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Performance evaluation of Hot In-Place Recycling Experience in Pakistan

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Performance evaluation of Hot In-Place Recycling Experience in Pakistan

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ABSTRACT: With the increasing use of hot mix asphalt (HMA) pavements, particularly in developing countries, management of these pavements and disposal of old pavements is becoming a challenging task. Recycling is one of the several rehabilitation alternatives available for flexible pavements. Among the recycling techniques, Hot In-Place Recycling (HIR) has proven to be a viable option for rehabilitation of pavements at low costs. In Pakistan, HIR technique was employed for the first time on Lahore-Islamabad Motorway (M-2) in March 2006. The purpose of this project was to rehabilitate the sections of M-2 to a depth of 38-50 mm. The project being first of its kind, performance evaluation was conducted to evaluate the effectiveness of this technique on motorways. Laboratory investigations included HMA volumeteric analysis, aggregate gradation analysis, extracted asphalt properties (penetration test and DSR), dynamic modulus and flow time after recycling of pavement. Based on results of dynamic modulus test, volumetric properties and gradation tests recycled asphalt pavement seems to be adequately crack-resistant and rut resistant in the field. The research enhanced awareness of HIR among local researchers and contractors.

BACKGROUND

Heavy volume of vehicular traffic, enhanced use of hot mix asphalt (HMA) pavements, high rehabilitation costs, construction impact on traffic and long term maintenance costs and disposal of old pavements have forced developing countries to search for efficient rehabilitation techniques. Efficient rehabilitation techniques with minimal wastage of old materials have become a necessity of the time in management of pavements at acceptable serviceability levels (*1*). Among various rehabilitation techniques of flexible pavements, hot in-place recycling (HIR) has proved most economical option. Known as an on- site method, HIR rehabilitates deteriorated asphalt pavements with minimal use of new materials. HIR can successfully treat surface defects, corrugation, surface rutting, longitudinal and slippage cracking upto a depth of 50 mm (*2*). In Pakistan, HIR technique was first used in March 2006 on Lahore - Kala Shah Kaku section of Lahore-Islamabad Motorway (M-2) which was in service since November 1997. Surface recycling technique of HIR was performed on the sections rutted to a depth of 38-50 mm with addition of 1 % fresh asphalt binder. At few places remixing technique of HIR was also used.

RESEARCH PLAN

Scope and Objective

The objective of the study was to evaluate performance of recycled asphalt pavement. Research involved both field work and lab investigations. Field work involved recording temperatures during various stages of HIR, HMA coring after HIR, preparing field compacted samples for wearing course following the field compaction temperature regime and collecting bulk HMA during HIR. Laboratory investigations included preparing laboratory compacted samples for wearing course, HMA volumetric analysis, aggregate gradation analysis, dynamic modulus and flow time tests after HIR of the selected pavement sections.

Methodology

Methodology adopted for research is illustrated in Figure 1.

SITE SELECTION

The test site was selected on south-bound carriageway of Lahore-Islamabad Motorway (M-2), approximately 20 Kms from Islamabad near Chakri (Figure 2). It was divided into three sections of 150 m stretch each separated by 10 m transition length as shown in Figure 3. The original pavement design of the test sections is illustrated in Figure 4.

HIR EQUIPMENT

The recycling unit used on the project is German made, Wirtgen's hot recycling unit. The unit consists of two main parts, i.e. Panel heating machine HM 4500 and Remixer RX 4500. The units are shown in Figures 5 to 7. Technical specifications of panel heating machine HM 4500 and Remixer RX 4500 units are tabulated in Table 1 and 2 (*3, 4*).

FIELD WORK

The coring plan is illustrated in Figure 8. A total of 6 HMA wearing course cores (2 cores from each section) after HIR were extracted for further laboratory testing and evaluation.

During Recycling

During the application of HIR process on 5 March, 2007, temperatures were measured at various stages of recycling. Temperatures recorded at different time during various stages of HIR process are tabulated in Table 3. Temperatures recorded at different time during various stages of HIR process indicated that they were well below the guidelines provided by Roberts et al. (*5*). About 1 % fresh asphalt binder was being added during recycling process. Virgin aggregate or new HMA was not added during HIR on test sections.

Large quantity of recycled HMA mix was taken to the laboratory in sealed jute bags for preparation of laboratory compacted samples for simple performance testing. Samples for simple performance testing of HMA wearing course were prepared at site also as described below.

HMA trial samples at test sections of diameter 150 mm (6 inch) and height 188 mm (7.4 inch) were prepared, using material taken from the screed. The samples were compacted in 4 layers using 4 kg Marshall hammer at compactive efforts of 75, 85 and 100 blows (each layer). These samples were based on calculated weight of 7800 gm, in order to achieve required specific gravity of 2.35 (specific gravity of 2.35 was found average density achieved at other locations after HIR). Samples were tested for bulk density in field and one prepared with 100 blows (each layer) was found to achieve the desired specific gravity of approximately 2.35. Subsequently, 3 samples were prepared in the field with 100 blows (each layer) compactive effort, following the field compaction temperature regime.

