FLEXURAL STIFFNESS AND FATIGUE PROPERTIES OF WARM MIX ASPHALT

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Abstract

With good reason, the past decade has seen a faster growing interest in the use of Warm Mix Asphalt (WMA) than any other new asphalt technology. The advantages attributed with WMA are primarily realised through a reduction in the production temperature by 15°C to 50°C that creates spinoff benefits in reduced energy consumption and emissions.

As part of the experimentation and evaluation of a range of different WMA, plant produced mixes were assessed by Stellenbosch University on a four point beam apparatus in terms of flexural stiffness and fatigue performance. Both surfacing and base WMA mixes were appraised. Each WMA mix type was evaluated relative to its equivalent HMA i.e. as a benchmark.

The results attained indicate that WMA performs favourably, with most WMA types providing comparative, and in some cases superior, performance to HMA. This paper provides insights into the load spreading ability and fatigue resistance capacity of WMA relative to HMA. The potential application of WMA technology in the southern African roads industry is also analysed.

1.0 INTRODUCTION

The global consensus to reduce greenhouse gases and emissions has taken its toll with the enactment of numerous stringent laws and regulations. The environmental stewardship remains focused mainly at the manufacturing sector. The manufacturing sector which includes the asphalt industry is known to contribute a significant percentage of emissions towards the global emissions. It is therefore crucial that, the asphalt industry devises methodologies to reduce the present emissions.

As part of the environmental stewardship, the asphalt industry has undertaken to invest in alternative asphalt mix types. However, there is need to examine the alternative mix types in terms of their application and performance requirements. In determining the relative engineering properties and performance criteria of the alternative mix types, Hot Mix Asphalt (HMA) is used as a benchmark.

In order to reduce energy consumption and emissions, Warm Mix Asphalt (WMA) is such mix type developed at lower production and paving temperatures than HMA. This encourages environmentally sustainable practices as well as conformity to future anticipated stringent environmental legislation. In other parts of the world, WMA is used in lieu of HMA. The use of WMA has generated interest due to reduced emissions, improved working conditions, reduced binder oxidation, longer possible hauling distances and reduced energy consumption among others (D'Angelo *et al*, 2008).

In South Africa, a WMA Interest Group has taken the initiative to investigate the production, construction and performance of different WMA mixes. As part of this initiative, Stellenbosch University (SU) undertook to evaluate flexural properties of WMA produced in full-scale trials i.e. the 3rd WMA plant trial along Shepstone Road and the final WMA trial along Higginson Highway, administered by eThekwini Municipality.

The objective of SU's experimentation was to evaluate WMA surfacing and base mixes in terms of flexural stiffness, a response property linked to load spreading. In addition, the relative fatigue performance of the mixes was also evaluated. The paper compares flexural stiffness and fatigue performance of WMA to the equivalent HMA. The analysis of different mixes takes cognisance of the variables such as recycled asphalt (RA) content, binder grade and compactability.

2.0 DESCRIPTION OF MIXES

Table 1 provides the mixes considered in the experimentation for surfacing and base applications. The surfacing and base mixes are listed against their equivalent HMA (i.e. control mixes) in the experimentation.

From Table 1 below, mix variables such as binder grade and RA content as well as their appurtenant WMA technology are outlined. All control mixes were produced at HMA production temperatures and compacted following the required HMA requirements. In the experimentation, surfacing mixes are referred to as Type D mixes and base mixes as Type B.

Table 1: WMA and HMA Mixes Evaluated in the Experimentation

HMA Surface Mix Control Mix (Type D)	WMA Surface Mix Trial Mix (Type D)	WMA Technology
10% RA 60/70 (Control 1)	10% RA 60/70 Rediset™ WMX *Chemical Additive*	Chemical Additive
20% RA 80/100 A-P1 (EVA) (Control 2)	20% RA 80/100 A-P1 (EVA and Rediset™ WMX) – *Plastomer and Chemical Additive*	
10% RA 60/70 (Control 1)	10% RA 60/70 Foam Tech -*Foam*	Foaming Process
	10% RA 60/70 Sasobit® - *Fischer Tropsch wax* (FT wax)	Organic Additive
20% RA 80/100 A-E2 (SBS) (Control 3)	20% RA 80/100 A-E2 (SBS and Sasobit) Sasoflex - *Elastomer and FT Wax*	
HMA Base Mix Control Mix (Type B)	**WMA Base Mix Trial Mix (Type B)**	**WMA Technology**
10% RA 60/70 A-P1 (EVA) (Control 4)	10% RA 60/70 A-P1 (EVA and Rediset™ WMX) - *Plastomer and Chemical Additive*	Chemical Additive
	10% RA 60/70 A-P1 - *Plastomer and Foam*	Foaming Process
40% RA 80/100 A-P1 (EVA) (Control 5)	40% RA 80/100 A-P1 (EVA and Rediset™ WMX) - *Plastomer and Chemical Additive*	Chemical Additive
10% RA 60/70 A-E2 (SBS) (Control 6)	10% RA 60/70 A-E2 (SBS and Sasobit) Sasoflex - *Elastomer and FT Wax*	Organic Additive
40% RA 80/100 A-E2 (SBS) (Control 7)	40% RA 80/100 A-E2 (SBS and Sasobit) Sasoflex - *Elastomer and FT Wax*	

The variables within the experimentation included binder grade (i.e. 80/100 and 60/70 Penetration grade), RA content (i.e. 10%, 20% and 40% RA content) and WMA technology types. WMA technologies included the organic additive (i.e. FT wax), foaming process (i.e. foam) and a chemical additive (i.e. Rediset). The experimentation also includes mixes with either an elastomer (SBS) or a plastomer (EVA) additive with a WMA technology, as indicated in Table 1 above.

3.0 METHODOLOGY

The grading specifications as used in HMA production were adapted in the production of WMA surfacing and base mixes. The RA stockpiles included two types i.e. RA1 (-16 mm) and RA2 (-8 mm). Furthermore, in the production of WMA mixes, considerations of HMA production procedures were followed. However, during the production of some of the WMA mixes, adjustments were made to the asphalt plant to provide the necessary temperature reduction. Plant adjustments were also made for the incorporation of the WMA technology such as the foam type.

For each mix type, three sample slabs were manufactured from the three production silos. The overall tonnage for paving was rationed into three or more productions and stored in the three silos at the production plant. It is from these production silos (rations) that plant produced mix was attained to manufacture the three sample slabs per mix type.

