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Evaluation of Stone Mastic Asphalt Performance

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EVALUATION OF STONE MASTIC ASPHALT PERFORMANCE

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1. INTRODUCTION

Stone mastic asphalt (SMA) is being increasingly used for road surfacing applications. The performance of the product to date has been variable due to a variety of reasons. For instance ALF testing at Beerburrum (AUSTROADS, 1996) indicated only moderate resistance to rutting. Field experience in USA (Brown et al., 1997) has noted some rutting problems in areas of high pavement temperatures. The poor SMA performance to date has been attributed to inappropriate mix designs. SMA has the potential of providing a mix which is impervious to water, resistant to rutting, has improved fatigue resistance and provides good skid resistance. There is therefore a need to better understand the effect of the key mix design parameters to ensure that the product performance is optimised.

An investigation into an improved SMA was initiated by CSR-Emoleum. The aim was to investigate how rutting and fatigue performance is affected by the mix grading, mineral composition and binder type. The latter point was of particular interest as it is widely believed that the influence of the binder is minimised once the mineral skeleton is optimised.

2. MATERIALS

Aggregate Source and Properties

Hornfels aggregate from Oaklands Junction, Victoria was used for this work. This aggregate is widely for asphalt manufacturing in the Melbourne metropolitan area. Typical properties of the 14mm aggregate are shown in Table 1 below.

TABLE 1. TYPICAL PROPERTIES OF AGGREGATE SOURCE (14 mm)

Unsound stone	2%
Los Angeles value	17%
Aggregate crushing value	10%
Flakiness index	17%
Angularity number	7
Water absorption	<1%

Binders used and Properties

The majority of testing was carried out with Class 320 bitumen. Two polymer modified binders were also evaluated to determine the effect they have on the SMA performance. The modified binders used were Mobilflex AG1 and Mobilplast R1-HS. These binders were chosen to be of the elastomeric type (Mobilflex AG1) and the plastomeric type (Mobilplast R1-HS) so that the merit of each polymer type could be evaluated. Key properties of the binders evaluated are shown in Table 2. Testing for consistency, stiffness and elastic recovery was according to AUSTROADS MBT test procedures using the ARRB Elastometer.

TABLE 2. PROPERTIES OF BINDERS EVALUATED

		Class 320	Mobilplast R1-HS	Mobilflex AG1
Test property and procedure	**Specifications met**	AS 2008	A35P, AUSTROADS, 1997	A10E, AUSTROADS, 1997
	Consistency at 60°C, Pa.s (MBT21, AUSTROADS)	330	4,500	17,400
	Stiffness at 25°C, kPa (MBT21, AUSTROADS)	29	131	25
	Elastic recovery at 25°C and 100 s, % (MBT21, AUSTROADS)	20	47	73
	Viscosity at 165°C, Pa.s (MBT11, AUSTROADS)	0.15	0.62	0.83

3. MIXES EVALUATED

Mixes with three gradings envelopes were evaluated for performance. These consisted of a dense graded asphalt mix (AC14), a conventional 14 mm stone mastic mix (SMA-14) with a grading fitting the envelope given in AUSTROADS (1993), and a series of optimised 14 mm stone mastic mixes designated in this work with the prefix: CSRE. The CSRE mixes were designed with a coarser grading than the conventional SMA-14 mix. The dense graded asphalt mix (AC14) was included in the evaluation so that the performance of the stone mastic mixes (SMA-14 and CSRE) could be compared to the current industry standard.

Mineral composition and grading

The composition of the asphalt mixes is shown in Table 3. The CSRE mixes were made to varying aggregate size composition, to enable an assessment of the importance of mix composition on mix performance.

