FIELD IMPLEMENTATION OF WARM MIX ASPHALT USING DIFFERENT BINDERS

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ABSTRACT

The objective of this paper is to present the results and observations obtained from the laboratory tests and field implementations of warm mix asphalt (WMA) formulated using different binders. Laboratory tests were performed using the WMA mixes and the conventional hot mix asphalt (HMA) as a reference prior to implementation at the sites. The WMA mixes were laid at 2 different locations (i.e. along a major road and in a road tunnel) in Singapore. The performance of the WMA mixes was assessed by conducting temperature measurements during laying operations and monitored through visual inspections and by measuring riding quality of the road in terms of International Roughness Index. From the laboratory results, it was observed that the WMA mixes provided similar results as compared with the conventional HMA. From the field implementations, it was noted that the WMA mixes produced similar workability as compared to HMA. In addition, it was observed that WMA can be compacted at the lower temperature of approximately 110 ˚C.

Keywords: Warm mix asphalt (WMA), hot mix asphalt (HMA), International Roughness Index (IRI), compaction temperature, workability

1. INTRODUCTION

A wide variety of industrial activities including those from the asphalt pavement industry contributes to the greenhouse gas emissions. Thus the pavement industry has continually strived to reduce the greenhouse effect by recycling more asphalt and reducing emissions in order to become a more environmental friendly industry. In the recent years, warm mix asphalt (WMA) technologies have been studied by many researchers in the pavement industry with an aim to reduce the mixing and compaction temperatures of asphalt mixes. Besides having lower mixing and compaction temperatures, the benefits of WMA have been reported as lower energy consumption, less greenhouse gas emissions, reduced oxidation of asphalt, early opening to traffic and a better work environment for workers [1-8].

In this study, 2 warm mix asphalt mixes formulated using an additive and a pre-blended binder were studied and implemented along Bedok North Road and in the road tunnel of Kallang Paya Lebar Expressway (KPE), respectively, to evaluate the performance. These warm mix asphalt mixes formulated using the additive and pre-blended binder are denoted as WMA-A and WMA-B, respectively, from here onwards. The main purpose of this study is to understand the performance of warm mix asphalt formulated using different binders. Prior to implementation at the sites, laboratory tests, namely moisture sensitivity test, indirect tensile test, rutting resistance test, dynamic creep test and maximum density test were performed using the WMA mixes (WMA-A and WMA-B) and the conventional hot mix asphalt (HMA) for comparison. The results and observations obtained from the laboratory tests and the field performance monitoring are presented in detail in the following sections.

2. MIX DESIGN AND PROPERTIES OF BITUMEN

2.1 Mix Design

The dense mix composition known as W3B commonly used in Singapore mix was employed in this study for both hot mix asphalt and warm mix asphalt with different binders. Figure 1 presents the typical aggregate gradation curve of W3B mix. The binder content used in the mix design ranged from 4.5 to 5.5 percent by the weight of total mix.