The WMA blends were produced at two temperatures depending on whether the mix type incorporated a modifier (i.e. a plastomer or elastomer) or not. All unmodified WMA mixes were produced at 125^{o}C while the modified WMA mixes were produced at 145^{o}C . In this respect, the compaction targets for the WMA mixes also followed suit i.e. 120^{o}C (modified mixes) and 110^{o}C (unmodified mixes). All HMA mixes (control mixes) were produced at and even above160^{o}C but compacted at 135^{o}C (unmodified mixes) and 140^{o}C (modified mixes).

The laboratory specimens were compacted using the modified laboratory compaction method and procedure as indicated by Mbaraga (2010). The slab compaction was evaluated by coring at the ends of the slab to measure the compaction achieved. The centre-portion of the compacted slab (approximately 420 mm by 390 mm and 70 mm height) was selected and later sawn into beam specimens used in the laboratory evaluation. The packaging followed a method devised by National Asphalt (NA) – Shongweni, in conjunction with SU. The packaging method helped secure the specimen in position, avoiding likely of movements (especially vertical bouncing) of the specimen during transportation.

At the SU ITT laboratories, the slabs were sawn into beams of approximately 400 mm (length), 60 mm (width) and 50 mm (height). The height of the specimen, which needs to be accurately controlled for fatigue testing, was fine tuned to attain the required 50 mm; this varied between 50 to 51 mm. All beam specimens were stored at 10^{o}C in the cold room to reduce the likelihood of ageing. The individual beam specimens were evaluated for compactability; this helped in the selection of specimens for flexural stiffness evaluation.

Test procedures and instructions as indicated in AASHTO T321 (2007) and Taute *et al.* (2007) were followed. The four-point beam fatigue apparatus was used in the evaluation of mixes for both fatigue and flexural stiffness. The evaluation of fatigue and flexural stiffness was conducted at a constant strain using sinusoidal as the loading mode. Specimens evaluated for fatigue were conditioned for a maximum of 2hrs before commencement of the test (i.e. at test temperature of 5^{o}C). Specimens for flexural stiffness followed a similar conditioning time over a range of temperature and frequency sweeps.

In particular, fatigue testing parameters included three selected strain regimes (i.e. low, low-medium and high) and at a frequency of 10Hz, conditioned at a temperature of 5^{o}C. A low-medium strain of 300με (peak to peak) or 150με (peak) was set as a starting-strain (benchmark strain) during the fatigue laboratory test. The applied 300με strain outcome assisted in the selection of the two other strains (either from the high or low strain regime) under which testing would proceed to accrue more data points.

Flexural stiffness testing was conducted at a strain of 300με (peak to peak) at different temperatures and frequency sweeps. For flexural stiffness evaluation, a temperature range from 5^{o}C to 25^{o}C (at an interval of 5^{o}C) was selected for every frequency. The frequency sweeps of 0.5Hz, 1Hz, 2Hz, 5Hz and 10Hz were applied during the flexural stiffness test for 300 cycles each. The data acquired was used in the development of the flexural stiffness master curve.

In the development of the flexural stiffness master curve, the Arrhenius equation was used to superposition of the isotherms (i.e. at set of different temperatures). This superposition allowed the extrapolation of the test data (i.e. temperatures and frequencies) against the flexural stiffness at a reference temperature of 20^{o}C. This allowed the evaluation of the mixes beyond the set test conditions at a full scale temperature of 20^{o}C along different frequencies beyond the test range.

3.1 Grading Specifications

Figures 1 and 2 illustrate the grading used in the production of the mixes used for the experimentation. Grading of aggregates complied with HMA specifications i.e. HMA surface and base grading specification limits.

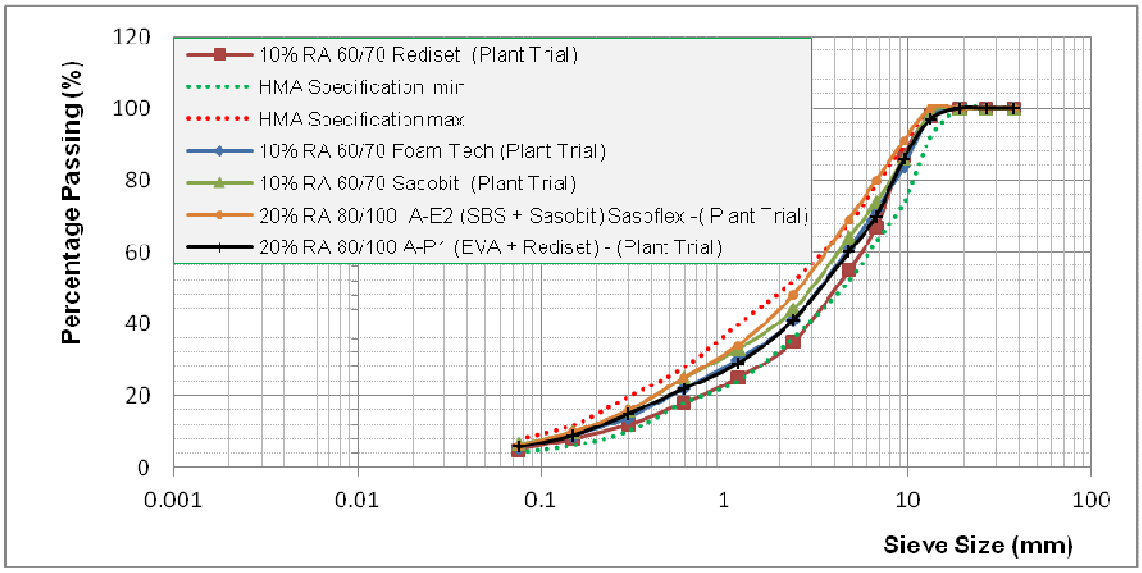

Figure 1: Aggregate Grading Data for WMA Surfacing mixes (Type D Mixes)

