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The Properties of Bitumen Modified With Wax

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ABSTRACT

This study investigated the fundamental properties of bitumen (binder) penetration 80/100 grade modified with an additive Sasobit wax. This additive is a long-chain aliphatic hydrocarbon and termed as S in this study. The properties evaluated included the rheological properties of the modified bitumen. The properties were evaluated using dynamic shear rheometer (DSR), rolling thin film oven (RTFOT), pressure aging vessel (PAV), and Viscometer, Penetro meter, Ring and Ball test. Results from the study indicated that the effect of S on the binder depends on the quantity of the additive used and test temperature. The general trend is with an increase in the additive the binder viscosity decreases at high temperature, however at low temperature the binder becomes more stiffen, this results in considerable reduction of the penetration and increasing the softening point. Adding S to the binder showed considerable increase in complex modulus and decrease phase angle of the modified bitumen at both medium and high temperatures, with minimal effect on the aging of the binder.

Keywords: *Bitumen, viscosity, Sasobit wax, dynamic shear rheometer, and pressure aging vessel*

1. INTRODUCTION

Bitumen is a black compendious substance natural derived from the fractional distillation of crude oil or in a natural form, it is composed of high molecular weight hydrocarbons and is particularly suitable for road construction [1]. Its behavior depends on temperature and loading time, as at room temperature bitumen is soft with a density of 1 g/cm3, but at low temperature it becomes brittle and at high temperature it flows like a viscous liquid [1-2]. Recently commercial wax such as S is added to bitumen in order to improve both the mechanical and rheological properties. The additive is a wax with long-chain aliphatic hydrocarbon chain of range CH_{40}-CH_{100} [3-4].

The rheology simply means the flow of fluids and deformation of solids under stress and strain. The study of the rheological properties enables the prepare understanding of the performance of bitumen with or without the additive [4]. The mechanical test normally conducted on bitumen is to ascertain the consistency of the binder, as it's been used in highway construction [1]. The performance of asphalt pavement is mainly governed by the properties of the binder, and it exhibit's a visco elastic behavior hence in pavement when exposed to high temperature permanent deformation (Rutting) takes place along the wheel path of the pavement. On the other hand, bitumen in pavement at low temperature exhibits brittleness and pavement cracking occurs [5].

However, in view of these factors, environmental awareness and the need to improve on the binder properties makes it imperative to modify bitumen used in road construction. The modification of bitumen with S has enable the reduction of the mixing and compaction temperature that translates to the reduction in emission of green house gases and energy saving termed as warm mix asphalt (WMA), this involves mixing the asphalt binder at a relatively lower temperature, typically the mixing temperatures of warm mix asphalt ranges from 110 to 130^{o}C compared to 170^{o}C for the conventional mixing temperatures for hot mix asphalt (HMA) and it is compacted at a temperature of 30-40^{o}C less than the compaction temperature of 130^{o}C for HMA [6-7]. The WMA technology has the potential to significantly reduce mixing temperatures, improve compaction, extend the paving season, reduce fuel consumption, and reduce emissions [2]. Its benefits are reduction in energy consumption during production and reduced emissions during production and placement this is achieved with the lowering of viscosity and increase mobility of the binder with the addition of the additive such as S [3].

In this study a commercial additive S was used to lower the viscosity of the binder at high temperature, making it less susceptible to high temperature damage, the decrease in viscosity of the binder in turn reduces the working temperatures by 45ºC. It also has a congealing temperature of about 100ºC and is completely soluble in binders at temperatures lower than 110ºC, at temperatures below its melting point; it forms a crystalline network structure in the binder that is reported to provide added stability [4]. Investigating the viscosity and rheology of the binder is of great importance as compaction, which is the most crucial stage in the construction of bituminous road pavements depends on fluidity of the binder, viscosity also provides, improve resistance to cracking and deformation of the pavement [8]. It should be noted that both temperature and pressure exert an important influence on bitumen viscosity and consequently, on its workability and road performance. The penetration and

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softening point test predicates the consistency of the binder, and its classification.