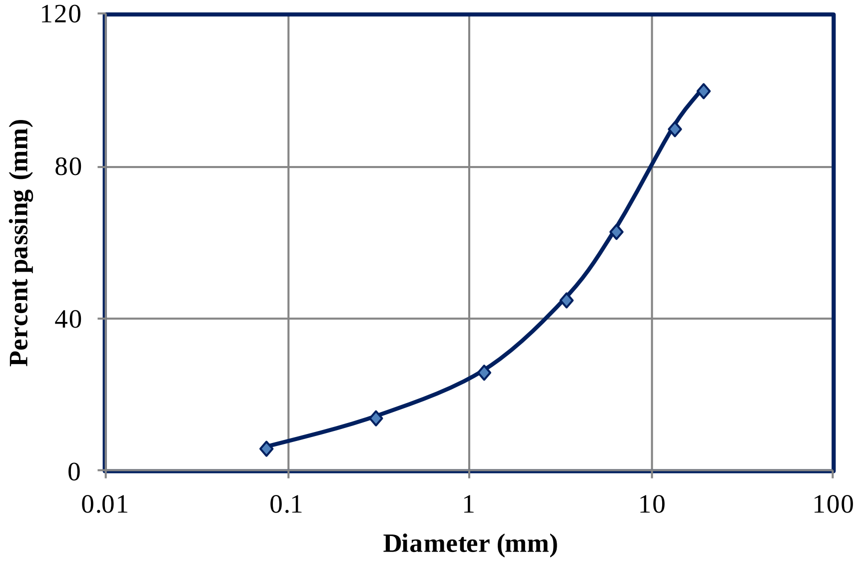

Figure 1: Typical aggregate gradation of W3B

2.2 Properties of Asphalt Binder

2.2.1 WMA-A

The binder used was the penetration grade Pen 60/70 and the additive dosage used was 0.5% by mass of binder. It is a viscous liquid with a pH value ranging from 10 to 12, a boiling point greater than 200˚C and a density of 0.99 g/cm^3. The binder was first heated in an oven and then the additive was added using a syringe and blended manually using a stirrer. The properties of the bitumen with and without the additive were tested with respect to penetration test, softening point and rotational viscosity test at various temperatures as summarized in Table 1. From the comparison as shown in Table 1, it was observed that there was no change in the values of the penetration and softening point. However, the percentage differences ranging from 9% to 22% were observed for the values of viscosity at different temperatures.

Table 1: Summary of properties of the bitumen with and without additive

Property	Without additive	With additive	Specification
Penetration	62	62	ASTM D5
Softening Point	45	45	ASTM D36
Viscosity @135˚C	0.45	0.41	ASTM D4402
Viscosity @120˚C	1.00	0.78	ASTM D4402
Viscosity @110˚C	1.90	1.50	ASTM D4402

2.2.2 WMA-B

The pre-blended binder used in this study was supplied by the manufacturer as a modified bitumen and its properties are summarized in Table 2.

Table 2: Summary of properties of pre-blended binder

Property	Value	Specification
Penetration at 25°C 0.1 mm	≥ 40	ASTM D5
Softening point R & B method °C	≥ 50	ASTM D36
Solubility in 1,1,1 trichloroethylene %	≥ 99	ASTM D2042
Flash Point (Cleveland Open Cup) °C	≥ 232	ASTM D92
Loss on heating %	≤ 0.2	ASTM D6
Drop in penetration after heating %	20	ASTM D5
Relative Density @ 25/25ºC	1.00 – 1.06	ASTM D70

3. TEST RESULTS

3.1 Laboratory Tests

3.1.1 Samples Preparation

Table 3 summarizes the laboratory tests performed using WMA-A and WMA-B. The laboratory tests were also carried out using the conventional HMA and the results were compared to evaluate the performance.

Table 3: Summary of laboratory tests performed for WMA-A, WMA-B, and HMA

Test	Specification
Moisture sensitivity test	BS EN 12697-12: 2007
Indirect tensile test	BS EN 12697-23: 2003
Rutting resistance test	BS EN 12697-22: 2003
Dynamic creep test	BS EN 12697-25: 2005 (Methods A and B)
Maximum density test	BS EN 12697-5: 2009

For preparation of samples, the required amount of aggregates were heated in an oven for about 2 hours and then mixed with heated bitumen in an asphalt mixer to provide a uniform mixing of the aggregates and bitumen. After mixing, the asphalt samples were then transferred to a mould and the compaction was carried out via a hydraulic laboratory roller compactor. To prepare identical samples, the same number of compaction passes was used for the hot and warm mix asphalt specimens. Figure 2 shows the sample preparation process. During sample preparation, temperatures during mixing and compaction were also measured and summarized in Table 4.

(a) (b)

(c)
Figure 2: Sample preparation process

Table 4: Average Mixing and compaction temperatures of WMA and HMA used in the study

Description	Comparison of WMA-A & HMA		Comparison of WMA-B & HMA	
	HMA	**WMA-A**	**HMA**	**WMA-B**
Mixing temperature (˚C)	150	130	150	130
Compaction temperature (˚C)	130	110	130	100

Different mould sizes were used for the compaction i.e. 305mm × 305mm × 50mm moulds were used for wheel tracking test specimens and 305mm × 305mm × 63.5mm moulds were used for all other tests. After the compacted samples were cooled for at least 24 hours, coring was carried out on the 305mm × 305mm × 63.5mm samples to obtain various sizes of cylindrical samples as shown in Figure 3. The size and the number of cores used for different tests are summarized in Tables 5 and 6. Prior to testing, the density of the samples was measured to check that they are adequately compacted to the required density.

