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Procedia - Social and Behavioral Sciences 104 (2013) 158 – 167

Procedia
Social and Behavioral Sciences2nd Conference of Transportation Research Group of India (2nd CTRG)

Evaluation of field performance of warm-mix asphalt pavements in India

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Abstract

The United States and European countries are increasingly using “warm-mix” technologies that allow a significant reduction in the production and placement temperatures of asphalt mixes. Such mixes are also gaining popularity in other parts of the world in countries like China, Brazil and India. Though warm-mix asphalt (WMA) is a relatively new technology, contractors and Government agencies in the West have been quick to recognize the environmental and performance benefits of warm-mixes due to extensive research. This research has also allowed several Government agencies, such as the Federal Highway Administration (FHWA), to promote WMA as an important technological innovation for the industry. Many agencies have developed specifications for the use of WMA, which allows more contractors to use WMA. In India, Central Road Research Institute (CRRRI) has carried out initial research on the effects of WMA on Indian mixes. Certain warm-mix technologies have since been used to pave major national and state highways as well. However, lack of awareness and skepticism of field performance is shying more contractors and agencies from using WMA extensively as in the West.

This paper attempts to evaluate the field performance of two pavements constructed using an IRC accredited surfactant based chemical warm-mix technology. The two pavements evaluated in this study were produced and placed at a significantly lower temperature relative to the control hot-mix sections. Both the pavements were evaluated after considerable exposure to weather elements and traffic. Methods like Benkelman beam deflection, bump integrator value, and Marshall stability, resilient modulus and static creep test on field cores were used to evaluate the performance of the WMA sections in comparison to the control hot-mix sections. The results of the study indicate that in spite of the several monsoons and heavy traffic both pavements were exposed to, the performance of the warm-mix sections was equal or better compared to the control hot-mix sections. Due to the improved densities achieved at the site, and due to the reduced oxidation of the bitumen as a result of the lower production and placement temperatures, the performance of the warm-mix seemed to be improved in terms of permanent deformation and resilient modulus.

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Selection and peer-review under responsibility of International Scientific Committee.

Keywords: Warm mix asphalt; warm mix asphalt performance; field performance

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1. Introduction

In order to reduce the emissions from the asphalt plants, the asphalt industry is constantly trying to reduce mixing and compaction temperatures of mixes, without significantly affecting the properties of the mixes. The asphalt industry has been experimenting with warm and cold asphalt mixtures for decades to reduce energy requirements and for environmental benefits. Warm mix asphalt (WMA) is an asphalt mixture which is mixed at temperatures lower than conventional hot mix asphalt. Typically, the mixing temperatures of warm mix asphalt range from 100 to 140 °C compared to the mixing temperatures of 150 to 180 °C for hot mix asphalt. Additionally, rising energy prices, global warming, and more stringent environmental regulations also have resulted in an interest in warm mix asphalt technologies as a mean to decrease energy consumption and emissions associated with conventional hot mix asphalt production.

Apart from the obvious advantages such as reduced fuel consumption and reduced emissions, there are several other advantages of using warm asphalt like longer paving ‘seasons’, longer hauling distances, reduced wear and tear of the plants, ability of opening the site to traffic sooner, higher use of reclaimed asphalt pavements (RAP), etc. Moreover, after years of extensive laboratory and field studies (Gandhi, T, 2008; Biro, S. et.al., 2009; Gandhi, T., et.al., 2010; Gandhi, et.al., 2009; Crews, E., et.al., 2012; Bower, N, 2012; Prowell, G., et.al, 2007; Aschenbrener, T, et.al, 2011), it has become apparent that warm asphalt technology provides a means of producing more durable asphalt pavements while simultaneously achieving the aforementioned environmental, human health, and constructability benefits.

The objective of this paper is to compare the field performance of similar hot mix and warm mix sections. This paper presents data collected right from the construction phase of two warm mix pavements located in different climatic regions of India to their performance over a period of time after being subjected to weather elements and heavy traffic. The warm mix pavement sections were compared to the adjacent control hot mix sections for both these projects.