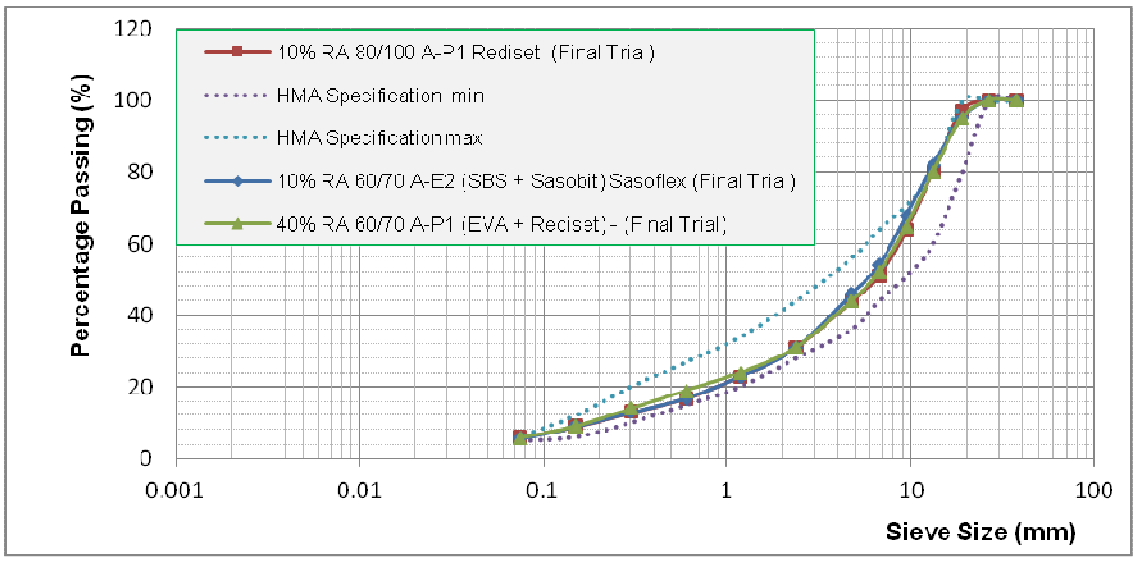

Figure 2: Aggregate Grading Data for WMA Base mixes (Type B Mixes)

3.2 Compactability of Mixes

In order to account for compaction efficiency of the slabs, it was necessary to reconcile the compaction efficiency by making a comparison between voids from lab versus field cores. The target compaction was 96% of Rice Density (4% void content), which was set as the benchmark for this trial. The target binder was 5.3%.

Table 3 lists compaction results for Type D 20% RA 80/100 A-E2 elastomer and FT wax (i.e. Sasoflex) mix type as a representative mix. In this trial 35 passes were set as compaction effort per mix.

Table 3: Compaction Results for Type D 20% RA 80/100 Elastomer and FT wax

Compaction Effort @ 35 Passes				
A-E2 Sasoflex	**Thickness (mm)**	**Rice Density(kg/m^3)**	**Core Bulk Density (kg/m^3)**	**Percentage of Rice (%)**
Slab 1	73	2464	2378	96.51
Slab 2	77	2464	2370	96.19
Slab 3	72	2464	2376	96.43
Average Compaction (%)				**96.93**
Field Compaction				
A-E2 Sasoflex	**Thickness (mm)**	**Rice Density(kg/m^3)**	**Core Bulk Density (kg/m^3)**	**Compaction of Rice (%)**
Core 1	54	2464	2330	94.56
Core 2	74	2464	2359	95.74
Core 3	60	2464	2351	95.41
Core 4	75	2464	2365	95.98
Core 5	70	2464	2362	95.86
Core 6	60	2464	2355	95.58
Average Compaction (%)				**95.52**

From Table 3, a close correlation between field compaction and laboratory compaction (i.e. using a compaction effort set at 35 passes) is observed. However, in using this compaction method it is imperative that the number of passes is set, depending on the type of compactor and the type of mix characteristics.

The representative beam characteristics and volumetric data are listed in Table 4 below. It was depictive that some WMA mix types were more compactable during the 35 passes, resulting in lower void contents. This indication observed implies that, the determination of the required number of passes should be made after adequate trials have been carried out with the selected roller on a specific mix type.

Whilst using this method, it was apparent that factors such as the number of passes, rate of rolling speed as well as deft operation of the roller, are fundamental to successful compaction. Inclusion of temperature monitoring with a gauge was also suggested. This required an introduction of a vertical slit to accommodate the downward movement during the compaction exercise. It was not implemented to all mixes but is nevertheless useful to ascertain the rate of cooling of the mix during compaction.

From Table 4, it is apparent that some of the mixes yielded a void content below 4%. The objective was to attempt to test each mix at approximately the same voids. The variations that are inherent will account for similar variations that can be expected in the field.

Table 4: Beam Specimen Results per Slab, Mix Type and RA Content

Beam No	Mass in Air (g)	Mass in water (g)	Rice Density (kg/m^3)	BRD (kg/m^3)	Void Content (%)
Type D: 10% RA 60/70 Plastomer and Chemical Additive (SLAB 1) at 35 Passes					
1	2968	1685	2476	2310	6.6
2	2982	1711	2476	2341	5.4
3	2971	1706	2476	2345	5.3
4	3013	1732	2476	2349	5.1
Type D: 10% RA 60/70 Plastomer and Chemical Additive (SLAB 2) at 35 Passes					
1	3012	1754	2476	2392	3.4
2	3140	1838	2476	2410	2.7
3	3004	1762	2476	2416	2.4
4	2990	1751	2476	2413	2.5
Type D: 10% RA 60/70 Elastomer and FT wax (Slab 1) at 35 Passes					
1	3023	1749	2471	2371	4.0
2	3013	1751	2471	2385	3.5
3	3045	1766	2471	2378	3.8
4	3074	1779	2471	2373	4.0
Type D: 20% RA 80/100 Elastomer and FT wax (Slab 1) at 35 Passes					
1	3063	1765	2470	2353	4.7
2	3147	1832	2470	2388	3.3
3	3057	1783	2470	2394	3.1
4	3007	1739	2470	2366	4.2
Type B: 10% RA 60/70 Elastomer and FT wax (Slab 2) at 35 Passes					
1	3146	1827	2489	2373	4.7
2	3079	1800	2489	2405	3.4
3	3030	1767	2489	2394	3.8
4	2949	1719	2489	2393	3.9
Type B: 40% RA 80/100 Plastomer and Chemical Additive (Slab 3) at 35 Passes					
1	2959	1713	2500	2355	5.8
2	3049	1776	2500	2378	4.9
3	3050	1770	2500	2377	4.9
4	3124	1816	2500	2378	4.9

4.0 LABORATORY RESULTS

The laboratory protocol considered at least two specimens for flexural stiffness evaluation and not more than three specimens at three different strain regimes for fatigue evaluation. However, some test data points from on-going fatigue laboratory testing are enlisted as an indication of relative fatigue performance of the mix types.