Figure 3: Cored samples used for different tests

Table 5: Numbers of sample used and sample sizes for different tests using WMA-A

Type of test	Hot mix asphalt	Warm mix asphalt	Shape and size of sample
Moisture sensitivity test	3	3	Cylinder, 100 mm x 63.5 mm thk
Indirect tensile test	6	6	Cylinder, 100 mm x 63.5 mm thk
Rutting resistance test	6	6	Square , 305 mm x 305 mm x 50 mm thk
Dynamic creep test	5	5	Cylinder, 150 mm x 63.5 mm thk (Method A)
Maximum density test	3	3	Loose sample

Table 6: Numbers of sample used and sample sizes for different tests using WMA-B

Type of test	Hot mix asphalt	Warm mix asphalt	Shape and size of sample
Moisture sensitivity test	3	3	Cylinder, 101.5 mm x 62.9 mm thk

Indirect tensile test	6	6	Cylinder, 100 mm x 63.5 mm thk
Rutting resistance test	3	3	Square , 300 mm x 300 mm x 50 mm thk
Dynamic creep test	4	4	Cylinder, 101.5 mm x 63.0 mm thk (Method B)
Maximum density test	1	1	Loose sample

3.1.2 Moisture Sensitivity Test and Indirect Tensile Test

Moisture sensitivity test was conducted to evaluate the effect of moisture damage on the indirect tensile strength (ITS) of samples. Indirect tensile tests were performed using wet and dry samples to obtain the indirect tensile strength ratio (ITSR). Prior to wet ITS tests, samples were partially saturated with moisture via vacuum pressure at 50 mm Hg and then soaked in water for a period of approximately 70 hrs at 40˚C as shown in Figure 4.

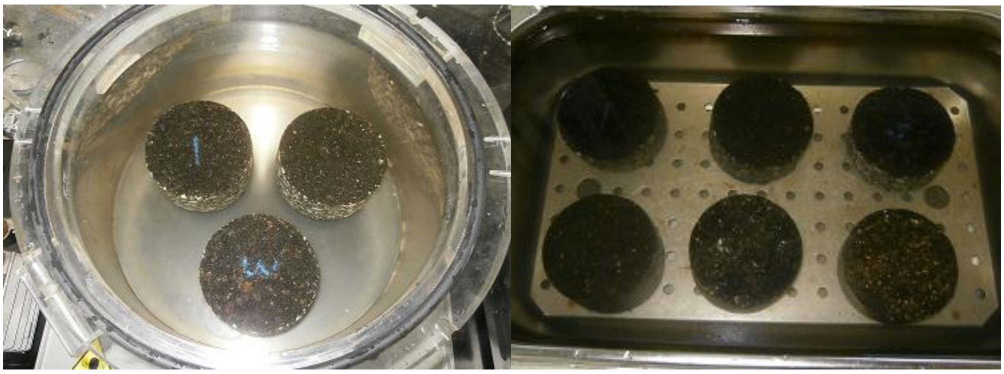

Figure 4: Typical moisture conditioning of wet samples

For ITS tests, a diametrical load is applied with a deformation rate of 50 mm/min until the peak load was reached as shown in Figure 5. All samples were tested at the room temperature (~ 25˚C). The values of dry and wet ITS obtained from the tests using WMA-A and WMA-B compared with HMA are summarized in Tables 7 and 8. In addition, the average ITSRs were also obtained by dividing the wet ITS with the respective dry ITS and the results are presented in Tables 7 and 8. A high ITSR implies a high resistance to moisture damage. From the results, both WMA-A and WMA-B achieved high ITSR which indicate both are high resistance to moisture susceptibility and comparable with HMA.

Figure 5: Typical indirect tensile strength test

Table 7: Summary of tensile strength tests for comparison of WMA-A with HMA

Sample no.	Hot mix asphalt		Warm mix asphalt	
	Dry ITS (kPa)	**Wet ITS (kPa)**	**Dry ITS (kPa)**	**Wet ITS (kPa)**
1	854.2	--	851.1	--
2	854.1	--	975.7	--
3	936.6	--	715.3	--
4	--	806.8	--	858.5
5	--	647.8	--	820.7
6	--	688.1	--	825.1
Average	**881.6**	**714.2**	**847.4**	**834.8**
ITSR	**81%**		**99%**	

