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DETERMINATION EXTENSIONAL VISCOSITY AND CRACKING INDEX OF SULFURE WASTE MODIFIED ASPHALT CEMENT

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ABSTRACT

In the northern Iraqi provinces, cracking distress due to the variations in temperatures is occurred in most of paved roads with asphaltic materials. This type of distress results in alligator and longitudinal cracking, spallings due to temperatures variations.This research determined the index of cracking and extensional viscosity of sulfur waste/asphalt cement (SWMAC). Four dosages of sulfur waste were selected and mixed into 40-50 pent. grade asphalt binder. Physical tests including: penetration, ductility, softening degree, absolute viscosity, elastic moduli, temperature effects, ageing, index of cracking, extensional viscosity, and morphology assays were performed on SWMAC. SWMAC presents higher extensional viscosity, moduli of elasticity and durability traits with superior cracking resistance at low temperature.

KEYWORDS:Sulfur waste; Ageing; Index of Cracking; Extensional viscosity.

1. INTRODUCTION

In the northern Iraqi provinces, cracking distress due to the variations in temperatures is occurred in most of paved roads with asphaltic materials. This type of distress results in alligator and longitudinal cracking, spallings due to temperatures variations. Thus reduction in life of pavements is happening. Theerefore evaluation of the rheological trais of asphalt seems essential.Warm mix asphalt additives (WMAA) plays significant role in manufacturing desired binder and mixture characteristics [1]. Thus, chosen of WMAA type is importance and depends on bitumen. Different kinds of WMAA are available worldwide, such as natural zeolite (NZ), synthetic zeolite (SZ), sasobit, Evotherm, Terex-foaming, Cecabase, Asphamin [1].

Asphalt mixes containing different kinds and contents of polymers present good application for the design of asphaltic pavements [2-16]. Due to the higher cost of the polymer and solid waste disposal problem, a need for alternative, cheapest modifiers that nonetheless impart enhanced characteristics comparable with the using of expensive polymers.

Nineveh is one Iraqi city having Al-Meshrak state for manufacturing of sulfur. This state company produces between 20 and 25% sulfur waste (SW) from the total production. SW is a fine gray to green powder mainly composed of sulfur, carbon and ash. It consists of 88 to 90 percent sulfur, 10 to 12 percent carbon, and small amount of ash (0.1 percent). The SW specific gravity ranges between 2.03 to 2.215. In addition, SW represents an ideal modifier for asphalt due to its lower cost. However, the optimum SW dosage for each type of bitumen still needs to be determined. It is supposed that an interaction happens between the bitumen and the SW alters the SW/bitumen binder characteristics, thus enhance the pavement performance.

On the other hand, the rheological characteristics of SW/ asphalt are quite scarce. Some data were documented by [18]. Ahmed et al. [18] were mixed 40% SW into 60-70 penetration grade asphalt binder. It was found that the ductility value of virgin asphalt decrease by 44%, whereas, the penetration value was increased by 9.3%.

However, this study tries to calculate the (1) penetration at 25ºC (P25), ductility at 25 deg. C (D25), softening degree (Ring&Ball point), absolute viscosity at 21 deg. C (A.V), elastic moduli (Eb.), penetration index (PI.), oxidation (ageing), cracking index (CI.), and extensional viscosity traits of SW/asphalt cement (SWMAC), then the tests results are compared with the virgin asphalt, and (2) the extensional viscosity of SW/asphalt mix (SWMAM), and compared the tests results with virgin mixes.

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2. RESEARCH OUTLIES

Traditional traits (penetration at 25 deg. C, ductility at 25 deg. C, softening degree, viscosity at 21 deg. C, elastic moduli, % losses in weight due to effects of heat and air at 163 deg.C (ageing), ageing index, cracking index, temperature effects, morphology, extensional viscosity of SWMAC, and SWMAM were performed in the current research.

3. UTILISED MATERIALS AND TESTING PROCEDURES

3.1. Asphalt cement

Asphalt cement of 40-50 pentreation grade was utilised to produce SWMAC. Table 1 summarizes the tradintional asphalt properties.

Table (1): Physicochemical properties of asphalt cement

Trait	ASTM Designation No.	Test conditions & units	Result	SCRB limits [20]	ASTM limits [21]
Penetration	D5	25 deg.C,100gm,5	42	50-60	40-50
Softening	D36	R&B, deg.C	54	51-62	50-58
Ductility	D113	25 deg.C, 50	150+	>100	>100
Sp. gr	D70	25 deg.C/ 25 deg.C	1.053	-	1.01-1.06
Flash point	D92	COC, deg.C	263	-	>240
Loss on heat	D1754	5hr, l63 deg.C, %	0.25	-	0.2 max
Asphaltenes	D2006	%	32.65	-	-

3.2. SW modifier

The SW in powder form with four different dosages was blended into Iraqi asphalt cement (40-50 pen.). SW was blended with 40-50 pen. for 8-12 minutes at 150ºC using a mixer of 500 rpm [19]. Table 2 presents the SW traits.