2. Projects evaluated

Two projects were identified and evaluated in this study. The first field trial of warm mix in India was laid over a 500 meter section of road at Bawana industrial area owned by the Delhi State Infrastructure Development Corporation (DSIDC). The trial was placed using a surfactant based chemical warm mix additive and crumb rubber modified bitumen (CRMB) on August 10th, 2009. The warm mix section was 11 meters wide and 40mm thick bituminous course mix. The field evaluations were carried out on March 5th and 6th, 2012.

The second project evaluated was placed on April 7th, 2011 on State Highway (SH) – 5 in Gujarat between Godhra and Halol. The warm mix section was one kilometer in length, 7.5 meters wide and 40mm thick in the bituminous course. Following the construction of the pavement, field evaluations were carried out on May 11th and 12th, 2012.

3. Construction details

3.1. DSIDC Road, Bawana, Haryana

The plant used to produce the warm mix as well as the control hot mix was an Enmount batch plant. The mix produced was a dense graded mix with a nominal maximum aggregate size of 13.2mm. Binder used in this mix was a VG-30 bitumen modified with 15% crumb rubber. The final grade of the bitumen was CRMB-60, added to the mix at a total asphalt content of 5.3% by weight of the mix. The job mix formula and the aggregate gradation are shown in Table 1 and 2. A surfactant based warm mix additive was used, added to the bitumen at 0.5% by weight of the bitumen before mixing with the aggregate and preparing the mix.

Table 1. Job mix formula of the mix produced

Property	Value
Grade of Bitumen Used	CRMB-60
Optimum binder content by weight of mix	5.3
Marshall Stability Value, kN	13.02
Flow, mm	3.1
Percent Retained Stability, %	92
Bulk Density, gm/cc	2.353
Air Voids, %	4.22

Table 2. Aggregate gradation used

IS Sieve	Percent Aggregate Passing				Blend Percent Passing
	A 13.2mm	B 6mm	C Stone Dust	D Lime	
19mm	100	100	100	100	100
13.2mm	90	100	100	100	97
9.5mm	31	100	100	100	79
4.75mm	2	63	100	100	62
2.36mm	0	22	94	100	48
1.18mm	0	0	85	100	39
600 μ	0	0	63	100	29
300 μ	0	0	51	100	24
150 μ	0	0	31	98	16
75 μ	0	0	11	88	7
Unit Weight (kg/m ³)	1512	1568	1704		

The control mix was produced at a temperature ranging from 155 – 160 °C, whereas the warm mix was produced at a temperature approximately 125 – 130 °C, leading to a drop of roughly 30 °C from the conventional hot mix production temperature. At the site, ambient conditions were roughly 40 °C air temperatures, bright

sunshine, and a slight wind with gusts up to 9 kmph. The site was about 30 minute haul from the plant. The temperature of the mix delivered at the site was roughly between 100 and 115 °C (as shown in Figure 1).



Figure 1. Warm mix delivery temperature at site

Two pavers were used in echelon to provide complete coverage of the 11-meter wide roadway. Warm mix was placed over an asphalt base course to which a tack coat had previously been applied. Two steel wheel compactors were being used to compact the pavement. Mat surface temperature just as compaction began ranged between 70 – 90 °C. Even at such low temperatures, there was excellent compaction of the mat. Additional details regarding the construction and placement of the warm mix pavement can be found in a previous paper (Behl, et.al., 2011).

3.2. State Highway – 5, Halol – Godhra, Gujarat

Warm mix was utilized to construct a portion of a new four lane divided highway. The mix was a 19mm nominal maximum aggregate size prepared with VG-30 grade bitumen. Two north bound lanes for one kilometer length were paved using a surfactant based warm mix additive added to the bitumen at 0.4% by weight of bitumen. A Lintec batch plant was used to produce the control hot mix as well as the warm mix. The plant produced lab compacted volumetric properties of the mixes and the gradation of the mixes are as shown in Table 3 and 4.