4.1 Flexural Stiffness Results

Tables 5, 6 and 7 list representative flexural stiffness results of some of mixes considered in the experimentation. A distinction is made between surfacing and base mixes as well as modified and unmodified mixes amongst the surface mixes (i.e. Tables 5 and 6). Of the two evaluated specimens for flexural stiffness, results of one of the specimen evaluated per mix, is reported. The results listed in the tables must be assessed with the cognisance of variables amongst the mix types.

Table 5: Flexural Stiffness Data for Type D Unmodified Mixes

Surface Mixes (Unmodified Mixes)Flexural Stiffness Data					
Freq. (Hz)	**5°C**	**10°C**	**15°C**	**20°C**	**25°C**
10% RA 60/70 Control Mix (Void Content = 4.3%)					
0.5	16371	11409	7900	4386	2374
1	17044	12783	9164	5768	3394
2	18296	14710	10568	6743	4084
5	20678	16774	13014	9274	6043
10	21559	18455	14942	10850	7601
10% RA 60/70 Foam (Void Content = 5.9%)					
0.5	12234	8031	4894	2544	1209
1	13911	9473	5924	2909	1557
2	14940	10914	7171	4468	2169
5	16700	13058	9087	5917	3431
10	18397	14849	11256	7886	4687
10% RA 60/70 FT wax (Void Content = 3.8%)					
0.5	10539	7005	4027	2259	1138
1	11495	8011	5082	2729	1380
2	12654	9549	6314	3632	1930
5	14309	11290	8176	5128	2932
10	15525	13000	9730	6641	4007
10% RA 60/70 Chemical Additive (Void Content = 4.5 %)					
0.5	8377	5249	2843	1451	693
1	9404	6332	3756	1905	944
2	10962	7400	4676	2554	1308
5	12932	9094	6200	3652	2139
10	14207	11044	7925	4910	2969

Table 6: Flexural Stiffness Data for Type D Unmodified Mixes

Surface Mixes (Modified Mixes)Flexural Stiffness Data					
Freq. (Hz)	**5°C**	**10°C**	**15°C**	**20°C**	**25°C**
20% RA 80/100 Plastomer Control Mix (Void Content = 2.7%)					
0.5	12710	8740	5609	3022	1517
1	13651	9829	6702	3750	1892
2	14588	11116	7882	4671	2521
5	16409	13144	9864	6390	3725
10	17920	14759	11504	8036	4999
20% RA 80/100 Plastomer and FT wax (Void Content = 3.2%)					
0.5	9171	6151	3538	1932	1014
1	10293	7140	4373	2398	1258
2	11375	8267	5331	3152	1762
5	12944	9977	6954	4390	2542
10	14102	11450	8511	5820	3544
20% RA 80/100 Plastomer Control Mix (Void Content = 2.3%)					
0.5	14979	9922	6076	3675	2096
1	16011	11130	7311	4542	2515
2	17318	12696	8623	5596	3264
5	19293	15015	10947	7536	4589
10	20533	16736	12852	9319	6070
20% RA 80/100 Plastomer and Chemical Additive (Void Content = 2.9%)					
0.5	11660	8133	5116	2783	1499
1	12941	9511	6239	3467	1867
2	14076	10866	7480	4440	2483
5	15980	13119	9522	6150	3623
10	17258	14651	11282	7798	4912

Table 7: Flexural Stiffness Data for Type B Mixes

Freq. (Hz)	Flexural Stiffness Data				
	5°C	10°C	15°C	20°C	25°C
10% RA 60/70 Elastomer Control Mix (Void Content = 3.1%)					
0.5	12921	9155	6237	3616	1874
1	13836	10288	7375	4535	2439
2	14907	11520	8622	5438	3120
5	16215	12943	10393	7089	4354
10	16786	14037	11773	8640	5663
10% RA 60/70 Elastomer and FT wax (Void Content = 3.8%)					
0.5	13332	9650	6068	3477	1688
1	14369	10991	7419	4443	2245
2	15535	12387	8713	5434	3039
5	17152	14074	10502	7259	4430
10	17922	15342	12091	8851	5770
10% RA 60/70 Plastomer Control Mix (Void Content = 4.1%)					
0.5	13694	10378	6585	4099	2285
1	15159	10877	7367	4846	2902
2	16429	11744	8144	5781	3761
5	18030	13528	9753	7261	5040
10	15836	13990	11179	8630	6563
10% RA 60/70 Plastomer and Foam (Void Content = 6.6%)					
0.5	11058	7857	5282	3196	1882
1	11597	8538	5963	3738	2234
2	12219	9390	6879	4493	2798
5	13412	10698	8250	5660	3787
10	13994	11772	9367	6789	4716

In terms of compactability as illustrated in Tables above, it is depictive that other factors besides the void content influence the flexural stiffness. In Table 5, 10% RA 60/70 Mix type with foam registered a 5.9% void content while mix type with the FT wax registered the lowest void content of 3.8% however, the flexural stiffness results indicated otherwise. At test temperatures of 5°C and 25°C (i.e. lowest and highest test temperatures), the foam mix type registered higher flexural stiffness values compared to mix with the FT wax. This analogy is depictive amongst the mixes in Tables 6 and 7. The flexural stiffness values indicate that besides the voids content other factors such as the WMA technology (i.e. the mechanism used by the technology) impacted on the laboratory outcomes. WMA technologies influence mix workability and compactability by either enhancing lubrication (i.e. at reduce binder viscosity) or wetting of aggregate surfaces.

4.1.1 Master Curves for Surfacing Mixes

A comparison of flexural stiffness amongst the mixes with 10% RA and 60/70 binder grade from both the plant and final trials is made in Figure 3. In both trials, the control mixes depicted a higher flexural stiffness compared to the WMA mixes.

In Figure 3, the 10% RA 60/70 FT wax (i.e. at plant and final trials) indicated a higher flexural stiffness (especially at lower frequencies) than the rest of the WMA mixes. However, the Foam and chemical additive mix types compared well (i.e. at plant trial) with the FT wax. At final trial, the chemical additive indicated the lowest flexural stiffness especially at lower frequency levels. The difference in flexural stiffness depicted by the FT wax at final trial compared to its equivalent plant trial mix is attributed to the adjustments made to the mix during the final trial. This analogy is observed amongst the chemical additive mix types.