Table (2): Physicochemical properties of sulfur waste

Element	Weight, %
Total sulfur	92.3
Combined sulfur with carbon	13.2
Free sulfur	79.02
Total carbon	7.63
Bitumen	0029
Ash as a pentonite	0.0693
Carbonized materials	20.985
Sp.gr.	2.03

4. DISCUSSIONS OF TESTING RESULTS

4.1. Physical properties

Table 3 presented the physical properties for SWMAC. The tests results show that SW has a significant effect on the physical properties as shown from the P25C, D25C and R&B values. 10%SWMAC present 83% higher P25C, 13% lower R&B than virgin asphalt. This reveals that SW varies virgin asphalt performance. This is due to the recrystalization of sulfur [19].

As can be seen in Table 3, 10%SWMAC satisfied the lowest limits of ≥100 cm set by SCRB [20] and ASTM [21] specifications.

Table (3): Physicochemical properties of SWMAC

% SW	P25C	D25C	$T_{R\&B}$,deg.C	A.V, 21deg.C (poises)
0.0	42.0	≥150	54.0	5.0×10^{6}
10	77	112	47	1.33×10^{6}
20	74.5	76	45.2	1.43×10^{6}
30	68	31.7	43.4	1.74×10^{6}

The viscosity at 21 deg. C in poises (A.V) of SWMAC was calculated utilizing shell graph. Table 3 presents the A.V and SW dosages. The results indicate that 10%SWMAC show 73.4% lower AV than 40-50 pen.

4.2. Elastic moduli

The elastic moduli (asphalt stiffness) of SWMAC were calculated utilizing Eq. No. 1 as depicted in the graph of Van der poel and as reported by [22], [23].

$$E_b = \left(\frac{1.157}{10^7}\right) * \tau^{\frac{1}{0.368}} * 2.718^{\frac{1}{PI}}\left(R\&B - T_{asph}\right)^5 \quad \text{.................................. (1)}$$

Where:

E_b= Elastic moduli of binder (N/sq.mm)

$T_{R\&B}$=Softening degree of the recovered binder (deg.C),

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T_{asph}= Temperature of the asphalt layer (deg.C),

PI.= PI. of the recovered binder, and

τ= Loading time (0.02 secs).

Equation 1 can be adopted when:

1/100 sec <τ< 1/10 sec,

-1 <P.I. < +1,

20deg.C < ($_{R\&B}$ - T_{asph})< 60deg.C.

$T_{aspha.}$ =25°C

Figure 1 presents that 10%SWMAC have 29.4% higher Eb. than 40-50 pen.

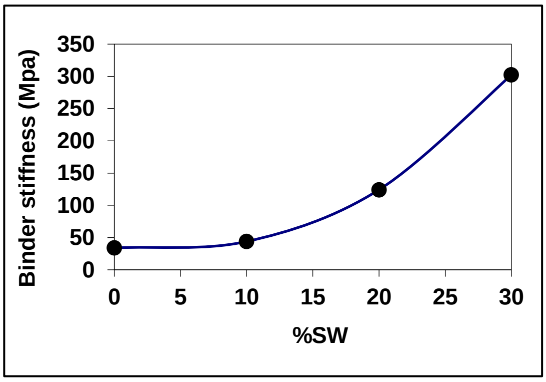

Fig. (1): Binder stiffness of SWMAB

4.4. Temperature Susceptibility

Temperature effect of SWMAC was obtained by P.I [Equation 2] [24]:

$$P.I = \frac{(0.2-5Z)}{(0.01+0.5Z)} \text{.......................}(2)$$

$$Z = \frac{(\log \text{pent.} @T - \log 800}{T - R\&B}$$

Where:

T = Testing temperature

R&B= Softening degree.

PI. test results, as depicted in Figure 2, reveals that the preliminary and extruded P.I values for 10%SWMAC lies between -1 and -0.5 as depicted in KSLA graph [23], which indicated the SWMA had normal temperature susceptibility.

