study, asphalt samples with a diameter of 150mm and a height of 95±5mm were prepared for mixture testing. The air void (Va) range of specimens used is 7.0±0.5% according to AASHTO T166, and a total of 125 specimens were prepared with 3 types of polymers in various dose percentages. Each polymer has been given a symbol with different percentages: neat bitumen (M0), 4% SBS (M1), 3% Titan7205 (M2), 5% Titan7205 (M3), and 8% CR (M4). Table II shows the physical appearance of each polymer type.

TABLE I. MIXTURE PROPERTIES

Mixture ID	M0	M1	M2	M3	M4
P_b (%)	5.3	5.3	5.3	5.3	5.3
Additive	None	4% SBS	3% Titan7205	5% Titan7205	8% CR
P25mm (%)	100	100	100	100	100
P19.0mm (%)	100	100	100	100	100
P12.5mm (%)	95.1	95.1	95.1	95.1	95.1
P9.5mm (%)	81.3	81.3	81.3	81.3	81.3
P4.75mm (%)	53	53	53	53	53
P2.36mm (%)	38	38	38	38	38
P1.18mm (%)	25.1	25.1	25.1	25.1	25.1
P0.60mm (%)	18.9	18.9	18.9	18.9	18.9
P0.30mm (%)	15	15	15	15	15
P1.5mm (%)	8.5	8.5	8.5	8.5	8.5
P0.075mm (%)	5.4	5.4	5.4	5.4	5.4
NMAS (mm)	12.5	12.5	12.5	12.5	12.5
VMA	14.4	15.3	15.4	15	14.5
V_F (%)	49.4	55.3	54.2	53.1	52.5
G_b	1	1	1	1	1
G_{sb}	2.7	2.7	2.7	2.7	2.7
P_s	94.7	94.7	94.7	94.7	94.7
G_{se}	2.8	2.7	2.8	2.8	2.7
P_{ba}	1.1	0.8	0.8	0.9	0.8
P_{be}	4.2	4.4	4.4	4.4	4.5
D_P	1.2	1.2	1.2	1.2	1.1

Pb = total binder content-mix mass basis, PXXmm= percent passing a XX mm sieve, NMAS = nominal maximum aggregate size, VMA = voids in mineral aggregate, VF = Voids Filled, Gb = specific gravity of the asphalt binder, Gsb= bulk specific gravity of the aggregates, Ps= aggregate percentage, Gse = effective specific gravity of the aggregates, Pba= % by mass of the absorbed asphalt binder on aggregate mass basis, Pbe = % by mass of effective asphalt binder on mix mass basis, DP= Dust Percentage.

TABLE II. ADDITIVE PROPERTIES

Property	SBS	Titan 7250	CR
Density	0.90 g/cc	0.93 g/cc	1.32 g/cc
Viscosity	400 – 4320 cps	450 cps	165 - 237 cps
Product form	Prill	Prill	Granule
Size	4-6mm diameter	2-3mm	0.2-0.4mm

A. Laboratory Conditioning

AASHTO R30 laboratory conditioning protocol was utilized to investigate HMA performance over time and simulate long-term aging effects. The specimens were cooled to room temperature before aging and then were placed in an oven at 85±3°C for 120±0.5h (Figure 1). Then, the oven was turn off, the oven doors were opened, and the test specimens were allowed to cool to room temperature, something that typically took about 16 hours.

Fig. 1. Oven conditioning of asphalt mixtures.

B. Binder Testing-Dynamic Shear Rheometer Testing (DSR)

Asphalt binder is a viscoelastic material, i.e. it behaves as both an elastic and viscous material at the same time. DSR testing was performed at high temperatures within a range of 64°C to 88°C with a 25-mm plate as per AASHTO M315 (Figure 2).

Fig. 2. The DSR device.