Table 3. Job mix formula of the SH-5 project

	Conventional HMA	WMA
Optimum Binder Content (%)	5.1	5.1
Max. Specific Gravity	2.578	2.578
Avg. Bulk Density	2.399 gm/cc	2.405 gm/cc
Air Voids (%)	6.94	6.71
VMA (%)	18.82	18.61
VFA (%)	63.12	63.94
Stability (kN)	13.69	13.65
Flow (mm)	2.6	2.5
Mixing Temperature (°C)	150-155	125-130
Compaction Temperature (°C)	130-135	100-105

Table 4. Aggregate gradation

Sieve Size (mm)	Percent Passing
26.5	100
19	100
13.2	87.2
9.5	77.7
4.75	58.4
2.36	47.9
1.18	38.8
0.6	34.9
0.3	24.5
0.075	7.7

The warm asphalt trial stretch was constructed on April 7th, 2011, with the conventional hot mix stretch on April 6th, 2011. The ambient air temperature was around 37 °C at the start of the day, rising to a maximum of 42 °C. Both stretches were one kilometer, 8.5m wide and 40mm thick, hot mix paved on the North bound lanes followed by warm mix paved on the North bound lanes. The observed temperatures during placement and compaction are as recorded in Table 5.

Table 5. Placement and compaction temperatures

	Conventional Hot Mix	Warm Mix
Production Temperature (°C)	~160	~130
Mix Delivery Temperature (°C)	140-150	125-130
Mix Temperature Behind Paver (°C)	130-145	120-125
Break-down Compaction Temperature (°C)	130-135	110-115
Finishing PTR Compaction Temperature (°C)	90-100	70-80
Mix Haul Time (min)	15-25	15-25
Core Air Voids after compaction (%)	5.70	3.99

Dropping the mixing temperature by 30°C resulted in the plant burner opening to drop from 50% down to about 15%, indicating a significant savings in the fuel consumed to produce the warm mix compared to the conventional hot mix. Additionally, the mixing time in the pug mill was lowered from 26 seconds for hot mix to 23 seconds for warm mix, indicating a 12% increase in the rate of production. This reduction in the mixing time was possible due to the ability of the surfactant based warm mix additive to impart better coating and workability at lower temperatures.

In spite of the lower placement and compaction temperatures, the site Engineers were surprised at the ability of the warm mix to hold temperature uniformly and steadily, allowing for uniform compaction of the pavement mat. The movement of material under the mat was noticeably less compared to the control hot mix, and the surface texture looked smoother and denser than the conventional hot mix section. The problems faced by them in handling hot mix that has cooled down due to paver breakdowns, etc. could be easily addressed by the warm mix.

4. Methods used for field performance monitoring

Typical test methods were used to collect data along the warm mix as well as the control hot mix stretches. This was done to compare the performance of the warm mix sections in comparison to the control hot mix sections. The evaluation process essentially consisted of tests like Benkelman beam deflection (BBD) test, bump integrator value and coring of field samples for laboratory evaluation. The cores were then subjected to the following tests.

- Marshall stability
- Static creep test
- Resilient modulus from indirect tensile modulus test

4.1. Benkelman beam deflection test

The deflection data was collected using a standard Benkelman beam. The test was carried out as per IRC 81:1997. A truck was loaded such that the weight on the rear axle was 8.20 ± 0.15 tonnes, equally distributed on dual tired wheels. The probe of the beam was inserted between the wheels.

The initial reading on the dial was noted. The truck was then moved slowly and the dial readings due to deflections in the pavement were noted when the rear axle had moved a distance of 2.7 meters and 9.0 meters. The BBD values were collected every 50 meters for the entire length of the warm mix and control hot mix stretches.

4.2. Bump integrator value

The fifth wheel bump integrator as per IRC SP 16 was used to carry out a roughness test on the warm mix and control hot mix pavement sections. The bump integrator used consisted of a single wheeled trailer comprising a rectangular chassis within which a pneumatic tire was mounted. The trailer was towed by a jeep at a constant speed of 30 kilometers per hour. A single leaf spring mounted on either side calculates the unevenness in the pavement in centimeters. During testing, the vertical movement of the wheel axle assembly relative to the chassis is measured by an integrator unit. The linear distance traveled is also measured.

