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Evaluation of Warm Mix Asphalt Performance with High RAP Content

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Graphical abstract

Type of Mix	Number of Cycles	Ruth Depth, mm
Control	8000	6.134
SASO 30%	8000	4.696
SASO 40%	8000	4.245
SASO 50%	8000	3.319

Abstract

The pavement industry is currently forced to find alternative ways to produce asphaltic concrete with the dwindling supply of new resources and the spiraling cost of materials. Warm Mix Asphalt (WMA) using reclaimed asphalt pavement (RAP) offers a sustainable solution to the problem by reducing energy requirements for production and the reuse of old pavement materials. The effects of warm mix asphalt additive (Sasobit) on mixes containing different percentages of RAP were investigated in the laboratory. Three different concentrations of RAP (30%, 40% and 50%) with 1.5% Sasobit by weight of binder were added, and Marshall method was used to produce all samples investigated. Two different mixing and compaction temperatures were used, 155°C and 135°C for mixing and 135°C and 120°C for compaction. The performance of the mixes in terms of stiffness and moisture damage were investigated by carrying out the Indirect Tensile Resilient Modulus Test (ASTM D4123) and moisture susceptibility test (ASTM D 4867). The results obtained showed that there were no substantial differences in volumetric properties, stability and stiffness values of reclaimed mixes than the control mix (conventional hot mix asphalt). In addition, all the mixes investigated achieved the required minimum TSR of 80%. Measured rut depth using the Asphalt Pavement Analyser (APA) device and fatigue cycles to failure using beam specimen indicated that the mixes performed similar to or better than the control mix. The results showed that warm mix asphalt using sasobit-additive and containing high percentages of RAP could be a sustainable alternative to the conventional HMA mix.

Keywords: Warm mix asphalt; reclaimed asphalt pavement; volumetric properties; mix performance

■1.0 INTRODUCTION

The pavement industry has long emphasized the need to use RAP materials obtained from deteriorated roads as these materials still possess desirable properties to be used for the surfacing layers, subject to the limitations set in the specification used. With the dwindling supply of new resources and spiraling cost of materials, the use of RAP is a suitable way to conserve non-renewable resources that is aggregates and bitumen used for asphaltic concrete mixes. Most road authorities allow the incorporation of not more than 30% of RAP in asphaltic concrete mixes (wearing course) to avoid any detrimental effects on the mix properties [1]. The increase in asphaltic concrete materials prices has led the road construction industry to strive for the use of higher percentages of RAP to reduce the cost of road projects. A higher addition of RAP should enhance the value of the recycled pavements and have the potential for reducing the quantity of waste materials [2]. In addition to the need to conserve materials by using RAP, there is also a need to conserve energy by lowering the production temperature of asphaltic concrete mixes.

Recent advances in technology have allowed the temperature for mixing and compaction of asphaltic concrete mixes to be lowered compared to the mixing and compaction temperatures for conventional asphaltic concrete mixes. Warm mix asphalt (WMA) is relatively a new technology which allows a reduction in the mixing and compaction temperatures. Mixing temperature is in range of 105°C to 135°C [3, 4, 5], which is substantially lower than the mixing temperature of 150°C to 160°C used for conventional hot mix asphalt [6,7]. Therefore, there are enormous benefits of incorporating high percentages of RAP in WMA mixes, namely the reduction of energy to produce asphaltic concrete mixes and the conservation of non-renewable resources (aggregates and bitumen) used for asphalt mixes.

The main objective of this research was to investigate and compare the performance of WMA containing 30%, 40% and 50 % of RAP by weight of the mix with the conventional asphaltic concrete. The performance of the mixes were compared by measuring the stiffness value, moisture susceptibility, rutting depth and fatigue life.

■2.0 EXPERIMENTAL

The bitumen used in this research is grade 80/100 penetration, having a specific gravity of 1.03 gm/cm^3. Granite aggregate used was obtained from Kajang Rock Quarry in the state of Selangor, Malaysia. The granite aggregates were mixed with various percentages of RAP to produce the warm mix asphalt mixes. For control samples, the combined new aggregates included coarse, fine and the ordinary Portland cement as mineral filler in accordance to PWD Malaysia's specification [8]. RAP materials were obtained from the millings of the asphaltic concrete surface layer obtained from the Grand Saga Highway which connects the city of Kuala Lumpur with the town of Kajang. The WMA additive used in this research is sasobit, a paraffin wax derived from coal gasification process using the Fischer-Tropsch (F-T) synthesis. It is produced by Sasol Wax Company of South Africa. The chemical composition of sasobit can be described as fine crystalline materials in long-chain hydrocarbons, composed from 40 to 115 carbon atoms. The melting point of sasobit is about 100°C and it is completely dissolved in bitumen at temperatures above 115°C [9].