LABORATORY INVESTIGATIONS

Laboratory Compacted Sample Preparation for Simple Performance Testing

Laboratory compacted samples were Prepared for Simple Performance Testing (SPT) from HMA mix collected from the test sections during Hot In-Place recycling and transported to laboratory in bags. These samples were prepared following the compaction procedure for the field prepared samples given in previous Section, however, the compaction temperatures was between 135°C to 140 °C. Sample diameter 150 mm (6 inch) and height 188 mm (7.4 inch) were cored and cut to standard size required for SPT as per procedure given by Witczak et al. (6). Field/laboratory compacted specimens were prepared as thickness of HMA wearing course samples from field cores was not sufficient to conduct simple performance testing. Dynamic modulus and flow time test were performed on Simple Performance Tester (SPT) developed by IPC Global (*7*).

Volumetrics/Gradation Testing

Bulk specific gravity of HMA specimens were tested in accordance with the AASHTO T 166-07. Extraction procedures for removing asphalt from aggregates in an asphalt mixture typically follow the methods listed in ASTM D2172 (Centrifuge Extraction). Recovery of asphalt binder from solution was done with binder recovery apparatus 45-3720 by ELE international according to BS 598. Volumetric properties of HMA wearing course cores after HIR and HMA field and laboratory compacted specimens are tabulated in Table 4. Aggregate gradation of asphalt wearing course cores after recycling, HMA field and laboratory compacted specimens was done to observe the effect of different compaction methods on gradation.

Reclaimed Asphalt Binder Testing

Conventional penetration grade as well as performance grade of recovered asphalt binder from HMA wearing course cores after recycling was determined. Penetration grade was determined according to ASTM D 5-06 e1. Penetration grades of recovered asphalt binder after recycling ranged between 58 and 60.

The performance grade (higher temperature only) was determined by dynamic shear rheometer (DSR) according to AASHTO T 315-06. The RAP binder was tested in the dynamic shear rheometer (DSR) at a high temperature as if it was original, unaged binder (*8*). Performance grades of recovered asphalt binder after recycling ranged between 52 and 58.

Dynamic Modulus and Flow Time Testing

The dynamic modulus/flow time tests were conducted according to AASHTO TP 62-07 on three field and three laboratory compacted HMA samples. The temperatures used for testing were 21, 40 and 54.4° C *(38)* and frequencies of loading were 25, 10, 5, 2, 1, and 0.5 Hz. Flow time test was performed after dynamic modulus testing using a static stress level of 30 psi at 54.4°C until the sample failed due to crack initiation in the tertiary zone or 40000 seconds (*9*). The purpose of dynamic modulus/flow time tests was to compare field and laboratory compacted HMA samples in terms of rutting and fatigue potential.

Table 5 shows results of dynamic modulus (|E*|), phase angle (Ø), flow time and parameters to relate rutting and fatigue cracking at different temperatures for field and laboratory compacted specimens.

TEST RESULTS AND ANALYSIS

Analysis of Volumetrics /Gradation

The air voids and bulk specific gravity of HMA wearing course after HIR ranges between 6.32 and 8.95 %, 2.26 and 2.34 (Table 4), respectively. Average air voids of 7.8%, average specific gravity of 2.30, asphalt content (5.5%) and VMA (19.2%) and VFA (59.3%), all within reasonable limits.

The volumetrics of HMA field/laboratory compacted wearing course samples (Table 4) are similar to HMA wearing course cores (field cores) after recycling because asphalt content, specific gravity, air voids, VMA and VFA of both samples lie in same range. Keeping in view above facts it can be fairly assumed that field compacted/laboratory compacted samples can represent cores after recycling for studying its other properties.

The gradations envelops of HMA wearing course after recycling and HMA field compacted wearing course samples are illustrated in Figure 8, 9 and 10. The gradation of HMA wearing course after recycling (Figure 8) was within gradation envelop of NHA "class B" specification. The degradation of the aggregates in field/laboratory compacted samples was observed as illustrated in Figure 9 and 10, probably due to crushing effect of hammer used during preparation of field compacted samples. The gradation of aggregate of field/laboratory compacted was on the finer side of gradation envelop in the coarser aggregate (up till sieve No 4). Volumetric properties show that field/laboratory compacted samples can represent HMA wearing course after recycling for other tests but gradation analysis suggest to be careful in interpreting results.

Analysis of Reclaimed Asphalt Data

The original binder used in construction of M-2 had penetration grade 60/70 (performance grading was not performed). Binder results (penetration grades and performance grades) indicate that hardness is in medium range after about 10 years of service life or fresh asphalt might have caused rejuvenation in age hardened asphalt causing binder to soften. Binder penetration and performance grades show that effect of infra red heating was relatively gentle and its effects on age hardening were negligible. Keeping in view limited number of samples used for extracting binder, it is recommended to further investigate the effects HIR has brought on binder.