TABLE 3. MIX DESIGNATION AND COMPOSITION

	Mix designation					
Material	AC14	SMA-14	CSRE-1	CSRE-2	CSRE-3	CSRE-4
14 mm aggregate	28	56	77	73	77	75
10 mm aggregate	5	10	0	0	0	0
7 mm aggregate	23	0	0	0	0	0
5 mm minus	25	26	14	12	0	12
Sand , Heatherton VIC	18	2	0	6	13	6
CWFD	1	6	9	9	10	7

The gradings of the asphalt mixes examined in this report are shown in Table 4 below. The difference in grading between the SMA mix and the CSRE mixes is most apparent at the 4.75mm and the 6.75mm sieve sizes. The percentage passing the 4.75mm sieve was > 30% for the SMA-14 mix and *less than 30% for the CSRE mixes.* Both the SMA-14 mix and the CSRE mixes had levels between 8% to 11% of the mineral composition passing the 0.075mm sieve.

TABLE 4. GRADATION OF MIXES

	Mix designation Percent passing nominated sieve size					
Sieve size, mm	AC14	SMA-14	CSRE-1	CSRE-2	CSRE-3	CSRE-4
19.0	100	100	100	100	100	100
13.2	97	93	91	91	91	91
9.5	77	54	38	42	38	40
6.7	66	38	25	29	25	27
4.75	51	34	23	27	24	25
2.36	38	27	19	24	24	22
1.18	30	21	17	21	23	19
0.600	24	18	15	19	21	17
0.300	17	15	14	16	17	14
0.150	8	12	13	13	11	11
0.075	4.8	10	10.7	10.4	9.5	8.6

4. MIX DESIGN

Binder Content

The binder content of the AC14 dense graded mix was 4.6% and the conventional SMA-14 mix contained 6.0% binder. These levels were chosen to satisfy a voids criteria of 4% to 5% using 120 gyratory cycle for the AC14 mix and 80 cycle gyratory compaction (equivalent to 50 blow Marshall compaction) for the SMA-14 mix, respectively. For volumetric characterisation of the CSRE mixes, binder contents were designed in the range of 5.8% to 6.8%.

Fibre addition and binder drain-down

All mixes used in the mechanical characterisation of the SMA mixes had a fibre addition level of 0.3% by mass. The real need of fibre in an SMA mix design to reduce binder drain-down from was also evaluated. SMA mixes were prepared using the CSRE-1 grading with 6.8% binder. Testing was performed according to the Schellenberg procedure (AUSTROADS 1997) using Class 320 bitumen and the two polymer modified binders mentioned earlier in this paper. Mix temperatures of 165°C and 170°C were used for the Class 320 and polymer modified mixes, respectively. The results shown in Table 5 indicate that fibre *is not necessary to prevent binder drain-down when either Mobilplast R1-HS or Mobilflex AG1 is used.* With Class 320 bitumen, the use of fibres is necessary to reduce binder drain-down to an acceptable level (< 0.3%). Binder drain-down could be reduced by lowering the mix temperature, however there will be a practical lower limit for mixing temperature as mix homogeneity and compaction will be adversely affected.

TABLE 5. EFFECT OF FIBRE AND BINDER TYPE ON BINDER DRAIN-DOWN

	Binder drain-down, %	
Binder type	0.3% fibre	nil fibre
Class 320	0.06	0.87
Mobilplast R1-HS	0.09	0.14
Mobilflex AG1	0.15	0.06
Binder drain-down criteria- (AUSTROADS,1997)	< 0.3%	

Sample preparation and compaction

Samples were prepared and conditioned according to the AUSTROADS mix design procedure. Mixes were batched and mixed at 165°C for Class 320 bitumen and were conditioned at 170°C when using the polymer modified binders. All mixes were conditioned at 150°C for 1 hour prior to compaction. Samples were compacted with a gyratory compactor (240 kPa and 20° angle) to produce 100 mm diameter samples for volumetric and stiffness determination. For volumetric property determination samples were compacted at 80, 120 and 350 cycles. A segment wheel compactor was used for compacting larger SMA slabs for wheel tracking and fatigue testing. These slabs were compacted to a density equivalent to that obtained with the 80 cycle gyratory compaction. The slab thicknesses used in this study were as follows: 50 mm for wheel track testing and 75 mm for fatigue beams.