The rotary evaporator method (ASTM D5404-11) [10] was carried out to extract the aged bitumen from the RAP sample and to determine the recovered bitumen behaviour (penetration and viscosity). These values are then used to calculate the amount of virgin bitumen required to be added for the combined mix (new aggregate and RAP aggregate). Four types of mix with AC14 gradation were designed using the Marshall method conforming to PWD Malaysia's specification. The control mix is 100% new aggregate with a dense-graded gradation designated as AC 14 in PWD Malaysia's specifications. The second mix combined 70% new aggregate with 30% RAP aggregate. The third mix combined 60% new aggregate with 40% RAP aggregate. The last mix combined 50% new aggregate and 50% RAP aggregate.

The combined materials were then mixed before bitumen is added to restore the aged bitumen in the RAP so as to comply with PWD Malaysia's specification. Two different batches of samples were prepared. The first batch was control samples using virgin bitumen grade 80/100 penetration produced at mixing temperature of 155°C and compacted at temperature of 135°C; the second batch was mixes with three different RAP contents of 30%, 40% and 50% respectively (SASO mixes), produced by adding bitumen grade 80/100 penetration with 1.5% sasobit at mixing temperature of 135°C and compacted at temperature of 120°C. The mixing/compaction temperatures and the amount of sasobit to be added were established previously by the authors for AC14 asphaltic concrete mixes and complied with all PWD Malaysia's specification requirements; these were discussed in an earlier paper [11]. The gradation for control samples and WMA mixes with RAP is shown in Table 1 while PWD Malaysia's specification requirements for asphaltic concrete is shown in Table 2 [8].

Marshall standard test procedure was carried out for all samples according to ASTM D1559-89 [12]. The OBC was determined without adding the warm mix asphalt additives to avoid any unnecessary reduction in the optimum bitumen which may lead to negative effects on mix durability and moisture susceptibility [11, 13, 14-18].

The test for stiffness was carried out in accordance to ASTM D 4123 - 82 [19] at test temperatures of 25 and 40°C. All samples were subjected to this test before the Marshall stability and flow test. A total of 18 samples were tested in accordance to ASTM 4867 – 09 to measure the moisture damage potential based on the Tensile Strength Ratio (TSR %).

The rut depth testing in accordance to AASHTO TP 63-03 [20] was performed using the Asphalt Pavement Analyzer (APA) on the laboratory specimens at a temperature of 64°C to evaluate any differences in rutting resistance between the control and the SASO mixtures. The rut depth values were calculated from measurements of rutting obtained prior to testing and after the completion of 8000 cycles of loading; the average values were automatically determined by the APA.

Fatigue test in accordance to AASHTO T 321-2008 [21] was carried out on specimens using the four-point beam fatigue test in constant strain control mode, at two strain levels, 200 and 300 micro-strains at a loading frequency of 10 Hz.

Table 1 Gradation limits for control mix and WMA with RAP mixes

Sieve Size	Percent Passing					
	Control Mix	Specification Gradation Limit for Control Mix	WMA with 30% RAP (SASO 30%)	WMA with 40% RAP (SASO 40%)	WMA with 50% RAP (SASO 50%)	Specification RAP Gradation Limit
20 mm	100	100	100	100	100	100
14 mm	95	90 – 100	94.3	94.4	94.5	80 - 95
10 mm	81	76 – 86	82.5	83	83.5	68 - 90
5 mm	56	50 – 62	61.4	62.2	63	52 - 72
3.35 mm	47	40 – 54	51.1	51.8	52.5	45 - 62
1.18 mm	26	18 – 34	32.3	32.4	32.5	30 - 45
0.425 mm	18	12 – 24	20.7	20.6	20.5	17 - 30
0.150 mm	10	6 – 14	11	11	11	7 - 16
0.075 mm	6	4 – 8	6.7	6.6	6.5	4 - 10
Bitumen Added	-	-	3.95%	3.55%	3.18%	-
Total Bitumen Content	4.82 %	4 - 6 %	5.53 %	5.63%	5.77 %	5 - 7 %

Table 2 Volumetric properties and marshall test results for control and saso mixes

Sasobit (%)	Mix Type	OBC (%)	G_{mb}	G_{mm}	AV (%)	VMA (%)	VFB (%)	Stability (N)	Flow (mm)
0	PWD Malaysia's Specification	4.0 – 6.0	-	-	3 - 5	-	70 - 80	> 8,000	2 - 4
0	Control	4.82	2.342	2.44	4.06	15.02	73.01	16,961	3.60
1.5	SASO 30 %	5.55	2.336	2.427	3.74	16.33	77.09	22,460	3.78
1.5	SASO 40%	5.63	2.330	2.419	3.78	16.41	77.59	23,253	3.74
1.5	SASO 50 %	5.77	2.321	2.415	3.89	16.89	76.99	24,728	4.22