Analysis of Dynamic Modulus/Flow Time Data

In order to evaluate dynamic modulus test results three parameters, |E*| and |E*|/sin δ at 54.4°C (130°F) and |E*| sin δ at 21°C (70°F) were selected as rut and fatigue indicators, respectively. The most applicable frequency (test sections being located on Motorway) is 10 Hz as it corresponds to high traffic speeds. Average |E*| and |E*|/sin δ values at 54.4°C (130°F) and at 1, 5 and 10 Hz of laboratory compacted samples (Table 8) are more than field compacted samples, indicating that, laboratory prepared samples are better rut resistant than field prepared samples as Witczak et al. (*6*) and others correlated parameters |E*| and |E*|/sin δ (unconfined tests) at higher temperatures (54.4°C) with rutting. Average |E*| sin δ values at

21°C (70°F) and at 10 Hz of field compacted specimens (Table 8) are less than laboratory compacted specimens, indicating that, field prepared samples are better fatigue resistant than laboratory prepared samples. Analysis can be summarized as follows:

- Laboratory prepared samples seems to be more rut-resistant than field prepared samples. The main factor seems to be temperature during sample preparation which was below the required in case of field prepared samples.
- As regard cracking characterization, field prepared samples seems to be more crack-resistant than laboratory prepared samples.
- Overall both groups of samples seem to have adequate rutting performance in the field when compared with dynamic modulus values of HMA mixtures from the South Central United States by Bhasin et al. *(9).*

CONCLUSIONS

Based on field, laboratory investigations and data analysis conducted during the course of this study, following conclusions are drawn:

- Rutting was found to be main distress present on M-2 test sections.
- The gradation of HMA wearing course after recycling was within gradation envelop of NHA "class B" specification.
- Based on results of dynamic modulus test, volumetric properties and gradation results recycled asphalt pavement seems to be adequately crack-resistant and rut resistant in the field.
- The recorded temperatures during the application of HIR are on lower side.

RECOMMENDATIONS

Based on the conclusions, following recommendations are made:

- A proper mix design procedure be developed validated by local project studies. This mix design procedure should ensure the proper design requirements of asphalt and aggregate.
- Proper mixing temperature should be maintained at site to ensure long service life and better performance.
- Rheological properties of binder after recycling be further studied keeping in view the local environments in Pakistan.

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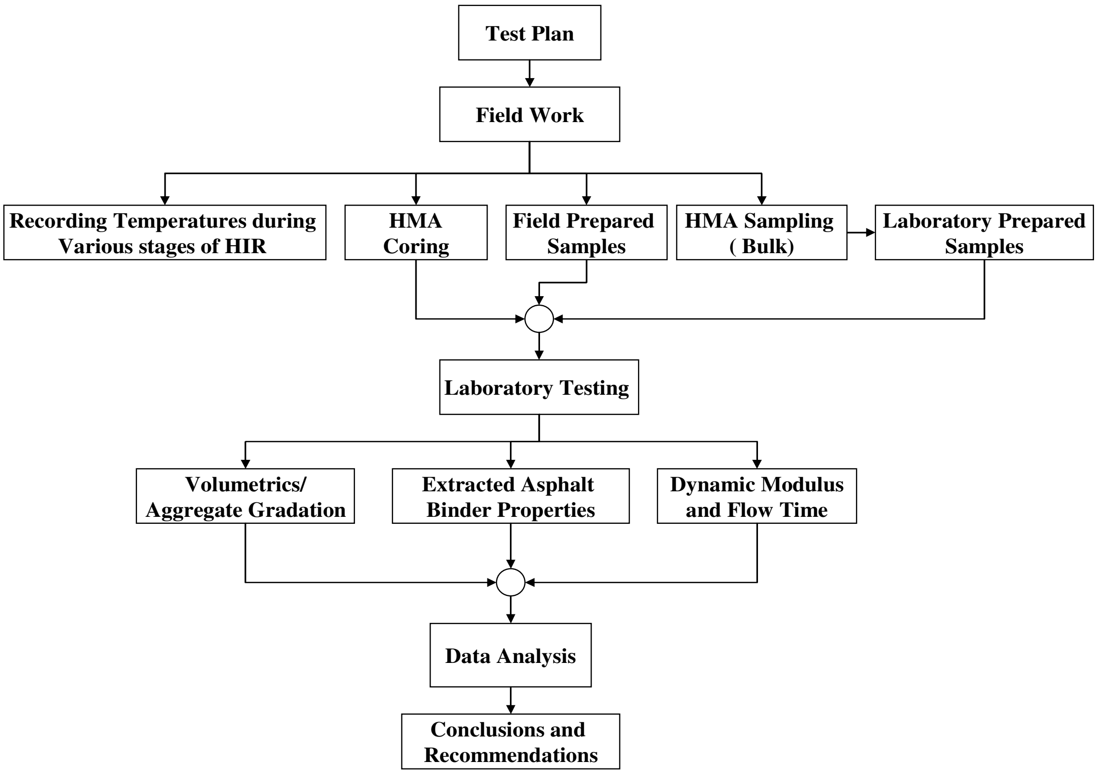


FIGURE 1 Evaluation methodology.