Volumetric properties

A summary of the volumetric properties obtained for the mixes investigated is shown in Table 6. For the mix designated as CSRE-1 a binder content of 6.8% is appropriate to meet the 5% voids criteria. The refusal voids (voids at 350 gyratory cycle compaction) for the SMA mixes ranged from 1.3% to 3.4% and the majority were below 2.5%. The difference in air voids from 80 cycles to 350 cycles compaction was in the range 1.4% - 3.5%, and 1.3% - 2.0% for the difference between 120 cycle to 350 cycles compaction. For all of the SMA mixes in this study, the bulk density at 80 gyratory cycle and 120 gyratory cycle compaction was about 95% of maximum density.

Workability

An assessment of the practical ease of compaction of the asphalt mix was estimated using asphalt workability as defined in AUSTROADS (1997). Workability was calculated for both the standard conditions of 5 to 30 gyratory cycles as well as 100 to 350 gyratory cycles. Workability values range from 91 to 119 for 5 -30 cycles and 37 to 66 for 100 - 350 cycles. As expected all mixes were easier to compact during the early part of compaction (5 to 30 cycles) as compared to the latter part of compaction (100 to 350 cycles). This latter compaction range is likely to be indicative of the compaction that would result long-term with traffic densification. Results indicate that mix designated as CSRE-1 with 6.8% binder was least likely to densify under traffic. Workability of the same mix in the early part of compaction is high compared to typical workability values for dense graded mixes. This indicates that field compaction should not pose any difficulties if the appropriate compaction equipment is used.

TABLE 6. SUMMARY OF VOLUMETRIC DATA AND WORKABILITY

	SMA-14	CSRE-1				CSRE-2		CSRE-3		CSRE-4
Bitumen content, %	6.0	5.8	6.1	6.4	6.8	6.2	6.8	6.4	6.8	6.0
Air voids, %										
80 cycles	4.3	7.8	6.8	6.1	5.1	4.6	3.0	5.9	3.9	5.6
120 cycles	2.8				4.9					5.1
350 cycles	1.3				2.9	2.0	1.6	2.4	1.9	3.4
Change in air voids										
80 c- 350 c	2.9				2.2	2.6	1.4	3.5		2.2
120 c -350 c	1.5				2.0					1.7
VMA										
80 cycles	19.7				21.6	20.2	20.4	21.6	20.9	21.2
120 cycles	18.4				21.5					20.8
350 cycles	17.2				19.9	18.1	19.3	18.7	19.3	19.4
Bulk density as a percentage of max density										
80 cycles	96				95	95	97	94	96	94
120 cycles	97				95					95
350 cycles	99				97	98	98	98	98	97
Workability										
5-30 cycles	119				101	124		91		97
100-350 cycles	58				37	66		62		58

5. TEST PROCEDURES USED FOR MECHANICAL CHARACTERISATION

Resilient modulus determination was carried out according to the procedure outlined in AS1289. Testing was carried out on samples compacted to 80 cycles and 120 cycle compaction. Wheel tracking was carried at 60°C for 10,000 load repetitions on slab compacted samples. The deformation curve was monitored and this enabled the both the deformation level and wheel tracking rate to be determined.

Flexural stiffness and fatigue was determined using an IPC Beam Fatigue Apparatus. Asphalt beams were prepared by slab compaction for fatigue testing. Tests were carried out at 20°C and at a strain level of 900 • strain. It should be noted that only one strain level was chosen for testing as it had previously been shown that relative fatigue life was independent of strain level in the range 300 to 800 • strain (Maccarrone et al., 1997).

6. RESULTS

Resilient Modulus

Resilient modulus results are shown in Table 7. The binder content used for the mixes was 6.0%, 6.8% and 4.6% for SMA-14, CSRE-1 and AC14 mixes, respectively. The SMA-14 mix has a similar modulus to an AC14 mix. However it is important to note that CSRE-1 mixes have resilient moduli approximately 20% to 30% lower than SMA-14.