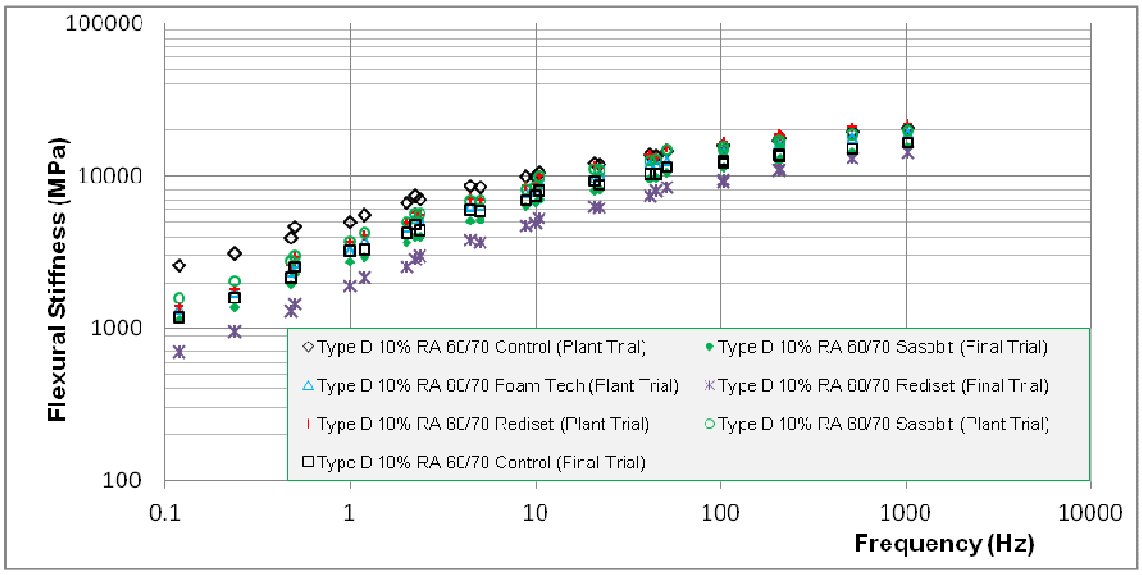

Figure 3: Master Curves of Type D 10% RA 60/70 Surfacing Mixes

The tendency for master curves convergence in flexural stiffness with increase in loading frequencies of the trial WMA mixes as well as the HMA was observed. At higher frequencies (and equivalent lower temperatures), higher flexural stiffness is undesirable as it leads to susceptibility to cracking. So the WMA technology appears beneficial. However, at lower frequencies (and equivalent higher temperatures), higher flexural stiffness is desirable as it leads to resistance to permanent deformation. Here the HMA reference mix appears superior, although further testing is required to verify this.

Figure 4 below, provides flexural stiffness for another category i.e. Type D 20% RA 80/100 (with either with an elastomer or plastomer modifier) and WMA technology. The elastomer was blended with FT wax while plastomer was blended with the chemical additive. A description to the particulars is made in Table 1 above. In this category, cognisance must be taken with regard the modifier used, binder grade and RA content.

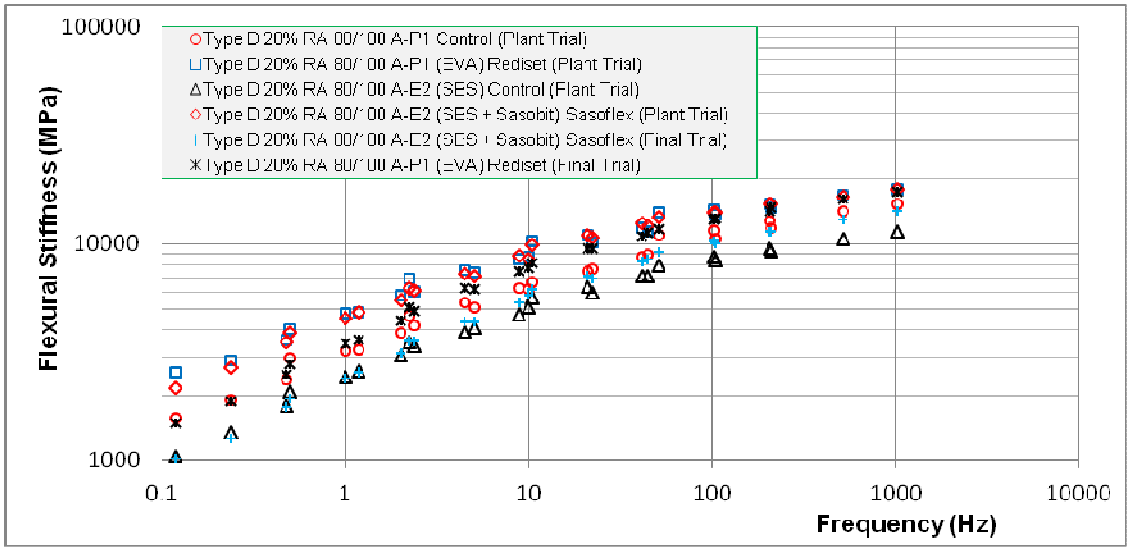

Figure 4: Master Curves of Type D 20% RA 80/100 Surfacing Mixes

A comparison between plant trial mixes of plastomer and elastomer indicated similar flexural stiffness values. Both of these WMA plant mixes provided a higher flexural stiffness than their respective control mixes (without the WMA technology). However, the elastomer control (plant) mix provided a significantly lower flexural stiffness than the WMA mix (plant). Nevertheless, the WMA mix (final) results were comparable to the control mix (plant); this could not be attributed to the technology type or even the variations amongst the mix such as grading, RA quality and void content.

In addition, the contribution of the RA content i.e. 20% RA versus 10% RA could be analysed. From the master curves of Figure 3 versus Figure 4, it is indicative that, the incorporation of higher percentages of RA into the WMA does not appear to result in detrimental effects. The lower production temperatures of RA do not encourage further plant-ageing of the binder, although the lower temperatures would also enable less blending of new and old bitumen with WMA.

It is also depictive that all the master curves indicated a convergence in flexural stiffness with increase in loading frequencies except for the elastomer control. At higher frequencies (and equivalent lower temperatures), the elastomer control indicated that it was less susceptibility to cracking. However, at lower frequencies, (and equivalent higher temperatures) the elastomer control depicted to be more prone to rutting. This construes that the use of the WMA technology (associated to its lower production temperatures) does appear beneficial. Here the HMA reference mixes (plant trial) appeared inferior to both the elastomer and plastomer mix types, although further testing is required to verify this.