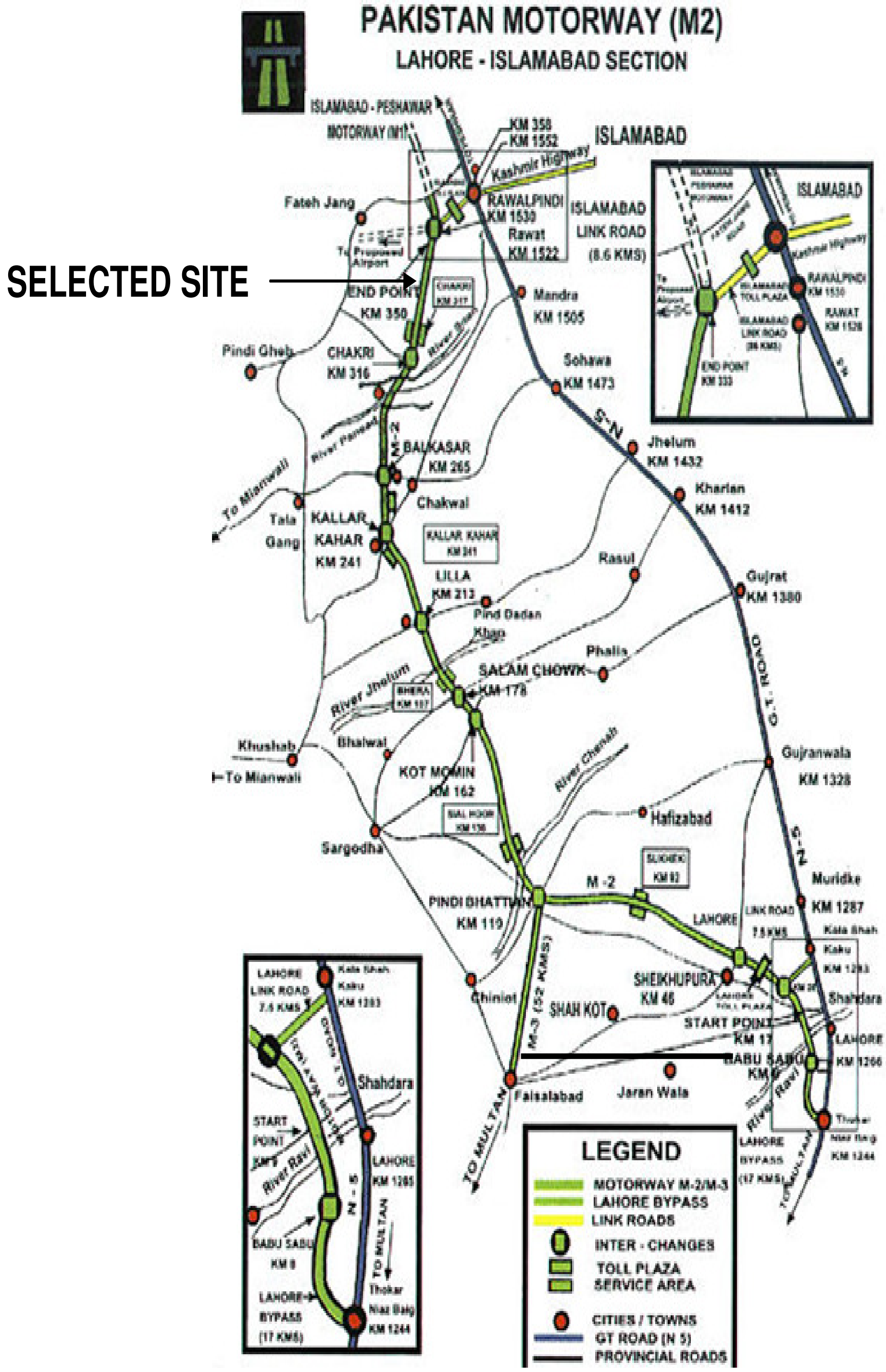


FIGURE 2 Selected site location.