Effect of polymer modified binder on resilient modulus

Replacing the Class 320 bitumen with Mobilplast R1-HS reduces the modulus of SMA-14 and CSRE-1 mixes by an average of about 10%. The use of Mobilflex AG1 binder reduces the SMA resilient modulus by about 40%. As expected, replacing Class 320 bitumen in the mixes with the two polymer modified binders did not alter the air voids of the mixes.

Effect of compaction on resilient modulus

Increasing the compaction level from 80 cycles to 120 cycles (about 1% increase in density) increases the SMA-14 mix by about 10% but only 5% for the CSRE-1 mix.

TABLE 7. RESULTS OF RESILIENT MODULUS (25°C and 40 ms loading)

		SMA-14		CSRE-1		AC14
Binder	Compaction level	80 cycles	120 cycles	80 cycles	120 cycles	120 cycles
Class 320	avg modulus (MPa); cv	4500 5.4	5240 0.5	3570 0.6	3560 2.9	5250 3.3
	avg air voids(%); std	4.3 0.3	2.8 0.1	5.1 0.3	4.9 0.3	5.2 0.1
Mobilplast R1-HS	avg modulus (MPa); cv	4480 0.9	4950 3.0	2920 3.2	3160 2.7	
	avg air voids(%); std	4.5 0.5	2.9 0.1	5.2 0.4	4.8 0.4	
Mobilflex AG1	avg modulus (MPa); cv	2630 2.6	2860 9.9	2230 13.7	2380 1.5	
	avg air voids(%); std	4.2 0.3	3.5 0.2	5.6 0.3	5.3 0.4	

Wheel Tracking

Results of wheel tracking tests on the asphalt slabs are shown in Fig 1. A summary of the data is represented in Table 8.

Effect of grading on rutting

When using Class 320 bitumen as the binder, Table 8 shows that the CSRE mixes performed better at resisting rutting than did the SMA-14 mix or the dense graded AC14 mix. The improved resistance to rutting of the CSRE mixes is largely attributed to the grading. Using the conventional SMA-14 mixture in place of the dense graded AC14 mix increases the rutting life by about 20%. Using the CSRE-1 mix in place of the dense graded AC14 mix increases the rutting life by a significant 240%.

Effect of binder type on rutting

In the rut resistant SMA mix CSRE-1, the use of polymer modified binders did not greatly reduce the level of deformation obtained. This is consistent with the thinking that the binder plays a lesser role in resisting rutting once the mineral skeleton has been optimised. For the CSRE-1 mix, deformation level reduced from about 3 mm to 2 mm when Class 320 bitumen was replaced with Mobilplast R1-HS or Mobilflex AG1. The asphalt rutting life as determined from rutting rate is increased by about 2.5 and 9 times when Class 320 bitumen *is replaced* with Mobilflex AG1 and Mobilplast R1-HS binders, respectively.

Effect of compaction level on rutting

The effect of compaction on rutting was investigated and results are shown in Table 9. These results show that there was about a three fold increase in resistance to rutting when the compaction level was increased from about 90% to 95% of maximum density. The strong dependence of rut resistance on compaction level highlights the need for good field compaction practice to ensure that the mix performs satisfactorily.