4.1.2 Master Curves for Base Mixes

The mix composition for the bases comprises 10% RA 60/70 with either an elastomer modifier combined with FT wax or a plastomer modifier combined with a chemical additive. Figure 5 illustrates the Master Curves of 10% RA 60/70 base mixes.

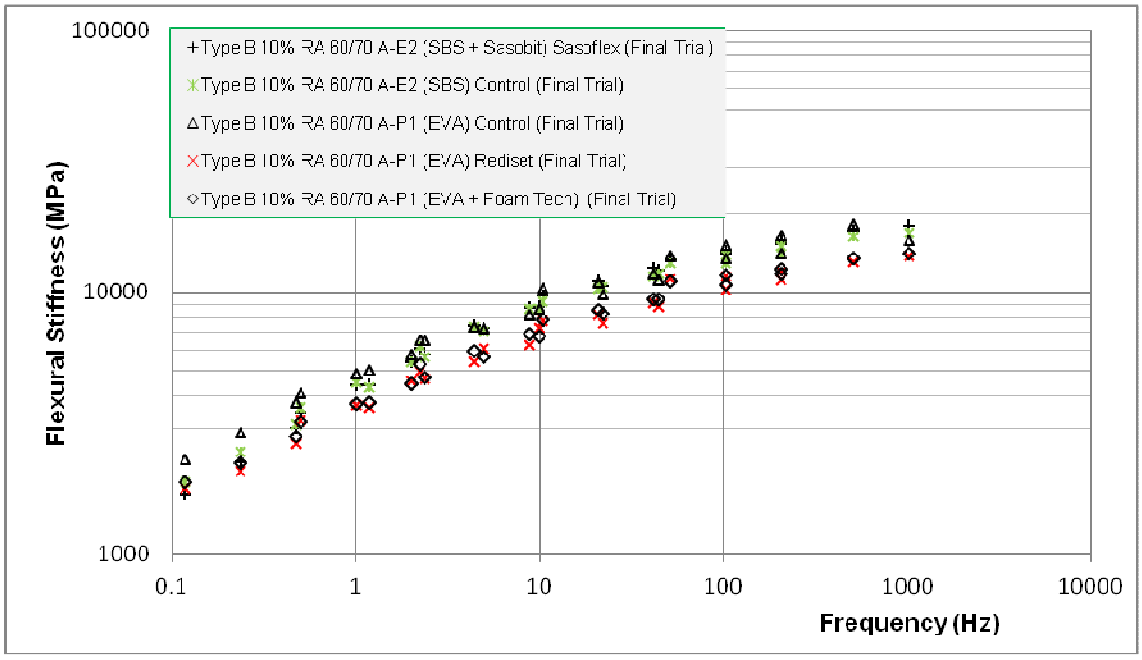

Figure 5 Master Curves of Type B 10% RA Base Mixes

The WMA trial mixes i.e. plastomer and elastomer trial mixes provide a marginally lower flexural stiffness than their respective control HMA mixes as illustrated in Figure 5. The plastomer control mix indicated the highest flexural stiffness. The base mixes yielded a narrower range of flexural stiffness from the master curves than the surfacing mixes.

Figure 6 illustrates Base mix types with 40% RA and 80/100 binder with either an elastomer or plastomer modifier that was blended with a WMA technology.

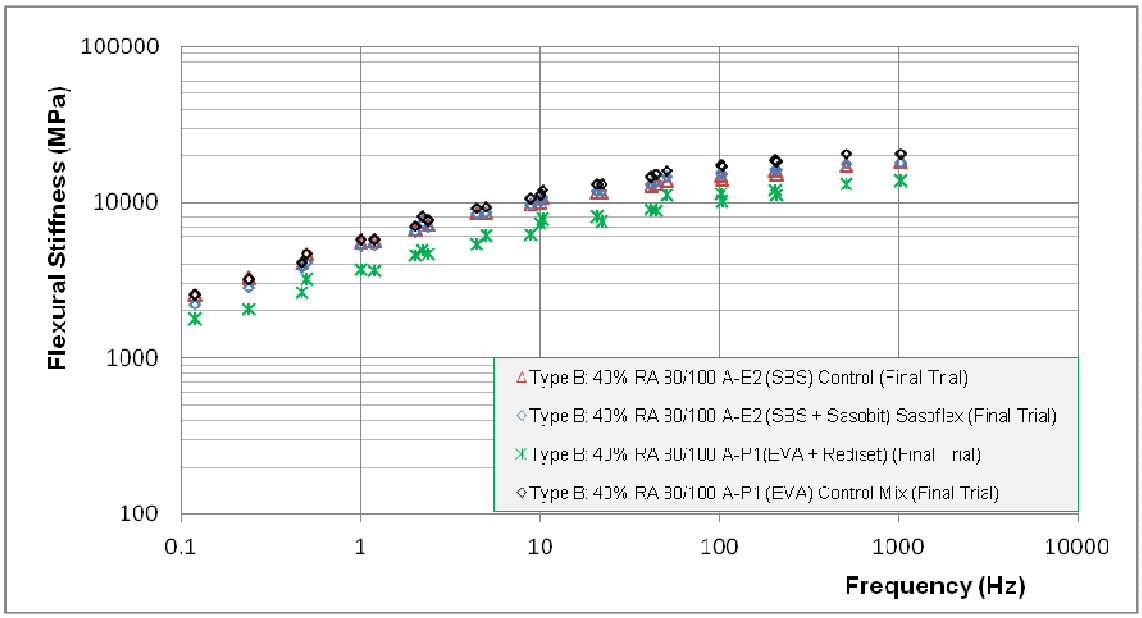

Figure 6: Master Curves of Type B 40% RA Base Mixes

In Figure 6, the plastomer control compared well with the elastomer control and elastomer WMA mixes unlike its plastomer WMA mix type. It was observed that, the difference amongst the 40% RA 80/100 mix types was also marginal.

4.1.3 Fatigue Results

The full set of fatigue results from the experimentation using the IPC Four Point Beam Apparatus, are discussed in this section. Table 7 lists three fatigue results per mix type as representative fatigue data. The strain regimes of high, low-medium and low are listed against the specimen number, initial and termination flexural stiffness as well as the resultant number of cycles to 50% reduction in initial flexural stiffness.

For base mixes, two low strain regimes were adapted after the application of a 300με (peak to peak) strain as noted earlier. Figures 7, 8 and 9 provide collective plots of the relative fatigue performance of surface and base mixes, respectfully.