4.3. Field cores

Field cores were collected from the warm mix as well as the control hot mix sections, and tested for Marshall stability, static creep test and Resilient Modulus. The cores were taken at random locations covering the entire width of the pavement.

In the Marshall stability test, the maximum load sustained by the mixes at a loading rate of 50.8mm/minute was measured. Field cores were subjected to the Marshall Stability test after immersion in a 60 °C water bath for 30 minutes.

The field cores were also subjected to the Resilient Modulus test at 40°C as per ASTM D4123. The cores were conditioned in an environmental chamber for 24 hours and haversine wave loading (100ms pulse with and 1000ms repetition period) was applied to the warm mix as well as the control hot mix cores.

Additionally, the field cores were subjected to a static creep test, where the response of the mix to a static load and its elastic recovery were measured. After initial elastic response when the static loading is applied, the creep portion of the response curve eventually becomes linear. After the release of the applied stress, elastic recovery occurs, and the residual strain after complete elastic recovery is the non-recoverable deformation. Since permanent deformation risks are greatest at high temperatures and high loads, the testing parameters were

selected such that the uniaxial load was 100kPa for a duration of 3600 seconds. The testing temperature selected was 40°C, to simulate the weather conditions of the region of the pavement.

5. Results and discussions

Both the projects mentioned in this paper were re-visited at a later stage for a round of field performance. The DSIDC stretches were evaluated after roughly 31 months, whereas the State Highway – 5 sections in Gujarat were revisited after approximately 13 months. Visual inspections at both project sites revealed that the warm mix as well as the control hot mix sections showed no signs of surface distress and all the pavement sections were found to be in a good condition. The surface of the warm mix section of the DSIDC project is as shown in Figure 2. Following the visual inspection, the aforementioned tests were conducted to evaluate the field performance of the two stretches. Due to time constraints, only the Benkelman Beam test was performed at the DSIDC site. The results of the tests performed are discussed below.

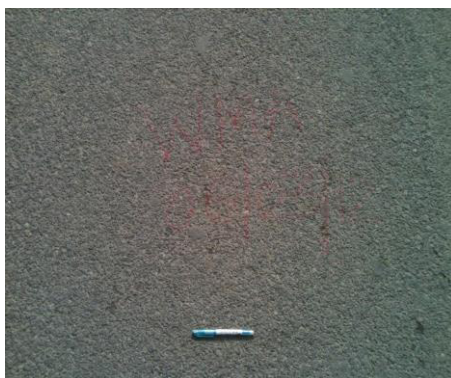


Figure 2. Surface of the warm mix pavement section in the DSIDC project, 31 months after construction

5.1. Benkelman beam test results

The data from the Benkelman beam tests were collected from the warm mix as well as hot mix sections of both project sites and analysed. The results are as shown in Tables 6 and 7.

Table 6. BBD results from DSIDC Project

	Final Deflection (mm)	Mean Deflection (mm)	Std. Dev. (mm)
Control Hot Mix	1.08	0.7	0.19
Warm Mix	1.04	0.63	0.205

Table 7. BBD results from State Highway – 5, Gujarat

	Final Deflection (mm)	Mean Deflection (mm)	Std. Dev. (mm)
Control Hot Mix	0.65	0.39	0.13
Warm Mix	0.68	0.43	0.126

The BBD results clearly indicate similar performance of the mat in terms of resisting deformation. All the pavement stretches were found to be structurally adequate.

5.2. Bump integrator test

The bump integrator test was run three times on the control hot mix and the warm mix stretches of the State Highway – 5 in Gujarat. Of the three runs, two were on the outer lane and one on the inner lane of the pavement. The roughness values were obtained separately for each run, and are as shown in Table 8.

Table 8. Roughness values on the State Highway – 5 sections in Gujarat

Trial Section	Reading	Average
	mm/km	mm/km
Outer Lane – Warm Mix	1660	1520
Inner Lane – Warm Mix	1380	
Outer Lane – Hot Mix	1640	1480
Inner Lane – Hot Mix	1320	

According to the roughness results, the differences in the warm mix stretch and the control hot mix stretch were not significant, indicating similar performance of the two stretches of the pavement sections. The values were also found to be within the limits as mentioned in the Indian Road Congress codes.