FIG 1. WHEEL TRACKING DEFORMATION DATA AT 60°C

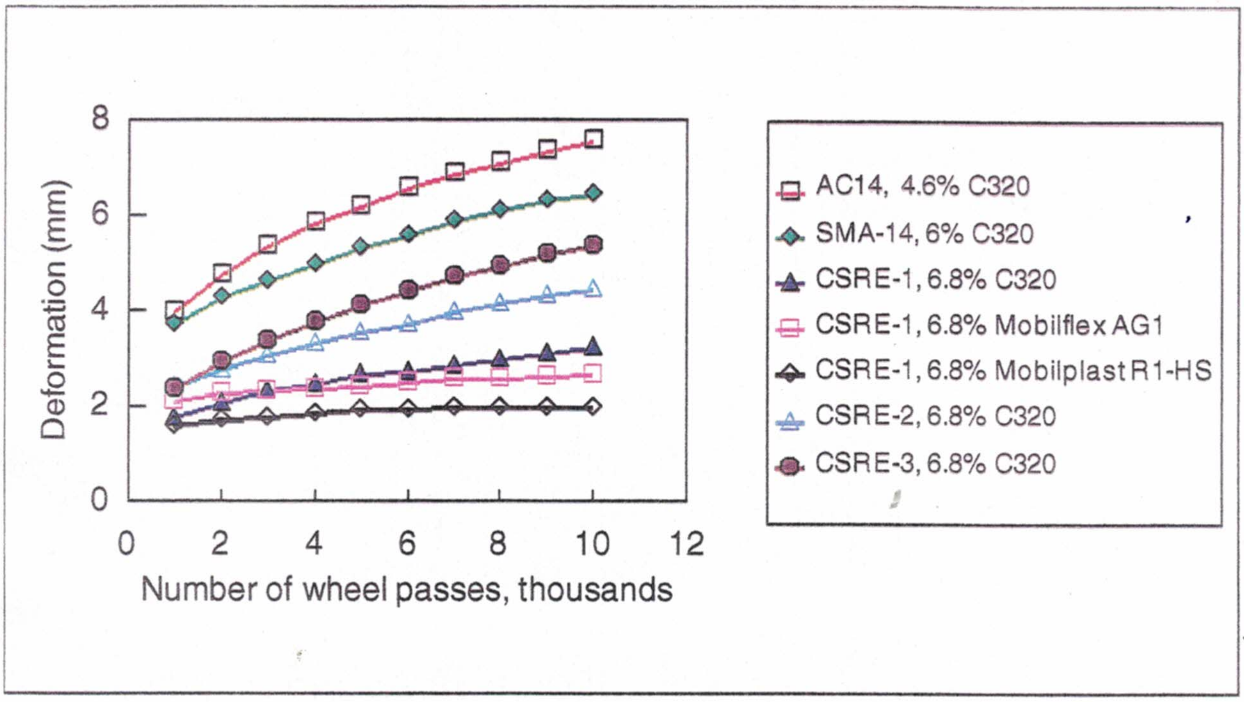

TABLE 8. SUMMARY OF WHEEL TRACKING DATA

Mix Type	AC14 DGA	SMA-14	CSRE-1	CSRE-1	CSRE-1	CSRE-2	CSRE-3
Binder content and type	4.6% C320	6% C320	6.8% C320	6.8% AG1	6.8% R1-HS	6.8% C320	6.8% C320
Deformation level after 10,000 passes, mm	7.6	6.5	3.3	2.7	2	4.5	5.4
Wheel Tracking rate, mm per 10,000 passes, (4-10 k passes)	0.29	0.25	0.12	0.049	0.015	0.19	0.26
Relative resistance to rutting (1/wtr)	1.0	1.2	2.4	5.9	19	1.5	1.1

TABLE 9. EFFECT OF COMPACTION LEVEL ON RUTTING

Mix type Binder content and type	AC14 4.6% C320	SMA-14 6% Class 320		CSRE-1 6.8% Class320		CSRE-1 6.8% Mobilflex AG1	
Compaction, % of 80 cycle density	100%	100%	92%	100%	95%	100%	95%
Compaction, % of maximum density	96%	95%	88%	95%	90%	95%	90%
Deformation level after 10,000 passes, mm	7.6	6.5	14.4	3.3	9.6	2.7	4.3
Wheel Tracking rate, mm per 1,000 passes, (4-10 k passes)	0.29	0.25	0.91	0.12	0.65	0.049	0.14
Relative resistance to rutting (1/wtr)	1	1.2	0.3	2.4	0.4	5.9	2.1

Fatigue

Fatigue data was determined for CSRE-1 mixes, SMA-14 and a dense graded AC14 mix. The data from these tests is presented in Table 10. A summary of fatigue data is presented in Table 11.