The assessment of the fatigue properties of the mix types requires cognisance of the variables amongst the mixes. Figure 7 records the 10% RA 60/70 surfacing mixes and shows the control mix (plant) provides better relative fatigue performance than the WMA (plant) mixes. Amongst the WMA mixes, Foam provided the highest relative fatigue performance. Nevertheless, all technologies yielded lower relative fatigue performance than their respective control mixes.

Table 7: Fatigue Results for Type D Mix Types

Type D: Surface Mixes Fatigue Data					
Mix Recipe	**Beam No.**	**Initial Flexural Stiffness (MPa)**	**Termination Stiffness (50% of the initial Stiffness) (MPa)**	**Strain (Peak to Peak) με**	**Number of Cycles**
10% RA 60/70 (Control 1)	1	16,650	8,325	180	2,470,600
	2	15,808	7,904	230	925,500
	3	15,215	7,608	300	105,890
10% RA 60/70 Foam	1	18,266	9,133	180	2,724,260
	2	20,997	10,498	300	724,190
	3	15,707	7,854	380	514,810
10% RA 60/70 Chemical Additive	1	12,273	6,137	180	2,139,310
	2	12,140	6,070	230	224,340
	3	12,888	6,444	300	103,050
10% RA 60/70 FT wax	1	17210	8605	180	1,374,170
	2	16275	8138	230	325,420
	3	17131	8566	300	155,900
20% RA 80/100 A-P1 (Control 2)	8	17,783	8,891	230	2,621,380
	4	17,808	8,904	300	1,303,420
	1	16,562	8,281	380	292,700
20% RA 80/100 A-P1 Chemical Additive	8	15,990	7,995	230	>3,000,000
	12	16,627	8,314	300	1,394,780
	3	16,258	8,129	380	332,270
20% RA 80/100 A-E2 (Control 3)	11	15,794	7,847	230	2,877,640
	6	17,615	8,807	300	978,390
	3	15,849	7,929	380	110,720
20% RA 80/100 A-E2 FT wax	8	14,618	7,309	230	2,425,380
	6	12,857	6,418	300	923,000
	2	13,005	6,502	380	58,210
Type B: Base Mixes Fatigue Data					
Mix Recipe	**Beam No.**	**Initial Flexural Stiffness (MPa)**	**Termination Stiffness (50% of the initial Stiffness) (MPa)**	**Strain (Peak to Peak) με**	**Number of Cycles**
10% RA 60/70 A-P1 (Control 4)	1	19,312	9,656	180	2,294,070
	2	21,161	10,581	230	1,246,230
	3	19,561	9,781	300	429,170
10% RA 60/70 A-P1 Rediset™	1	18,471	9,236	230	327,380
	2	18,276	9,138	300	146,390
	3	17,444	8,722	380	118,320
10% RA 60/70 A-P1 Foam Tech	1	14,369	7,185	180	>3,500,000*
	2	16,393	8,197	230	160,510
	3	14,415	7,208	300	70,110
10% RA 60/70 A-E2 (Control 6)	1	17,526	8,763	180	1,408,000
	2	21,643	10,821	230	1,823,570
	3	17154	8577	300	344,430
10% RA 60/70 A-E2 Sasobit®	1	18,386	9,193	180	>3,000,000*
	2	17846	8923	230	>3,000,000*
	3	16,490	8,245	300	75,780
40% RA 80/100 A-E2 (Control 7)	1	18,026	9,013	180	1,920,090
	2	17,988	8,994	230	649,580
	3	17,377	8,688	300	331,100
40% RA 80/100 A-E2 Sasobit®	1	16,581	8,290	180	1,475,790
	2	19,709	9,855	230	411,410
	3	16,981	8,491	300	159,830