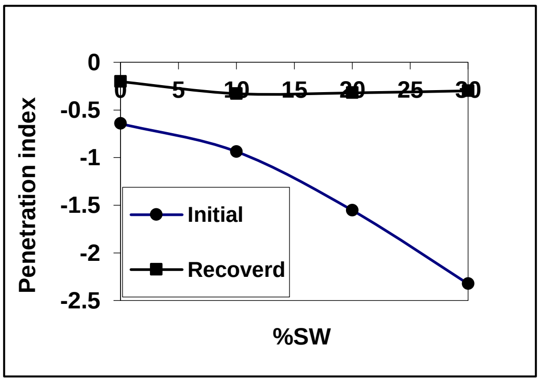

Fig. (2): Penetration index of SWMAB

4.3. Aging (Durability) Characteristics

P25, D25 and TR&B after thin film oven test (TFOT) were determined. Aging index (AI) = (residue P25/ P25) was also determined as hardening indicator. Table 4 shows the test results, including AI, aged softening point and aged ductility values measured on polymer-modified asphalt specimens. SWMAC presented lower AI than 40-50 pen. due to the recrystalization of SW, resulting in the brittleness of the resultant binders [19]. Examining Table 4 indicates that R&B of aged 10%SWMAC was increased by 10%, wheares, aged D25 was found to be greater than 100 cm (the min. value set by SCRB) [20].

Table (4): TFOT Characteristics of SW-asphalt binders

% SW	Residue P25	A.I.	Residue D25	$T_{R\&B}$, ° C	Loss of heat and air, %
0	37	0.88	142	56	0.025
10	7.5	0.097	100	61.5	1.526
20	4.5	0.06	11	70	2.7
30	3.0	0.044	1.5	79	3.423

Table 4 indicates that the percentage loss of SWMAC raises as the sulfue waste dosage raises (i.e. oxidation increased with the sulfur waste addition in SWMAC). This is related to the higher loss by dehydrogenation and oxidation of 40-50 pen. when the SW/asphalt mix exposed to temperature higher than 150°C, as a result fumes of H_2S, So_2 and Co_2 can be occurred.

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4.4. Cracking characteristic at low temperatures

Cracking of AC- pavements is due to the presence of low temperature, which produces materials tensile stress and in turn results in fracture [25]. A lot of evaluating procedures for transverse cracking distresses have been utilised in the literature. Cracking index (CI) is one of the most widely used approaches in determining the pavement cracking. Al-ani [26] introduce a good correlation (R^2 = 0.843) for predicting low temperature cracking based on binders characteristics before and after TFOT. The CI is defined in Eq. (3):

$$CI = 10.13 * AI^{0.5} + 0.334 * logPen. + \frac{22}{7} * (R\&B) - 166.204 \quad (3)$$

Where
CI = Cracking Index,
AI= Index of ageing,
Pen.= Std. penetration (25 deg.C),
R&B= softening degree (deg.C) after ageing.

Results of CI., as presented in Figure 3, reveal that the CI. for 40-50 pen. and 10%SW/40-50 pen. are 20.04 and 41.42, respectively. 10% SW raises the CI. by 106.7%. This depicts that the SWMAC enhances asphalt mixtures resistance against cracking due to their lower temperature susceptibility.

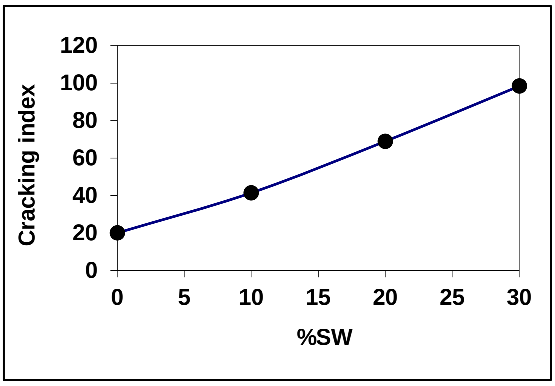

Fig. (3): Cracking index of SWMAC

4.5. Extensional viscosity

The extensional viscosity (EV) of SW/virgin asphalt and SW/mix are defined in Equation 4 and Equation 5 [27].

$$\lambda_b = 3 * 10^{-6}[1.3 * 10^{\frac{[3+(TR\&B-Tasph.]}{10}}] \quad (4)$$

Where:
λ_b = EV of binder (Mpa.s.),
$T_{R\&B}$ = softening degree of extruded asphalt (deg.C), and
T_{asph} = Surface temperature (25 deg.C).

$$log\lambda_a = \phi_1(N) + \phi_2(N)log\lambda_b \quad (5)$$

$$\phi_1(N) = 186 * 10^{-5} * N^2 - 165 * 10^{-3} * N + 698 * 10^{-2}$$

$$\phi_2(N) = 75 * 10^{-2} - 22 * 10^{-5} * N$$

Where:
λ_a = EV of asphalt mixture (Mpa.s.), and
N = Mineral aggregate voids (%).