Flexural stiffness

Flexural stiffness data at 200°C and 10Hz loading shows that the CSRE-1 mix containing Class 320 bitumen is similar to the AC14 dense graded mix (4000 MPa) and about 20% higher than the conventional SMA-14 mix. Replacement of Class 320 bitumen in CSRE-1 with Mobilplast R1-HS resulted in a minor increase in stiffness (about 5%) but the use of Mobilflex AG1 caused stiffness to reduce by 40%.

Fatigue life

Stone mastic mixes display a greater fatigue life than dense graded Class 320 based mixes. A Fatigue life increase of about two and six times is achieved when SMA-14 and CSRE-1 mix is used in place of the dense graded AC14 mix. Replacing Class 320 bitumen with polymer modified binder further improves the fatigue life.

With the CSRE-1 mix using Mobilplast R1-HS and Mobilflex AG1 further increases the life by factors of about 2 and 4 times, respectively.

TABLE 10. FATIGUE DATA (20°C, 10Hz, 900• strain)

Mix Description	Beam No.	Smix (MPa)	Vb %	Av %	Measured Life
SMA-14	A7-0217B	3,019	15.3%	4.5	3,675
6% Class 320	A7-0222B	3,134	15.3%	5.3	3,750
	Average	**3,077**		**4.9**	**3,713**
	%cv	**2.6**		**12.2**	**1.4**
CSRE-1	A7-0226B	3,639	16.6%	4.3	12,150
6.8% C320	A7-0227B	3,415	16.6%	4.1	13,350
	A7-0228B	4,138	16.6%	4.6	10,850
	A7-0261B	3,672	16.6%	4.5	10,075
	Average	**3,716**		**4.4**	**11,606**
	%cv	**8.2**		**4.5**	**12.4**
CSRE-1	A7-0232B	1,560	16.6%	4.6	56,975
6.8% Mobilflex AG1	A7-0233B	1,247	16.6%	4.3	45,750
	A7-0234B	1,982	16.6%	4.1	36,950
	A7-0235B	1,521	16.6%	4.3	83,125
	A7-0238B	1,787	16.6%	5.3	36,325
	Average	**1,619**		**4.5**	**51,825**
	%cv	**17.2**		**11.1**	**37.4**
CSRE-1	A7-0240B	3,887	16.6%	4.1	28,175
6.8% Mobilplast R1-HS	A7-0241B	3,875	16.6%	4.1	28,975
	A7-0242B	4,005	16.6%	3.6	22,225
	A7-0243B	3,669	16.6%	4.0	34,000
	A7-0244B	3,888	16.6%	4.4	20,625
	A7-0245B	3,913	16.6%	4.4	18,550
	Average	**3,873**		**4.1**	**25,425**
	%cv	**2.9**		**7.3**	**23.3**
AC14 DGA	A7-123	4,000	10.5%	5.2	2,000
4.6% Class 320					

	Avg Fatigue life	Average air voids,%	%cv	Relative fatigue life	%cv
CSRE-1, 6.8% Mobilflex AG1	5.18E+04	4.5	11.1	25.9	37.4
CSRE-1, 6.8%Mobilplast R1-HS	2.54E+04	4.1	7.3	12.7	23.3
CSRE-1, 6.8% Class 320	1.16E+04	4.4	4.5	5.8	12.4
SMA-14, 6% Class 320	3.71E+03	4.9	12.2	1.9	1.4
AC14 , 4.6% Class 320	2.0E+03	5.2	13.2	1.0	21.4

7. DISCUSSION

Mix design for rut resistance

The conventional SMA-14 mix was designed using an 80 gyratory cycle voids criteria of 4% to 5%. This design produced refusal air voids (air voids at 350 cycle gyratory compaction) of 1.3%.
The resistance to rutting of this mixture was only marginally better that a dense graded AC14 mix. To improve the resistance to rutting for conditions of high traffic and high temperatures it is *strongly suggested that the design air voids be based on samples compacted to 120 cycle gyratory.*