In this study the compatibility of bitumen and the additive was investigated based on the storage stability test D13399 [9], the difference of the softening point temperatures of the top and bottom to be adequate less than 5°C, using the ring and ball test indicating that they are compatible even in storage ASTM Standards. Early research and marketing efforts have mainly focused on the environmental benefits and the reduced energy consumption of the technology not as much on the viscosity, rheology and consistency of the modified binder at mid-range and high temperature.

2. MATERIALS AND METHODS

For this study twenty-four samples of two different bitumen PEN 80/100 grade labeled PM and EX obtain from the UTM highway laboratory (unknown source), and pellets of sasobit wax was used for the study. Each sample contains 300grm of bitumen PEN80/100 was obtained from the container after heating at 150°C for 3hrs, the additive was added at test quantities and a mechanical stirrer at 800rmp for 15min was used to mix it up. The various test samples were evaluated in terms of their mechanical and rheological properties. Also the temperature susceptibility of the modified binder was determined based on the penetration index (PI) by using the results obtained from penetration and softening point tests, based on equation developed by Pfeiffer and Van Door mal;

a. Penetration and Softening Point

The penetration grade of the neat bitumen with and without S was investigated using the penetro meter in accordance with ASTMD5-97 specification, while the softening point of the various test samples was determined using the ring and ball test in accordance to ASTM D36-95.

$$P.I = \frac{1952 - 500\log Pen_{25^oC} - 20SP}{50\log Pen_{25^oC} - SP - 120}$$

Where SP is the softening point and Pen_{25^oC} is the penetration at 25°C

b. Viscosity

The viscosity of the binder was measured using the brooks field viscometer (ASTM D 2170), the equipment was used to measure the viscosity characteristics of the neat and modified binder PEN 80/100. This test determined whether the additive decreases the viscosity of the binders used in the study, which consequently depends on the test temperatures (in the range 75-150 °C). The viscosity of each bitumen sample with and without S was measured at various test temperatures and at a shear rate of 6.8/s. This shear rate was selected because it conforms to the rotational speed of 20rpm with the Brookfield Spindle 27 recommended for Super- pave (SHRP).

c. Aging

The short-term aging test of the binder was conducted using RTFOT (ASTM D 2872), at 163 °C for 85min, the long-term aging was performed using PAV (ASTM D6521-05) at 100 °C for 20hrs with 2.1mpa. The aged samples were evaluated by measuring their rheological properties.

d. Rheology

The bitumen rheological properties were performed using dynamic shear rheometer (DSR), on temperature sweep with a frequency of 1.59Hz and 1mm gap. The values of the rutting resistance factor (G*/ sin δ) and other parameters were recorded. The bitumen as a visco-elastic material has two components comprising the complex shearing (G*) modulus, the in-phase (G') storage modulus or elastic component and the out of phase (G") loss modulus or viscous component. Since these two moduli are vectors, the angle between them will define the elastic and viscosity of the binder and its termed as the phase angle (δ).
Some physical-chemical characteristics of the bitumen used in this study can be seen i
Tables 1 below;

Table 1: Characteristics of binder

Test	ASTM codes	Results	Specification
Penetration	D5-97		
(dmm)		87	80-100
EX		93	
PM	D36-95		
Softening point			
R&B (°C)		46.5	46-50
EX		47	-
PM	D4402		
Viscosity at		0.40	
(135°C)		0.30	
EX	D1754		
PM			
RTFOT		0.1	0.5(max)
Change of mass		0.2	
EX			-
PM	D70	1.030	
PAV		3	5(max)
Specific gravity			
Storage stability	D13399	-0.9	-1 to +1
(°C)		0.8	
Penetration			
index (PI)			
EX			
PM			

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3. RESULTS AND DISCUSSION

a. Effect of the Additive on Binder Viscosity

The viscosity of the binder is normally investigated interns of the kinematic viscosity (KV) at 135°C and dynamic viscosity (DV) at 60°C,but for this study the DV was tested at 75°C as the modified binder was so stiff, making it impossible for the brooks field spindle to rotate. Table 2 shows the measure values for both DV and KV of the warm mix binders. For both binder PM and EX with or without the additive, they indicated increase in viscosity at low temperature, but it was also observed that the binder with greatest percentage of the additive produces the highest viscosity value as can be seen Figure 1;