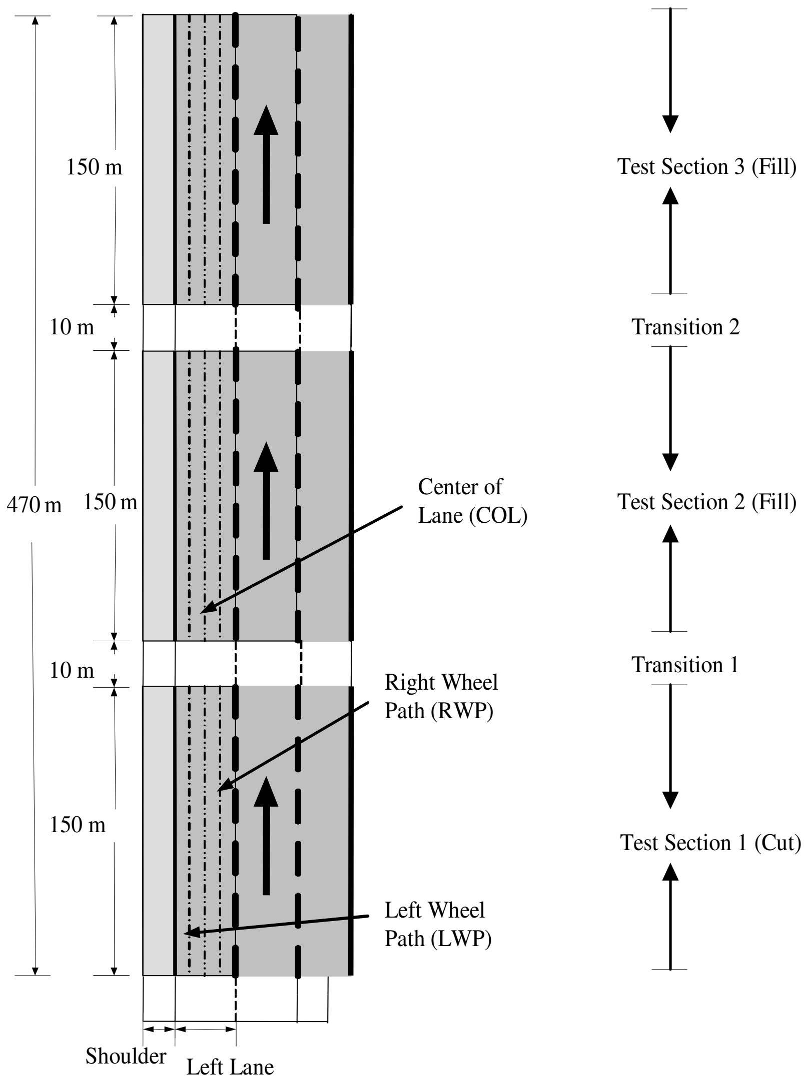


FIGURE 3 Division of test site into sections.

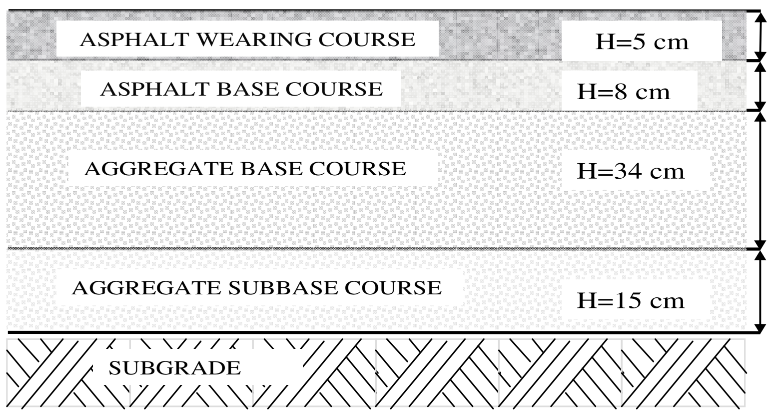
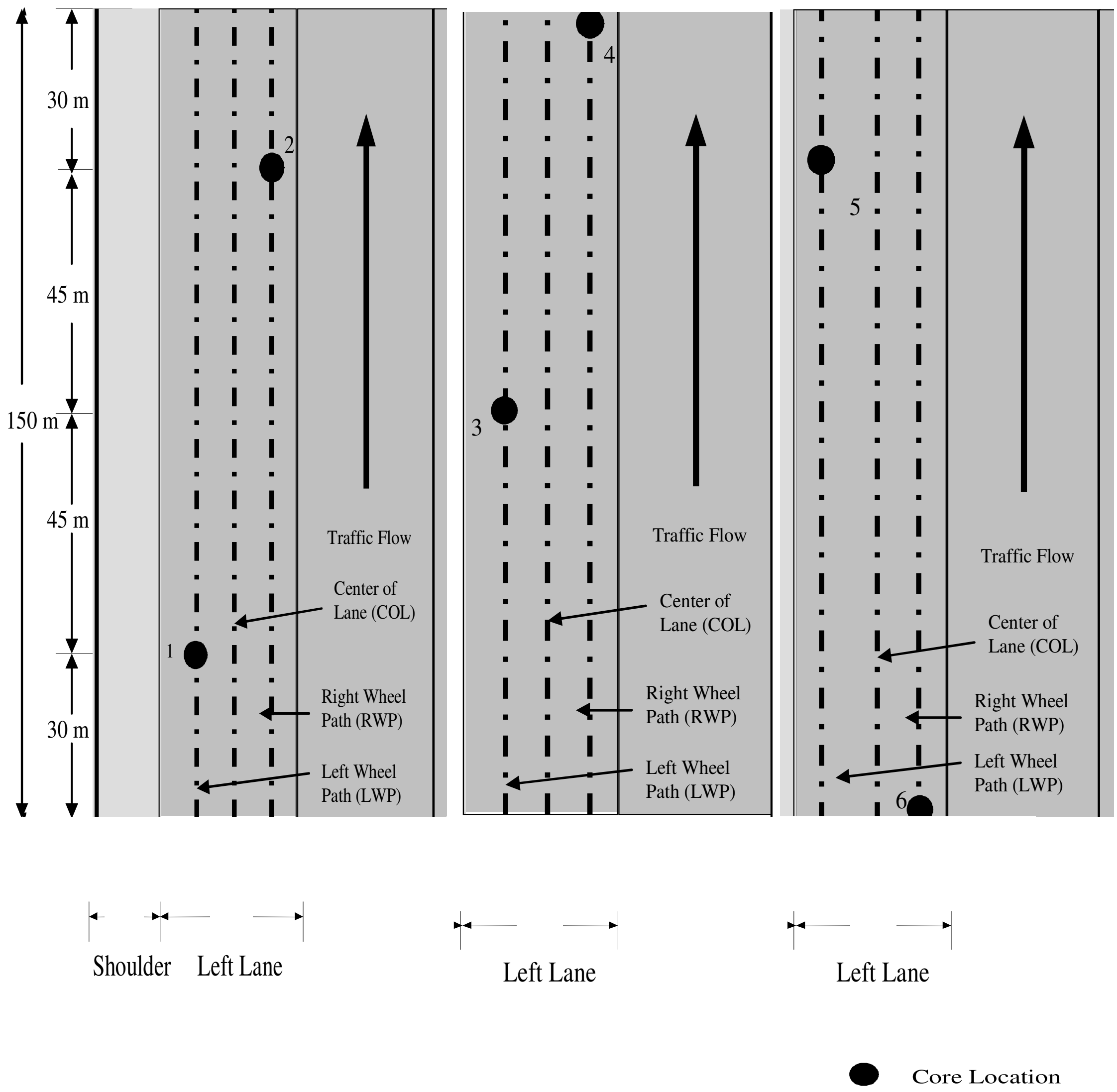