Table 8: Summary of tensile strength tests for comparison of WMA-B with HMA

Sample no.	Hot mix asphalt		Warm mix asphalt	
	Dry ITS (kPa)	**Wet ITS (kPa)**	**Dry ITS (kPa)**	**Wet ITS (kPa)**
1	1559.5	--	1226.9	--
2	1346.1	--	921.1	--
3	1429.6	--	978.6	--
4	--	1607.6	--	1014.7
5	--	1285.4	--	846.7
6	--	1138.0	--	1000.0
Average	**1445.1**	**1343.7**	**1042.2**	**953.8**
ITSR	**93%**		**92%**	

3.1.3 Rutting Resistance Test

The rutting resistance tests were carried out at a test temperature of 60˚C under a wheel load of 700 N. Figure 6 shows a typical test set-up for rutting resistance test. The experimental results obtained from the tests using WMA-A and WMA-B are compared with that of HMA in Tables 9 and 10. From the comparison, it was observed that similar values of rut depth ranging from 2.20 mm to 3.13 were obtained for WMA-A, WMA-B and HMA.

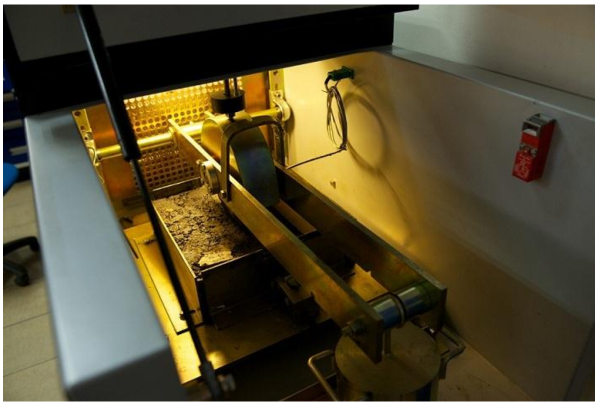

Figure 6: Typical wheel tracking test

Table 9: Summary of wheel tracking tests for comparison of WMA-A with HMA

Sample no.	Hot mix asphalt		Warm mix asphalt	
	Rut depth (mm)	Wheel tracking rate (μm/cycle)	Rut depth (mm)	Wheel tracking rate (μm/cycle)
1	2.80	0.94	3.40	1.18
2	3.00	1.06	2.70	0.89
3	2.40	0.77	2.90	1.00
4	2.50	0.77	3.20	1.11
5	2.90	0.99	3.60	1.34
6	2.70	0.87	3.00	1.02
Average	**2.72**	**0.90**	**3.13**	**1.09**

Table 10: Summary of wheel tracking tests for comparison of WMA-B with HMA

Sample no.	Hot mix asphalt		Warm mix asphalt	
	Rut depth (mm)	Wheel tracking rate (mm/hr)	Rut depth (mm)	Wheel tracking rate (mm/hr)
1	2.7	1.6	2.7	1.6
2	3.1	1.7	1.7	1.0
3	3.1	2.0	2.3	1.7
Average	**3.0**	**1.8**	**2.2**	**1.4**

3.1.4 Dynamic Creep Test

Dynamic creep test was conducted at a test temperature of 40˚C and under the uniaxial compressive stress of 100 kPa for both WMA-A and WMA-B samples. However different load cycles and specimen diameters were employed for the tests performed using WMA-A and WMA-B as indicated in Tables 11 and 12. The results obtained from different tests are also summarized in Tables 11 and 12 for comparison with HMA. As shown in Table 11 and Table 12, both WMA-A and WMA-B showed that the creep moduli are quite similar to HMA under the same test conditions.

Figure 7: Typical dynamic creep test

Table 11: Summary of dynamic creep tests for comparison of WMA-A and HMA

Sample no.	Hot mix asphalt Creep Modulus (MPa) under 3600 cycles @ 150mm diameter sample	Warm mix asphalt Creep Modulus (MPa) under 3600 cycles @ 150mm diameter sample
1	4.86	4.72
2	3.66	5.97
3	5.98	5.01
4	4.91	3.9
5	4.54	4.5
Average	**4.79**	**4.82**