Table 2: Results from viscosity test

Binder	Temperature (°C) 75	110	135	150
	Viscosity (cp)			
PM	4100	2900	400	200
PM +1%S	4510	1820	400	200
PM +2%S	4110	1700	300	180
PM +3%S	4230	1500	200	150
PM +4%S	4500	1500	100	100
PM +5%S	4700	1600	100	100
EX	4000	2900	300	200
EX +1%S	3910	1820	300	180
EX +2%S	5000	1700	200	150
EX +3%S	5250	1500	200	150
EX +4%S	5500	1500	100	100
EX +5%S	5700	1600	100	100

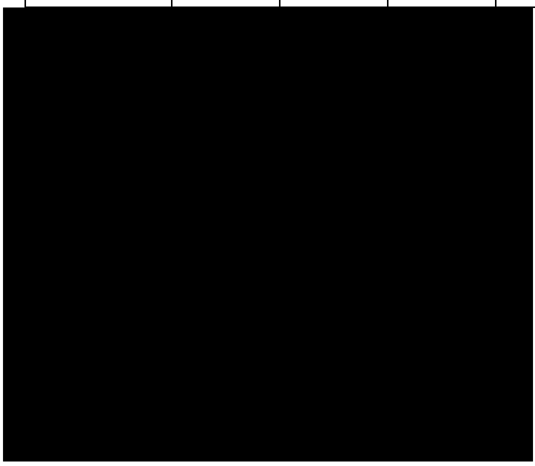

Fig 1: Viscosities Pm Binder With or Without S at Various Temperatures.

For the binder EX with or without S showed greater values of viscosity as compared to binder PM indicating that the former is more viscous at low temperature compared with the former as can be seen in figure 2. It was observed that for both binders with S at high temperatures there was a decrease in viscosity, this could be attributed to the presence of the additive, as seen in Figure 4 below;

Fig 2: Viscosities ex Binder With or Without S at Various Temperatures

The results obtained from the viscosity test indicated binders with highest content of the additive for both modified binder PM and EX producing least viscosity, this could be attributed to the S (depressant) as could be seen in figure 4below;

b. Effect of S on the aging, Penetration and Softening points

Tables 3 showed the measured values for penetration and softening points of the aged and unpaged warm mix binders. For both the binders PM and EX their penetration (P) reduces with an increase in the additive especially after aging. While for the softening point (S.F) for both binders showed an increase in S.F, this could be attributed to hardening of the warm mix binders as can be seen below;

Table 3: Empirical Tests

Binder + S	Aging	Penetration (dmm)		Ring and Ball Softening point (°C)
		at 25 °C	at 10 °C	

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+ PM 0%	Unaged	85	43	46
+1%	-	81	40	47
+2%	-	55	25	52
+3%	-	40	15	69
+4%	-	30	10	78
+5%		22	7	86
EX + 0%	Unaged	79	40	47
+1%	-	79	40	47
+2%	-	52	24	60
+3%	-	40	16	79
+4%	-	35	12	82
+5%		20	6	91
PM+0%	RTFOT-PAV	33	9	71
+1%	-	30	8	71
+2%	-	22	5	85
+3%	-	18	3	89
+4%		10	2	96
+5%		5	nd	98
EX+0%	RTFOT-PAV	30	9	70
+1%	-	30	8	71
+2%	-	23	6	86
+3%	-	20	5	89
+4%	-	12	2	93
+5%		6	Nd	99

nd= not detectab

c. Effect of additive on the rheological properties of the binder

The table 4 presents the dynamic shear rheo meter test results for un aged warm mix binders used in this study. The results showed higher values of complex modulus (G*/sinσ) at midrange and high temperature for unmodified binder PM and EX compared to the modified, indicating better resistance to rutting.