FIGURE 4 Cross section details of test sections.

FIGURE 5 Pre-heating unit.

FIGURE 6 Scarifying and heating unit.

FIGURE 7 Remixing unit.



(a) Section 1 **(b) Section 2** **(c) Section 3**

FIGURE 8 Coring plan within a test section.

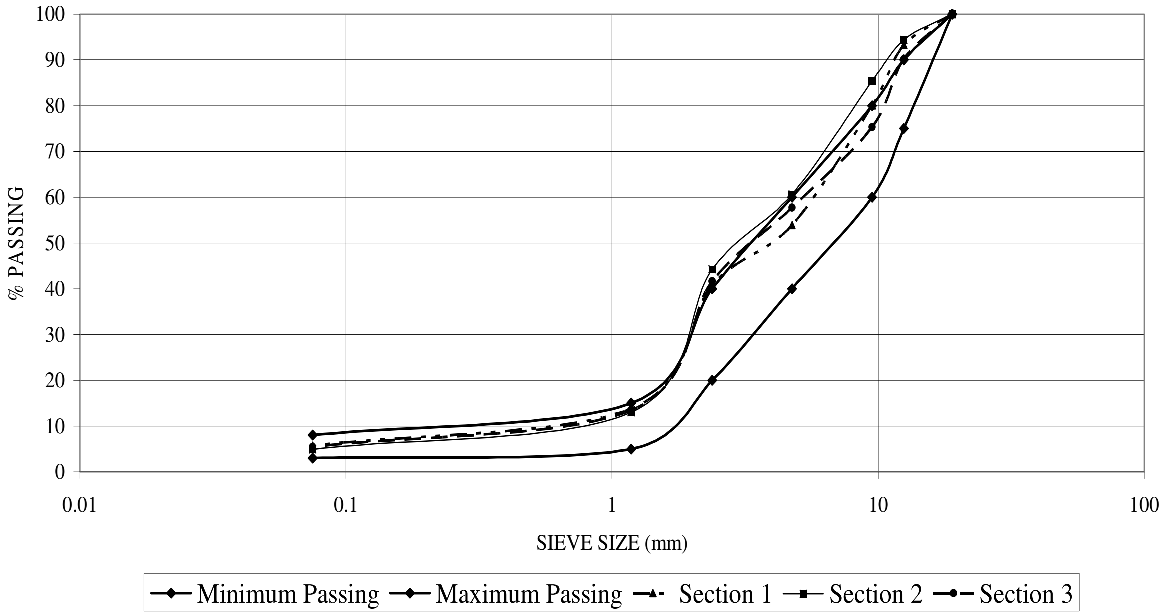


FIGURE 9 Gradation analysis of HMA wearing course cores after recycling in comparison with NHA "class B" specification.