Table 12: Summary of dynamic creep tests for comparison of WMA-B and HMA

Sample no.	Hot mix asphalt Creep Modulus (MPa) under 7200 cycles @101.5 mm diameter sample	Warm mix asphalt Creep Modulus (MPa) under 7200 cycles @101.5 mm diameter sample
1	20.6	23.1
2	30.5	29.9
3	29.5	28.2
4	24.7	28.1
Average	**26.3**	**27.3**

3.1.5 Maximum Density Test

Maximum density tests were performed for WMA-A, WMA-B and HMA for comparison. The uncompacted samples were placed in the pyknometer and filled with water for vacuuming process. A partial vacuum of a residual pressure of 4 kPa was applied for 15 minutes to evacuate entrapped air. After vacuuming, the pyknometer was fully filled with water and the maximum density of the test sample was determined according to the test standard. The average maximum density of 2.4 Mg/m^3 was obtained for all tested samples.

3.2 Field Implementations

3.2.1 Implementation of WMA-A along Bedok North Road

In total 665 lane meters and 598 lane meters of WMA-A and HMA, respectively, were laid along Bedok North Road as shown in Figure 8. The sections laid using HMA were used as the control sections for performance monitoring. The existing wearing course was milled and replaced with a 50 mm thickness wearing course using WMA-A and HMA. The works was completed on 3 and 4 March 2011.

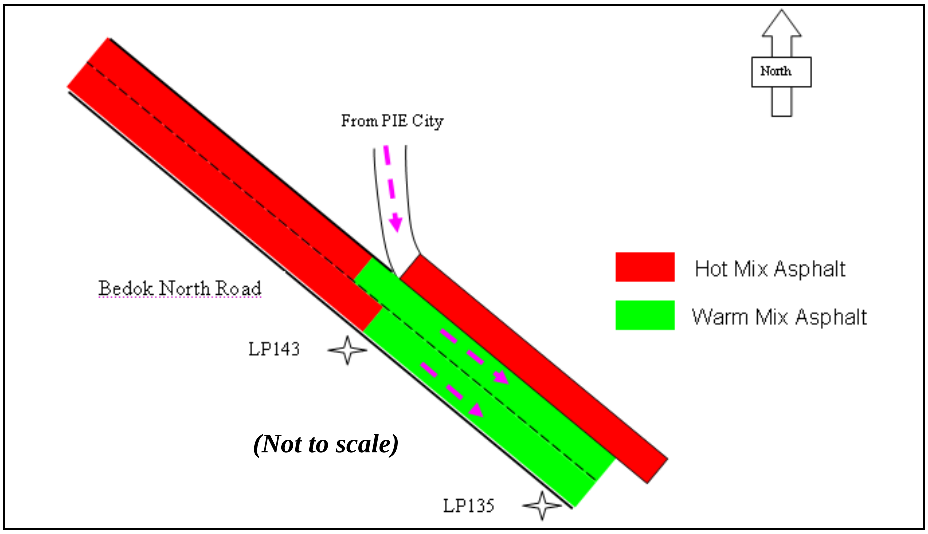

Figure 8: Schematic layout of field implementation

Figure 9 shows the photos indicating the surface temperatures of WMA-A and HMA measured using a digital thermometer and the photos taken during loading of respective asphalt mixes into the paver during laying process. It was observed from the field implementation that WMA-A can be compacted at the lower temperature (~110 ˚C) and produced lesser fume emissions than HMA. For performance monitoring, riding quality of the pavement expressed in terms of International Roughness Index (IRI) was obtained for both WMA-A and HMA, respectively, and the results were summarized in Table 13. The values of IRI for WMA-A and HMA ranged from 1.78 mm/m to 2.50 mm/m. In addition, visual inspections were also conducted and to date, no surface distresses or defects were observed at the site.

Hot Mix Asphalt

Temperature measurement for HMA

Warm Mix Asphalt

Temperature measruement for WMA-A

Smoky HMA during loading

Relatively smoke-free WMA-A during loading

Figure 9: Field implementation of WMA-A and HMA along Bedok North Road

Table 13: Summary of IRI results for WMA-A and HMA

Date	IRI (mm/m) on Lane 1		IRI (mm/m) on Lane 2	
	HMA	WMA-A	HMA	WMA-A
17/03/2011	1.71	1.91	2.16	2.52
19/04/2011	1.74	1.99	2.08	2.41
01/08/2011	1.81	1.86	2.10	2.47
24/02/2014	1.85	2.02	2.35	2.60
Average	**1.78**	**1.94**	**2.17**	**2.50**