Table 4: Dsr Test for un Aged Binder

Unaged-binder	Temperature (°C)			
	46	52	64	76
	G*/sin σ at 1.59Hz (kpa)			
PM	7.62	3.70	1.34	0.66
PM +1%ST	5.33	2.92	1.23	0.64
PM +2%ST	4.77	1.85	1.01	0.45
PM +3%ST	4.30	0.98	0.94	0.29
PM +4%ST	2.52	0.09	0.65	0.22
PM +5%ST	0.90	0.04	0.04	0.09
EX	8.95	4.90	2.10	0.95
EX +1%ST	6.45	3.10	1.75	0.78
EX +2%ST	5.71	1.95	1.05	0.55
EX +3%ST	4.95	1.01	0.98	0.32
EX +4%ST	2.87	0.95	0.68	0.25
EX +5%ST	0.95	0.05	0.07	0.08

It was observed from the study that as the temperature increases the complex modulus of the binders' decreases relative to an increase in the additive as could be seen in Figure 3 below;

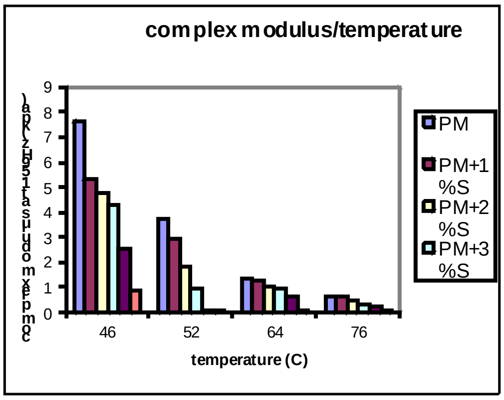

Fig 3: Complex Modulus of Un aged Binders

The Table 5 presents the dynamic shear rheo meter test results for aged warm mix binders used in this study. The results showed higher values of complex modulus (G*/sinσ) at midrange and high temperature compared to the un aged samples, indicating better resistance to rutting after aging.

Table 5: DSR test for aged binder

Aged-binder RTFOT-PAV	Temperature (°C)			
	46	52	64	76
	G*/sin σ at 1.59Hz (kpa)			
PM	13.44	4.95	3.94	1.66
PM +1%ST	10.60	2.65	2.23	1.04
PM +2%ST	8.20	2.85	2.01	0.85
PM +3%ST	6.20	1.98	0.94	0.49
PM +4%ST	4.82	1.09	0.65	0.22
PM +5%ST	4.42	0.04	0.04	0.09
EX	15.95	8.90	4.10	1.95
EX +1%ST	11.45	6.10	3.75	1.08
EX +2%ST	9.71	2.95	2.05	0.75
EX +3%ST	6.95	1.01	1.98	0.32
EX +4%ST	2.87	0.95	0.68	0.25
EX +5%ST	0.95	0.05	0.07	0.08

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From Figure 4 below it was observed that as the temperature increases the complex modulus of the binders' decreases relative to an increase in the additive after aging.

Fig 4: complex modulus of aged binders

4. CONCLUSSION

The global drive for improve and durable pavements taking into cognizance green sustainability of the environment, made it imperative to investigate the option of adopting warm mix asphalt (WMA) technology, as a viable option to the conventional hot mix asphalt (HMA) practice that requires high temperatures there by emitting noxious gases. In this study S was used as a bitumen flow improver or viscosity depressants, it melts at about 100^{o}C and reduces the viscosity of the binder at high temperature this is considered to be an advantage, providing a better resistance to rutting. Also the addition of S at midrange temperature indicated an increase in viscosity as the percentage of the additive was increased. As S is a wax, which recrystallizes in the binder on cooling, there by increasing the viscosity of the binder at lower temperatures, this enhances the flow of the binder and ease workability. At low temperature the additive S hardens the binder there by increasing its stiffness, the softening point, and decrease penetration. The short and long-term aging test indicated that with less than 3% S in the binder the stiffness control for fatigue and rutting conforms to SHRP. The modification of the binder improved workability, increase resistance to permanent deformation and fatigue, also at high temperatures the study indicated increase in complex shear modulus of the modified bitumen using DSR. As a result of the chemical changes, the mechanical properties of aged bitumen become more solid-like, as indicated by increased complex modulus and decreased phase angle.

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