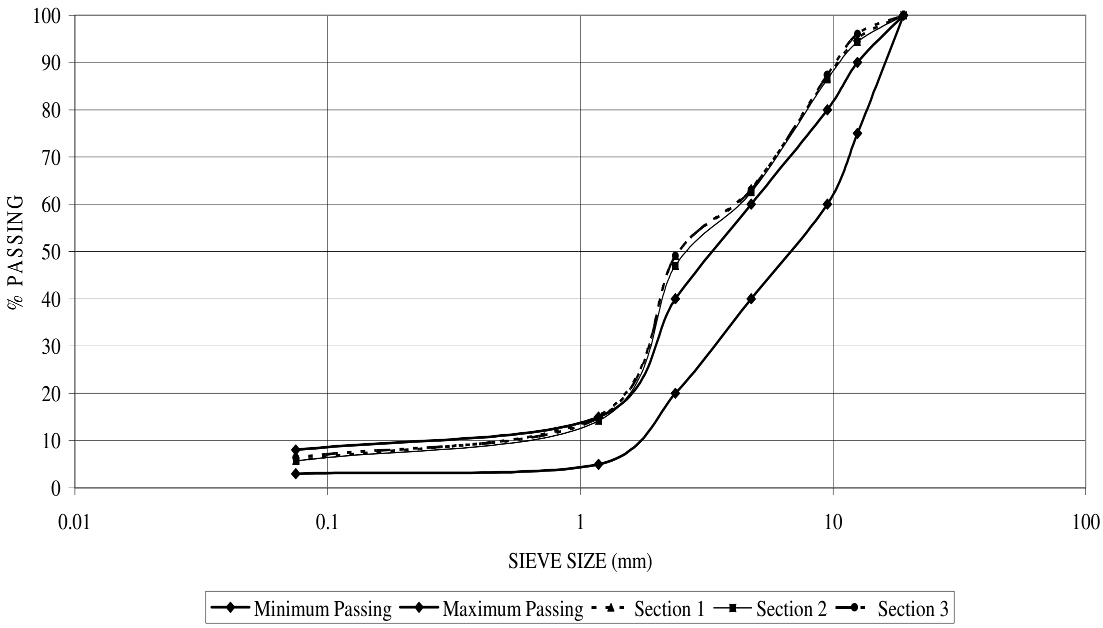


FIGURE 10 Gradation analysis of HMA field compacted wearing course specimens after recycling in comparison with NHA "class B" specification.

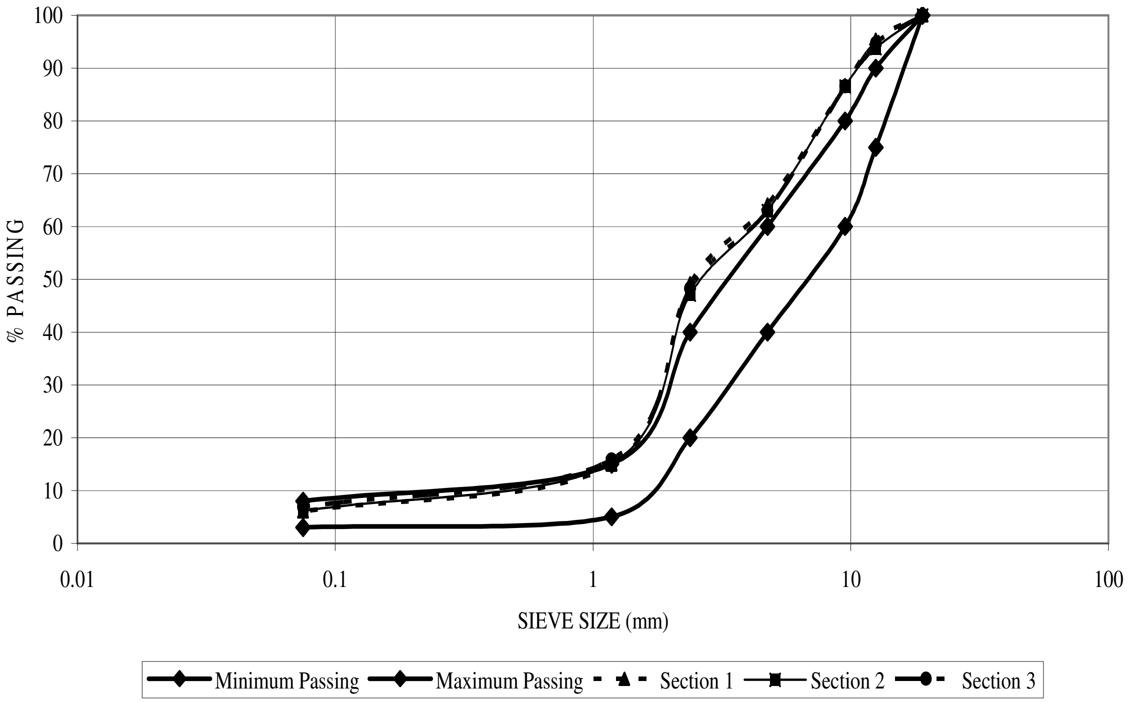


FIGURE 11 Gradation analysis of HMA Laboratory compacted wearing course specimens after recycling in comparison with NHA "class B" specification.