5.3. Core testing results

A core cutter was used to obtain samples from the control hot mix as well as warm mix stretches of the State Highway – 5 in Gujarat. Samples were obtained to the depth of the binder layer. A total of 20 such samples were obtained, 12 samples from the warm mix stretch and 8 samples from the control hot mix stretch at random locations along the entire width of the pavement. The cores obtained were then tested for the following tests.

5.3.1. Marshall stability test

Marshall Stability is related to the resistance of bituminous materials to displacement. The stability is derived mainly from internal friction and cohesion. Cohesion is the binding force of binder material while internal friction is the interlocking and frictional resistance of aggregates. As bituminous pavement is subjected to severe traffic loads from time to time, it is necessary to adopt bituminous material with good stability and flow. The cores extracted from the warm mix section as well as the control section were subjected to Marshall stability test and the results are reported in the Table 9. The results clearly indicate improved Marshall stability values of the warm mix section cores. This suggests better resistance of the mix to distortion, displacement, rutting and shearing stresses. This improved performance of the warm mix in the Marshall stability test is possibly as a result of improved compaction and slightly better densities during the construction of the warm mix pavement.

Table 9. Marshall stability values

Type of Mix	Avg. stability after 1/2hour in water at 60°C (kg)
Warm Mix Section Core	1032
Control Section Core	727

5.3.2. Resilient modulus test

To check the effect of warm mix additive on the resilient modulus values, repeated loading indirect tensile test on cores extracted from the trial stretches was performed as per ASTM D-4123. The test was conducted by applying a compressive load in the form of haversine wave at 40 °C for warm mix and control hot mix section cores. The specimens were conditioned for 24 hours in an environmental chamber at the given temperature and then subjected to repeated loading pulse width of 100 ms, and pulse repetition period of 1000 ms. The results of five cores are plotted in Fig 3. Just like the Marshall stability values, it appears that the warm mix has a higher resilient modulus, indicating a stiffer mix that can resist resistance to deformation and rutting better. Again, it is hypothesised that the improved compaction and better densities during the construction of the warm mix section was the reason for the improved resilient modulus of the mix.

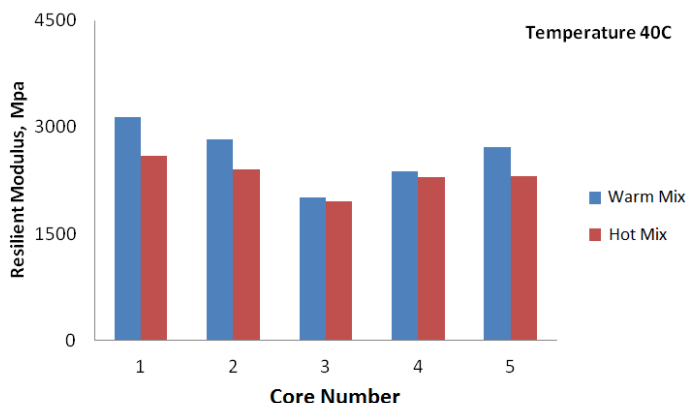


Figure 3. Resilient modulus values

5.3.3. Static creep test

5.3.4. A static creep test is conducted by applying a uniaxial static load to a specimen and then measuring the permanent deformation of the specimen and the elastic recovery after the load has been unloaded. A 100 kPa uniaxial load was applied for 3600 seconds at a test temperature of 40°C. The permanent deformation and percentage recovery are as shown in Table 10. The data clearly shows improved performance of the warm mix section relative to the control hot mix section against creep loading and improved percentage recovery. The increase in the percentage recovery can be attributed to the reduced oxidation of the bitumen due to lower mixing and compaction temperatures during construction. Additionally, the improved compactability of the warm mix also helps in improving the resistance of the mix to extended creep loads, thereby rendering a mix that is more resistant to permanent deformation.