Effect of grading and volumetric properties on rutting performance

Both the grading and the volumetric properties (air voids at 350 cycles, refusal voids) of a mix will influence the asphalt's resistance to rutting. This is clearly shown in Table 12 below.
Generally, there is a noticeable trend of decreasing level of rutting and rutting rate as the percentage passing the 4.75mm sieve decreases. There is also a trend of decreased level of rutting and rutting rate as the refusal air voids increased. It is concluded from this that both the grading and refusal voids should be included as part of the SMA mix design process to ensure high resistance to rutting. It is proposed that the following combined criteria be adopted in mix design procedures to reduce rutting for conditions of heavy traffic and high temperature:

- percentage passing 4.75 mm sieve should be less than 30%, and
- refusal air voids be greater than 2.5%.

TABLE 12 .
EFFECT OF GRADING AND VOLUMETRIC PROPERTIES ON RUTTING PERFORMANCE

Mix Type	AC14	SMA-14	CSRE-1	CSRE-2	CSRE-3
Class 320 bitumen content, %	4.6	6.0	6.8	6.8	6.8
Deformation level after 10,000 passes, mm	7.6	6.5	3.3	4.5	5.4
Wheel tracking rate (wtr) , mm per 10,000 passes, (4-10 k passes)	0.29	0.25	0.12	0.19	0.26
Relative resistance to rutting (1/wtr)	1	1.2	2.4	1.5	1.1
Mass percentage passing 4.75 mm sieve	51	34	23	27	24
Air voids at 350 cycle compaction, %		1.3	2.9	1.6	1.9

Effect of polymer modified binders on mix performance

It was previously shown that when polymer modified binders are used as the binder the use of fibres is not necessary to control binder drain-down. Appropriately selected polymer modified binders will also increase the resistance to rutting and fatigue. Binders such as Mobilplast R1-HS are preferred for rut resistance and Mobilflex AG1 for fatigue, however both are suitable for improving asphalt resistance to rutting and fatigue. The mix stiffness of polymer modified mixes depends on the binder type and binders similar to Mobilplast R1-HS produce little change compared to Class 320 bitumen, however it should be noted that Mobilflex AG1 type binders will reduce the mix stiffness considerably (40%)

8. CONCLUSIONS

The following conclusions can be made about the design and performance of the asphalt mixes evaluated:

- stone mastic mixes for heavy duty applications (heavy traffic and high pavement temperatures) should have design air voids based upon 120 cycle gyratory compaction

- Both grading and refusal air voids (350 cycle gyratory compaction) influence the rut resistant performance of stone mastic mixes. For heavy duty applications the combined mix design criteria of a mineral grading with less than 30% passing the 4.75 m sieve and a refusal air void content greater than 2.5% should ensure good rut resistance.

- Stone mastic mixes are both more rut resistant and fatigue resistant than dense graded asphalt. The increased resistance to rutting is mostly due to the grading and the increased fatigue is due to the higher binder content. Mixes made to the CSRE-1 grading and composition increased resistance to rutting by 240% and fatigue life by 580% compared to a dense graded asphalt mix of the same nominal mix size.

- Use of polymer modified binders in stone mastic mixes further increases both the rut resistance and fatigue. Binders such as Mobilplast R1-HS are preferred for rut resistance and Mobilflex AG1 for improved fatigue life.

- Fibres are necessary to control binder drain-down with conventional bitumen, but are not necessary when polymer modified binders similar to Mobilplast R1-HS or Mobilflex AG1 are used.

- The Resilient modulus of stone mastic mixes depends on the grading and composition, binder content and binder type. The Resilient modulus can be 40% to 100% of that produced with a dense graded mix of the same nominal size.

- The degree of compaction greatly affects the rutting performance of a mix. There was approximately a three fold increase in resistance to rutting when the compaction level was increased from about 90% to 95% of maximum density. The high dependence of rut resistance on compaction level highlights the need for good field compaction practices to ensure that the mix performs satisfactorily.

9. REFERENCES

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