3.2.2 Implementation of WMA-B in the KPE tunnel

Field implementation of WMA-B was carried out in the KPE road tunnel on 25 Sep 2013. Figure 10 shows the schematic layout of the field implementation of WMA-B. A total of 450 lane meters of WMA-B was laid on the slow lane in the KPE road tunnel with a single lane closure as shown in Figure 11. This figure also shows the surface temperatures of WMA-B and the tunnel ceiling measured during the laying process. It was observed that WMA-B can be compacted at the lower temperature of approximately 103 ˚C in the tunnel environment. The condition of the pavement was also monitored by performing IRI measurements and the results are summarized in Table 14. From the IRI results, improved riding quality of the pavement was observed after laying WMA-B in the road tunnel. Besides measuring the riding quality, visual inspections were performed to monitor the pavement conditions. From the visual inspections, no surface distresses and defects were observed at the site.

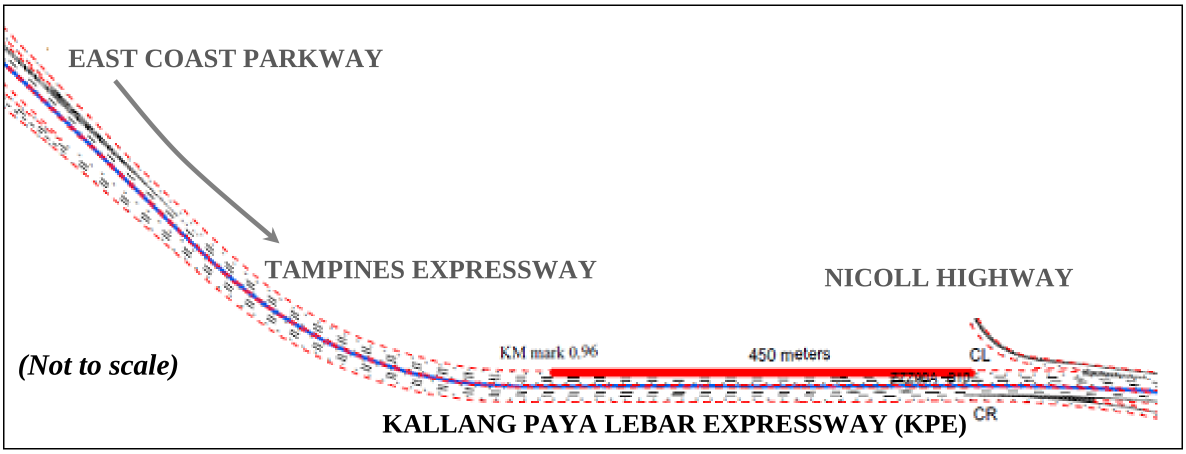

Figure 10: Schematic layout for the field implementation of WMA-B in the KPE road tunnel

Work carried out within a single lane closure

Almost smoke-free WMA-B

Temperature monitoring at the tunnel's ceiling

Temperature measurement for WMA-B

Figure 11: Field implementation of WMA-B in the KPE road tunnel

4. SUMMARY

The performance of WMA formulated using two different binders (i.e. WMA-A and WMA-B) were investigated and compared with the conventional HMA in this study. Laboratory tests were performed prior to implementation at the sites. The field implementations of WMA-A and WMA-B were carried out along Bedok North Road and in the KPE road tunnel to evaluate the on-site performance under different work environments. Based on the laboratory tests and field implementations, the following findings can be concluded as:

- From the moisture sensitivity and indirect tensile tests, it was observed that both WMA-A and WMA-B achieved high ITSR ratios which indicate both are high resistance to moisture susceptibility and comparable with HMA.
- Based on the experimental results obtained from rutting resistance tests, similar values of rut depth ranging from 2.20 mm to 3.13 were obtained for all tested samples of WMA-A, WMA-B and HMA.
- For the dynamic creep tests, both WMA-A and WMA-B showed similar values of creep modulus as that of HMA under the same test conditions.
- From the field implementation performed along Bedok North Road and in the KPE road tunnel, it was observed that both WMA-A and WMA-B were compacted at the lower temperature with less fume emissions and provided comparable performance as that of HMA in terms of riding quality and workability.

5. ACKNOWLEDGEMENTS

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