Table 10. Static creep test results

Mix Type	Permanent Deformation(mm)	Percentage Recovery	Creep Modulus (MPa)
Warm Mix 1	0.248	22.7	9.67
Warm Mix 2	0.20	34.5	10.78
Control Mix 1	0.26	20.7	10.02
Control Mix 2	0.69	10.06	5.69

6. Conclusions

Based on this study of two pavements where the field performance was monitored for a duration ranging from 13 – 31 months, the following can be concluded about the short term field performance of warm mixes relative to the control hot mixes.

Visual inspections reveal that the warm mix sections are equally comparable to the control hot mix sections and there were not visible cracks and deformations in both the sections in both the project sites.

The Benkelman beam deflection values of the warm mix as well as the hot mix sections were found to be identical, indicating similar performance and ability to maintain structural adequacy.

The roughness values of the warm mix and the hot mix sections were also found to be similar, indicating equal performance of the warm mix section. Additionally, all values were found to be well within the limitations as mentioned in the Indian Road Congress codes.

The Marshall stability test results, resilient modulus test results and the static creep test results all indicate that the compactibility and constructability benefits associated with the warm mix asphalts render pavements that are stiffer and denser and therefore better able to resist distortion, displacement, rutting and shearing stresses when subjected to heavy static and dynamic loads.

Since density is the most important aspect associated with the performance of a pavement, it can be concluded that the compactibility and constructability benefits of warm mix asphalts allow the contractors to easily achieve the required densities during construction and therefore construct pavements that can perform better in the long run.

Acknowledgements

The authors are thankful to Dr.S.Gangopadhyay, Director, Central Road Research Institute, New Delhi, for his encouragement during the study. The authors are thankful to the officials of M/s Mead West Vaco India Pvt. Ltd, for their support during the laying and field evaluation of the test sections mentioned in this paper. The research sponsoring organization and authors do not endorse any proprietary products or technologies mentioned in this paper. These appear herein only because they are considered essential to the objective of this paper”.

References

- Belh, Ambika, Bose, Sunil, Sharma, Girish, Kumar, Gajendra, and Devi, Uma (2011), “Warm Bituminous Mixes: The Wave of the Future?”, *Journal of the Indian Road Congress*, July – September 2011.
- Gandhi, Tejash. Effects of warm asphalt additives on asphalt binder and mixture properties. Dissertation, Clemson University, 2008.
- Biro, Szabolcs, Tejash Gandhi, and Serji Amirkhanian. "Midrange temperature rheological properties of warm asphalt binders." *Journal of Materials in Civil Engineering* 21.7 (2009): 316-323.
- Gandhi, Tejash, William Rogers, and Serji Amirkhanian. "Laboratory evaluation of warm mix asphalt ageing characteristics." *International Journal of Pavement Engineering* 11.2 (2010): 133-142.
- Gandhi, Tejash, Chandrakiran Akisetty, and Serji Amirkhanian. "Laboratory evaluation of warm asphalt binder aging characteristics." *International Journal of Pavement Engineering* 10.5 (2009): 353-359.
- Crews, Everett, et al. "Prediction of Stiffness of Asphalt Treated with Surfactant-Based Warm-Mix Additive." *Transportation Research Record: Journal of the Transportation Research Board* 2293.1 (2012): 89-95.
- Bower, Nathan, et. al. "Evaluation of the Performance of Warm Mix Asphalt in Washington State", Washington State Department of Transportation Research Report # WA-RD 789.1 (2012), Available online at <http://www.wsdot.wa.gov/research/reports/fullreports/789.1.pdf>
- Prowell, Brian D., Graham C. Hurley, and Everett Crews. "Field performance of warm-mix asphalt at national center for asphalt technology test track." *Transportation Research Record: Journal of the Transportation Research Board* 1998.1 (2007): 96-102.
- Aschenbrener, Tim, Schiebel, Bill and West, Randy, (2011), “Three Year Evaluation of the Colorado Department of Transportation’s Warm Mix Asphalt Experimental Feature on I-70 in Silverthorne, Colorado”, Final Report # NCAT Report 11-02, Prepared by the National Center for Asphalt Technology.