TABLE 1 Salient Features of Panel Heating Machine HM 4500

Heating Width (max)	4.50 m
Heating Area	44.64 m^2
Heater Elements (adjustable)	Infrared
Max. Heating Performance	2,260 kW
Volume Gas Tank (Propane)	6,000 liters
Engine Output	79 kW
Operating Weight	22,600 kg

TABLE 2 Salient Features of Remixer RX 4500

Working Width	3.0-4.5 m
Working Depth	0-60 mm
Engine Output	220 kW
Operating Weight	48,820 kg
Number of Wheels	4
Max. Heating Performance	2,210 kW
Travel Drive System	Hydraulic / all-wheel

TABLE 3 Temperatures (^{o}C) during Various Stages of HIR Process

Section No.	Time (hrs)	Date	Panel Heating Machine Front			Panel Heating Machine Rear	Mix under Screed	Laying	Near Completion
1	1000	5^{th} March 2007	81.8	92.5	127.0	136.0	92.0	83.0	66.0
1	1200	5^{th} March 2007	90.0	102.0	150.0	155.0	97.0	87.0	70.0
2	1300	5^{th} March 2007	100	117.0	170.0	175.0	102.0	93.0	74.0
2	1400	5^{th} March 2007	85.0	96.0	135.0	145.0	95.0	85.0	69.0
3	1600	5^{th} March 2007	94.0	107.0	160.0	160.0	101.0	92.0	72.0
Average			90	103	148	154	97	88	70

Table 4 Volumetric Properties of HMA Wearing Course Cores after Recycling, HMA Field and laboratory Compacted Specimens

Sample No.	Agg %	Asphalt %	Weight (gm)			(b)-(a)	Bulk Specific Gravity (Gmb)	Asphalt Gs	Gse of Agg	Max Theoretical Gs (Gmm)	% Air Voids	VMA %	VFA %
After Recycling Wearing Course Cores													
ARL1-8	94.5	5.5	830	472.8	830	357.4	2.34	1.03	2.70	2.48	6.32	17.6	64.1
ARL2-9	94.4	5.6	852.4	477.8	856	378.2	2.28	1.03	2.70	2.48	8.95	20.1	55.5
ARL3-3	94.2	5.8	694.8	385.8	693	307.2	2.26	1.03	2.70	2.47	8.36	20.0	58.2
Average	94.4	5.6					2.30				7.8	19.2	59.3
After Recycling HMA Field Compacted Specimens													
1/1	94.3	5.7	775.4	436.2	777.3	341.10	2.27	1.03	2.72	2.49	8.61	20.1	57.1
2/2	94.2	5.8	775.6	438.1	784.3	346.20	2.24	1.03	2.72	2.48	9.80	21.3	54.1
3/3	94	6	799.9	446.8	799.8	353.00	2.27	1.03	2.72	2.48	8.49	20.6	58.8
Average	94.1	5.9					2.26				8.97	20.7	56.7
After Recycling HMA Laboratory Compacted Specimens													
1/1	94.2	5.8	765.4	431.2	765.3	334.10	2.29	1.03	2.72	2.48	7.76	19.5	60.3
2/2	94.1	5.9	771.9	431.1	772.3	341.20	2.26	1.03	2.72	2.48	8.78	20.6	57.5
3/3	93.8	6.2	788.9	440.8	787.8	347.00	2.27	1.03	2.72	2.47	7.91	20.5	61.4
Average	94.1	5.9					2.28				8.15	20.2	59.7

Note: Agg stands for Aggregate.

Table 5 Dynamic Modulus Test Results

Section No./ Sample No.	|E*|	Ø	|E*| /SinØ	|E*|	Ø	|E*| /SinØ	|E*|	Ø	|E*| /SinØ	|E*|	Ø	|E*| *SinØ	Flow Time
	54.4^0C									21^0C			54.4^0C
	1HZ			5HZ			10HZ			10HZ			
	MPa	Deg	MPa	MPa	Deg	MPa	MPa	Deg	MPa	MPa	Deg	MPa	Sec
HMA Field Compacted Specimens after Recycling													
1/1	938	29	1958	1620	28	3489	1993	27	4413	5075	18	1558	1387
2/2	627	35	1096	1386	34	2496	1903	33	3503	4509	25	1889	198
3/3	607	31	1186	1062	30	2124	1331	30	2696	3813	22	1413	603
Average	724	31	1,412	1,358	30	2,704	1,744	30	3,535	4,464	21	1,620	729
CoV*	26%	10%	34%	21%	10%	26%	21%	10%	24%	14%	16%	15%	83%
HMA Laboratory Compacted Specimens after Recycling													
1/1	993	31	1931	2062	30	4082	2772	30	5585	8770	21	3110	3868
2/2	572	36	965	1193	36	2048	1558	35	2717	8253	22	3027	1432
3/3	1448	29	2965	2772	29	5778	3565	28	7619	11163	17	3248	3588
Average	1,005	32	1,953	2,009	32	3,971	2,633	31	5,306	9,396	20	3,128	2963
CoV*	44%	11%	51%	39%	12%	47%	38%	12%	46%	16%	13%	3%	45%

**CoV stands for Coefficient of Variance*