C. Mixture Testing

1) Cantabro Mass Loss Testing (CML)

CML testing was performed on specimens with 150mm diameter and 95±5mm height. The specimens were conditioned in the air at 25°C before testing. Compacted specimens were tumbled each in turn in a Los Angles (LA) Abrasion Drum (Figure 3) without steel spheres for 300 rotations. The difference in the specimens mass before (m_1) and after (m_2) testing was determined according to (1) and referred to as Mass Loss (ML).

$$\mathrm{ML} = \frac{m_1 - m_2}{m_1} \times 100 \quad (1)$$

2) Tensile Strength Ratio (TSR)

The TSR test was performed according to AASHTO T-283 to evaluate the moisture susceptibility of asphalt mixtures. The specimen size was 150mm diameter and 95±5mm height. The samples were divided into two groups: the first group was placed at environment conditions at 25°C for 2h before dry condition testing. The second group was conditioned in a water bath at 60°C for 24h and then at 25°C for 2h before testing.

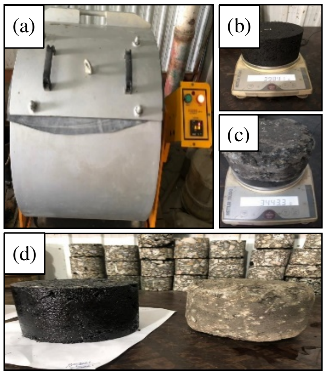

Fig. 3. Mixtures in the dynamic shear rheometer device (a) Abrasion drum, (b) CML before testing, (c) CML after testing, (d) CML before and after testing.

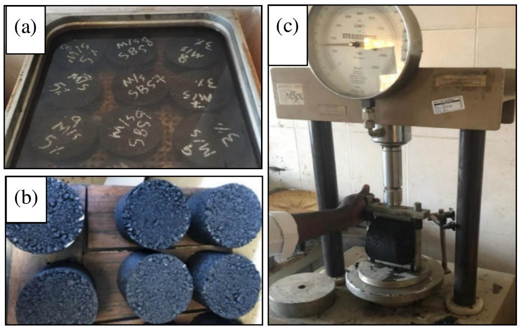

Fig. 4. a) Wet samples, (b) dry samples, (c) IDT testing.

3) Indirect Tensile Tension (IDT)

The IDT test was used to determine the tensile strength (S_t) of the mixture specimens (Figure 5). The IDT specimens had 150mm diameter and 95 ± 5mm height. The specimens were air-conditioned at 25°C before testing. Tensile strength at failure (S_t) was measured according to (2):

$$S_t = \frac{200 \times P_{max}}{\pi \times t \times D} \quad (2)$$

Fig. 5. IDT instrument.

III. RESULTS AND DISCUSSION

Table III shows the test results for unconditioned and AASHTO R30-conditioned mixtures. The value for a given test method represents the average of the measurement of 3 samples replicated for the mixture test.

TABLE III. RESULT OF MIXTURE AND BINDER TESTING

Condition	MIX	IDT (kPa)	TSR (%)	CML (%)	DSR (°C)
Unaged	M0	879.36	54.26	10.52	64
	M1	877.90	80.50	18.39	88
	M2	781.47	86.38	14.17	76
	M3	937.97	78.03	13.98	82
	M4	765.38	82.43	15.12	70
AASHTO R30	M0	967.29	57.44	14.82	—
	M1	2192.97	41.32	22.69	—
	M2	1566.42	55.11	21.30	—
	M3	2270.16	38.72	23.41	—
	M4	2166.28	44.47	19.14	—

1) Statistical Assessment of the Mixtures

Table IV shows a statistical assessment of the obtained results that are mentioned in Table III for the 5 mixtures. The values of Δ are calculated by subtracting the results of each mix (M1, M2, M3, and M4) from M0. The P-values were obtained from the statistical analysis of the *t*-test, which indicates the significance of the difference between the sample's results. If the P-value is less than 0.05, there is a significant difference between the results. If it is higher than 0.05, then there is no significant difference.