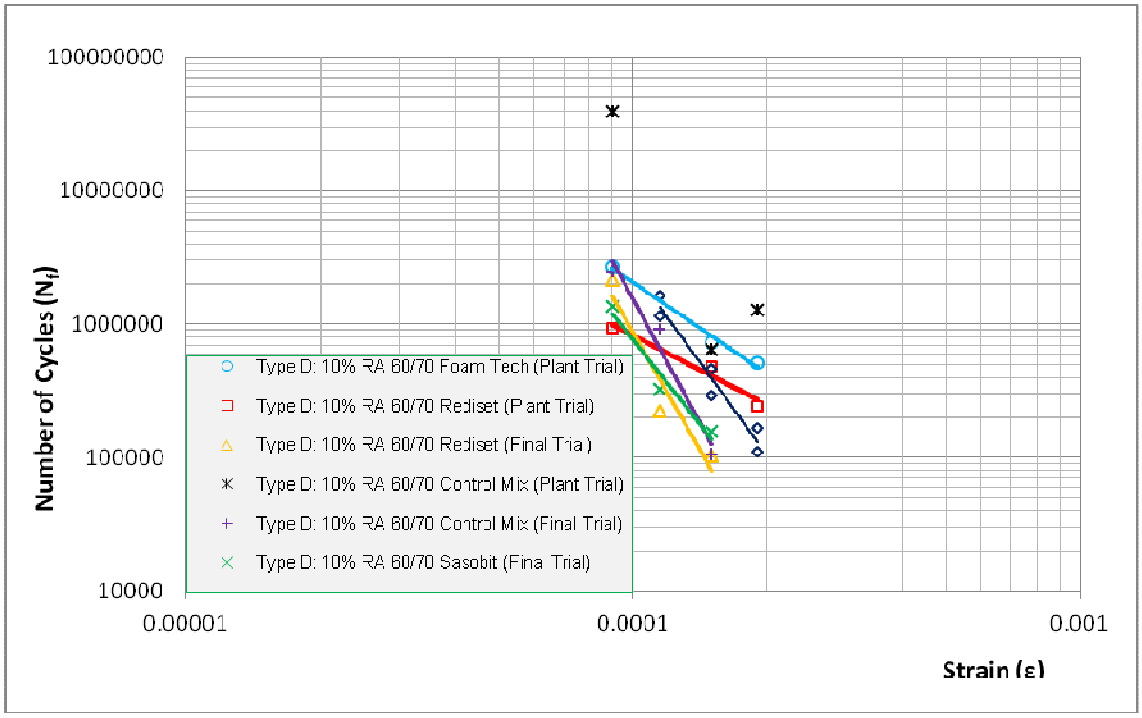

Figure 7 Fatigue Relations for Type D Surfacing Mixes with 10% RA and 60/70

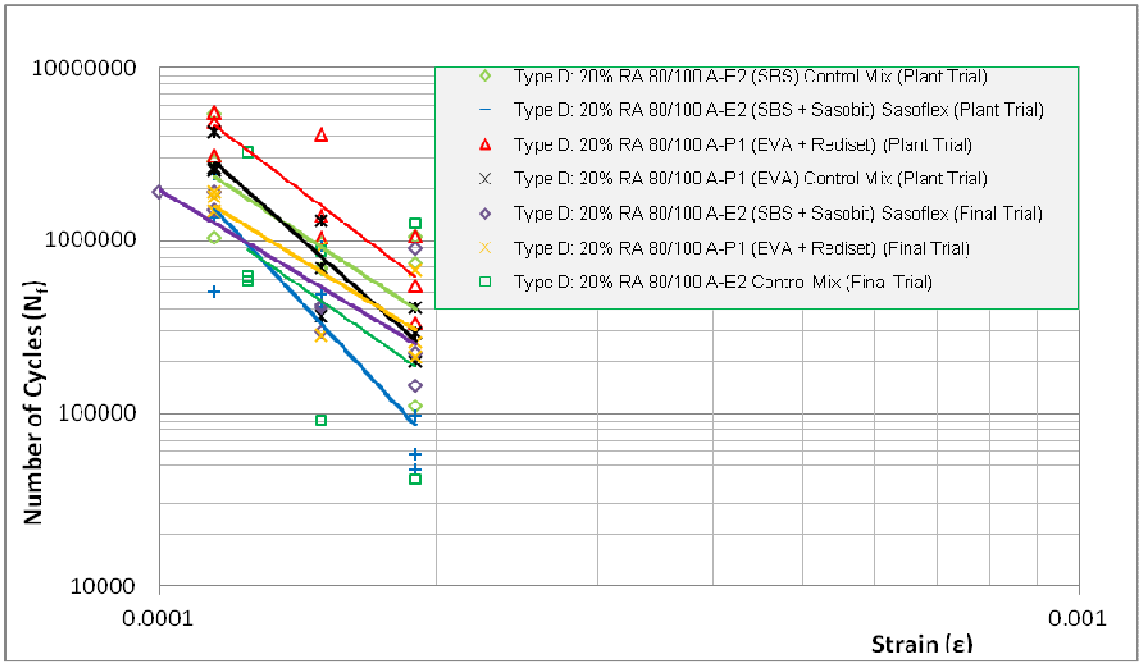

Figure 8: Fatigue Relations for Type D Surfacing Mixes with 20% RA and 80/100

The WMA plastomer mix type i.e. with the chemical additive (plant trial), provided better relative fatigue performance than its equivalent control mixes and the elastomer mixes as shown in Figure 8. Unlike the WMA plastomer (plant trial), the WMA elastomer (plant trial) indicated a lower relative fatigue performance than its control mix (plant trial). However, with the final trial a better fatigue performance (though marginal) was observed. This is attributed to mix adjustments made during the final trial.

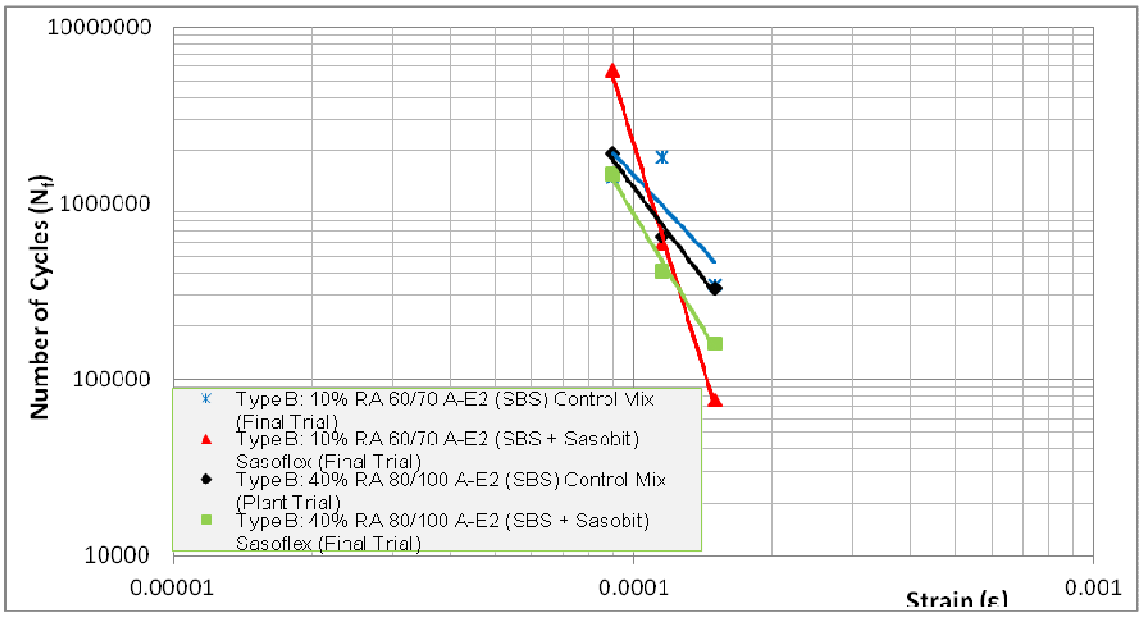

Figure 9: Fatigue Relations for Type B Mixes with 10% RA 60/70 and 40% RA 80/100

The modified binders introduced some differences to the WMA fatigue trends, as seen in Figure 8. The incorporation of an elastomeric modifier has the benefit of higher relative fatigue performance. However, the 40% RA 80/100 elastomer with the FT wax did not provide as good fatigue properties as the 10% RA 60/70 elastomer. Further research into the limits of recycled asphalt content and bitumen chemistry is recommended.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Preliminary evaluations of WMA mixes in full-scale production have identified the potential for their use as surface and base materials in southern Africa. In general, the flexural stiffness and fatigue properties of the WMA are slightly (but acceptably) lower than those of HMA. However, it has been shown that elastomers and plastomers can be used to enhance the performance of WMA very effectively, if required. It is recommended that ongoing trials and laboratory studies be conducted to accrue knowledge and enhance expertise in this technology. This will encourage sustainable solutions to be found for the southern African road networks.

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Disclaimer

Trade names entailed in this paper are used for the purposes of information only and not for trade or product endorsement.

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