Figure 4 and Figure 5 present that 10% SW raises the EV of 40-50 pen. and virgin mix at 60 deg.C by 27% and 0.0%, respectively. Besides, rising in temperature leads to drop in asphalt binder and mix EV for all SW dosages as presented in Figure 6 and Figure 7.

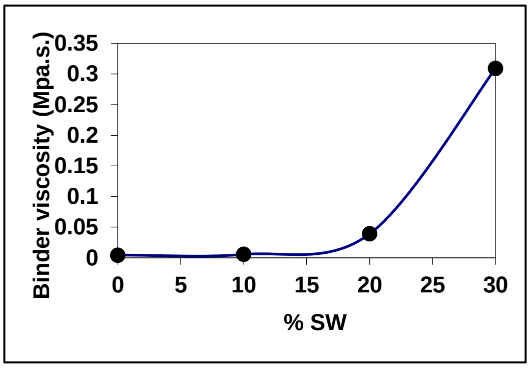

Fig. (4): SWMAC extensional viscosities (60 deg.C)

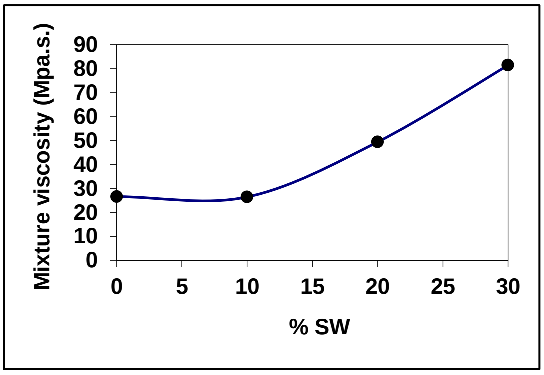

Fig. (5): SWMAC extensional viscosities (60 deg.C)

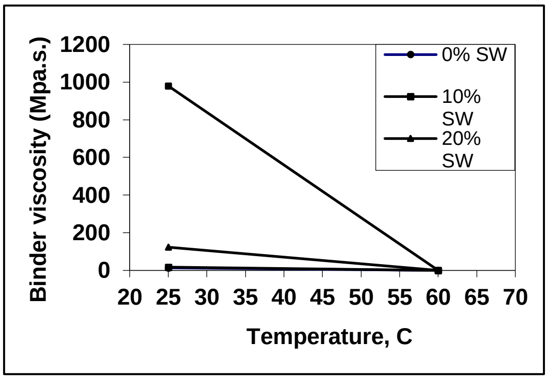

Fig. (6): SWMAC extensional viscosities (25&60 deg.C)

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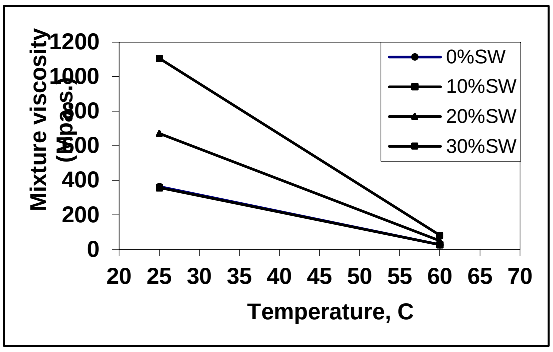

Fig. (7): SWMAC extensional viscosities (25 & 60 deg.C)

5. CONCLUSION

From the assays adopted in this research, the following conclusions were presented:

1. Ductility at 25 deg.C reduced as increasing the sulfur waste content increases. This depicts an enhanced in shear resistance of SWMAC in moderate to cold climate.
2. 10%SWMAC presents ductility value of more than 100 cm which is the lowest limt set according to SCRB and ASTM specifications.
3. 10%SWMAC shows 13% lower R&B than that for virgin asphalt. This presents that SW decreases the resistance of asphalt mixture against shear deformation.
4. It is noticed that all SWMA binders are more affects by temperature varies compared by virgin. In addition, the 10% SW content kept on the P.I. value of virgin asphalt at preferable range between -1 and -0.5 as depicted in KSLA graph.
5. The results showed 10% SW decreases the AV of virgin asphalt about 73.4%.
6. It was found that the addition of 10% SW increases the elastic modulus of virgin asphalt about 29.4%.
7. SWMAC presented lowest aging index, which indicates that SWMA binders are more susceptible to aging effects than virgin asphalt.
8. 10% SW raises the CI. about 107%. This depicts that the SWMAC enhances the asphalt mixtures to resist cracking; and
9. At 60 deg.C, 10%SWMAC presented 27% higher extensional viscosities than 40-50 pen.

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