2) Dynamic Shear Rheometer (DSR)

In DSR testing, it appears that with the addition of polymers, the failure temperature rises. M3 has a failure temperature of 82°C, and M2 one of 76°C. This concludes that the failure temperature of the binder increases with an increase in the percentage of Titan7205. Also, M1 has a higher failure temperature (88°C) than M4. Comparing the additives to M0, they all show an increase in the failure temperature. Overall, the addition of polymers to HMA can improve its rutting resistance.

3) Indirect Tensile Strength (IDT)

Figure 6 shows the test result of IDT. Comparing M0 to the other additives for unconditioned, the results show that M0 has a similar or higher S*t* value than the other additives. Subsequently, M2 and M4 have similar performance, while M3 shows a slightly higher S*t* value. All modified HMA in the study display a higher S*t* value compared to M0 for AASHTO R30 conditioning. Comparing the additives with each other, the S*t* value of M2 is less than that of the other additives. In addition, there is statistical difference between M2 and the other additives (M1, M3, and M4). Comparing M2 with M3, M3 had higher S*t* value, while M2 still had higher S*t* value than M0. Overall, when comparing M0 to other additives, M0 shows similar or less crack resistance in most cases. Conditioned mixtures exhibit higher S*t* values than the unconditioned mixtures.

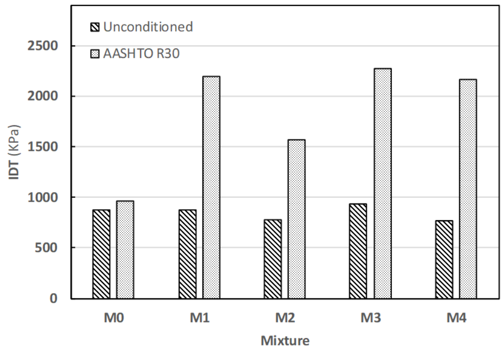

Fig. 6. Comparison of the unconditioned with AASHTO R30 conditioned IDT.

TABLE IV. STATISTICAL ASSESSMENT OF MIXTURES

Condition	MIX	IDT (kPa)				TSR (%)				CML (%)			
		Δ (Mi-M0)	P-value	T-test	Significant differ	Δ (Mi-M0)	P-value	T-test	Significant differ	Δ (Mi-M0)	P-value	T-test	Significant differ
Unaged	M1	-1.49	0.82	B	No	26.24	<0.01	AB	Yes	7.87	<0.01	A	Yes
	M2	-97.89	<0.01	C	Yes	32.13	<0.01	B	Yes	3.65	<0.01	C	Yes
	M3	85.62	<0.01	A	Yes	23.77	<0.01	B	Yes	3.46	<0.01	C	Yes
	M4	-113.98	<0.01	D	Yes	28.17	<0.01	A	Yes	4.60	<0.01	B	Yes
AASHTO R30	M1	1225.67	<0.01	AB	Yes	-16.12	<0.01	C	Yes	7.87	<0.01	B	Yes
	M2	599.12	<0.01	C	Yes	-2.33	0.18	A	No	6.49	<0.01	C	Yes
	M3	1302.87	<0.01	A	Yes	-18.72	<0.01	C	Yes	8.59	<0.01	A	Yes
	M4	1198.99	<0.01	B	Yes	-12.97	<0.01	B	Yes	4.33	<0.01	D	Yes

4) Tensile Strength Ratio (TSR)

All the additives exhibit a higher value of TSR than M0, which means that they all improved the moisture resistance of the mixture. M1, M3, and M4 show similar performance, while M2 shows slightly better moisture resistance. Also, M2 shows a statistically significant difference compared to the other additives. Considering AASHTO R30 conditioning, it appears that when comparing the additives with M0, the control M0 has similar or better moisture resistance after AASHTO R30 conditioning. M2 has better moisture resistance after AASHTO R30 conditioning than the other additives. Referring to Table IV, M2 has a significantly higher TSR value, while its TSR value is statistically not significantly different from that of M0. Overall, M0 shows similar performance before and after conditioning. All the additives show higher moisture resistance before conditioning and lower moisture resistance after conditioning. M2 has a higher TSR value than other additives in unconditioned and AASHTO R30 conditions. For unconditioned mixtures, M2 shows better performance than M0, while it shows similar performance after conditioning to M0.