3.0 RESULTS AND DISCUSSION

Table 2 shows the volumetric properties, Marshall stability and flow values for all the mixes (control, SASO 30%, SASO 40% and SASO 50% mixes). It can be deduced from the total air voids in the compacted mixes that the addition of sasobit-additive with 30%, 40% and 50% RAP could assist in producing mixes with similar amount of air voids to that of the control mix. This can be attributed to the nature of sasobit structure within the bitumen. The addition of sasobit in asphaltic concrete mix caused the air voids content to decrease in compacted mixes, however, at same time, by incorporating RAP into the asphaltic concrete mix increased the air voids content. Therefore, the sasobit-additive play the role of balancing between the two different air voids behaviour of the virgin mix and the RAP materials. For the flow parameter, it is observed that the values for SASO mixes are higher than the control mix, but within the specification requirement, except for SASO 50% mix, which is higher than 4 mm. The stability values in SASO mixes shown in Table 2 were higher than the control mix. The SASO mixes were affected by the presence of both the modifier and the aged binder, and the higher stability value was obtained with the higher RAP content. This can be attributed to the effect of aged binder which exist in the RAP materials [22-24].

Table 3 shows the the resilient modulus results for the control and saso mixes. It could be deduced that for the the resilient modulus test, the SASO 50% mix shows the highest value, followed by SASO 40%, SASO 30% mixes and the control mix. This can be attributed to the higher amount of aged binder with the addition of sasobit into the asphaltic concrete mixes. The behaviour of these mixes could enhance the ability of modified mixes with RAP to resist permanent deformation.

Table 3 Resilient modulus (m_r) values for control and SASO mixes at 25°c and 40°c

Mix Type	M_R at 25°C (MPa)	M_R at 40°C (MPa)
Control	3219	932
SASO 30%	4600	1546
SASO 40%	4656	1671
SASO 50%	4997	1812

The indirect tensile strength test in accordance to ASTM D4867-09 was carried out to determine the moisture sensitivity of the mixes. The Tensile Strength Ratio (TSR) results are shown in Table 4. The control mix and SASO mixes complied with the minimum required TSR of 80%. For control mix and SASO 30% mix, the moisture-conditioned tensile strength was higher than dry tensile strength. However, the dry and wet tensile strength are almost similar for SASO 40% and SASO 50% mixes, possibly due to the higher binder content which makes the mixes less permeable to water, thus reducing the effect on tensile strength.

Table 4 Tensile strength ratio for control and SASO mixes

Mix Type	Dry Tensile Strength, (psi)	Moisture-conditioned Tensile Strength, (psi)	TSR (%)
Control	0.713	0.813	114
SASO 30%	0.896	1.053	118
SASO 40%	0.920	0.926	101
SASO 50%	1.100	1.096	100

Table 5 shows the rut depth values after the completion of 8000 cycles of loading. The rutting depth decreased with the increase in the addition of RAP to the asphalt mix. The SASO 30%, SASO 40%, and SASO 50% mixtures were shown to have an average of around 24.5%, 30.80% and 45.90% less rut depth than the control mix due to the stiffening influence of both aged binder within RAP materials and the sasobit-additive. SASO 50% has the lowest rut depth possibly due to the higher amount of aged binder in the mix which increases its resistance to rutting.

Table 5 Rut depth test results for control and SASO mixes

Type of Mix	Number of Cycles	Ruth Depth, mm
Control	8000	6.134
SASO 30%	8000	4.696
SASO 40%	8000	4.245
SASO 50%	8000	3.319

Table 6 shows the fatigue test results for Control and SASO mixes at low (200 micro-strain) and high levels of strain (300 micro-strain). All the SASO mixes have higher fatigue cycles compared to the control mix; SASO 30% achieved the highest number of cycles to failure for both levels of strain. This can be attributed to the lower amount of aged binder in the SASO 30% mix, which increases the number of cycles for fatigue failure. It could be deduced that the addition of sasobit-additive improved the properties of the aged binder to perform better than control mix in terms of fatigue resistance.

Table 6 Fatigue test results for control and SASO mixes

Type of Mix	Fatigue Cycles to failure for 300 micro-strain level	Fatigue Cycles to failure for 200 micro-strain level
Control	50,655	291,676
SASO 30%	127,321	869,500
SASO 40%	96,406	651,583
SASO 50%	104,250	835,780

4.0 CONCLUSION

The volumetric properties obtained by the SASO mixes complied to all PWD Malaysia's specification requirements. Also, the resilient modulus values for the SASO mixes were higher than the control mix; indicating the stiffening effects of sasobit and the aged binder on the SASO mixes properties.With respect to moisture susceptibility, all mixes investigated have exceeded the minimum TSR requirement of 80%. The indirect tensile strengths of the RAP mixes were similar or slightly higher compared to the control mix. The SASO mixes were shown to have less rut depth than the control mix due to the influence of both aged binder within RAP materials and the sasobit-additive. The fatigue test results also showed higher cycles to failure for SASO mixes than the control mix. It can be concluded that warm mix asphalt using sasobit-additive and containing high percentages of RAP of up to 50% could produce a mix which is better or at least similar performance to the conventional asphaltic concrete mix.

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