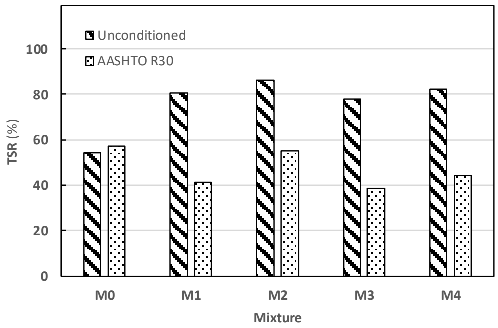

Fig. 7. Comparison of the Unconditioned with AASHTO R30 Conditioned TSR.

5) *Cantabro Mass Loos (CML)*

Referring to Figure 8 for the unconditioned case, all additives have a higher CML value than M0, which means the additives reduce mixture durability. Also, there are statistically significant differences between M0 and the other additives. M1 has lower durability compared to the other additives, while M2, M3, and M4 show similar performance. All additives have a CML value higher than M0 after AASHTO R30 conditioning. M4 is slightly more durable than the other additives followed by M2. The CML value of M2 is statistically significant different compared to other additives. In summary, AASHTO R30 mass loss values increase more than the unconditioned ones, which is logical given that the durability of asphalt mixtures should decrease over time with aging. All the additives have a CML value higher than M0 either unconditioned or after AASHTO R30 conditioning. In most cases, M2 shows similar or better performance compared to the other additives.

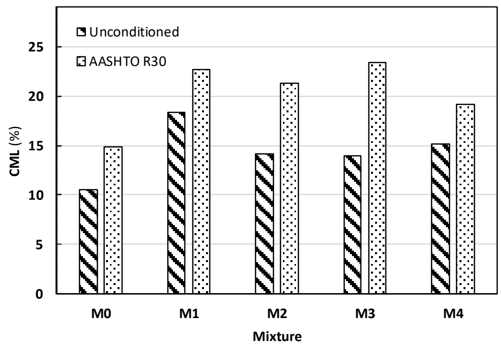

Fig. 8. Comparison of the unconditioned with AASHTO R30-conditioned CML.

6) *Cost Comparison*

The comparison of polymer additive prices is conducted to show the economic impact of their utilization. Two supplier's prices were used, and the prices were averaged. Table V shows the price per ton for each additive. Crumb rubber has the lowest price, and SBS the highest. The price of the Titan7205 is slightly lower than that of the SBS, which makes it a preferable choice over the SBS. Comparing the performance of Titan7205 to other additives with respect to price, Titan7205 could be another alternative to be used with HMA.

TABLE V. ADDITIVE PRICE COMPARISON

Additives	Unit	Price (SR/ton)
SBS	1 Ton	9000
CR	1 Ton	2750
Titan 7205	1 Ton	8000

IV. CONCLUSIONS

This article's objective was to evaluate the performance of Hot Mix Asphalt (HMA) modified with Titan7205 polymers. Two percentages (3% and 5%) of Titan 7205 were utilized in this study and showed similar or better performance compared to other mixtures (M0, M1, and M4). Both percentages of Titan 7205 (M2 and M3) met the required failure temperature in this study (72^{o}C). Generally, the addition of polymers to HMA improves the rutting resistance. Both Titan 7205 mixtures (M2 and M3) showed similar or better cracking resistance and better moisture resistance.

Considering the overall performance and economic viability of the mixtures, Titan7205 could be an alternative additive to be used in HMA. Subsequently, additional investigation is recommended to better understand the performance of Titan7205 with HMA.

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