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INVESTIGATION OF HOT IN-PLACE RECYCLING EFFECTS ON HOT MIX ASPHALT PAVEMENT

Dr Nadeem Anwer Qureshi, Assistant Professor, Military College of Engineering (MCE), National University of Science and Technology (NUST), Risalpur Campus, Pakistan. Email: nza0014@tigermail.auburn.edu

Dr Bilal Khurshid, Associate Professor, Military College of Engineering (MCE), National University of Science and Technology (NUST), Risalpur Campus, Pakistan. Email: mbilal@mce.nust.edu.pk

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ABSTRACT

In March 2006, a hot in-place recycling (HIR) technique was employed for the first time on Lahore-Islamabad Motorway (M-2) to rehabilitate sections where the rut depth was about 40 mm. Since HIR technology was new to Pakistan, research was carried out to study the effects of recycled wearing course on overall pavement performance. This was accomplished by comparing structural adequacy of pavement and material characterization before and after recycling. Laboratory investigations included hot mix asphalt (HMA) volumeteric analysis, aggregate gradation analysis, extracted asphalt properties (penetration test and dynamic shear rheometer (DSR)) and resilient modulus. Analysis of recycled HMA wearing course indicated a reduction in modulus for a mix which was stiff and aged prior to recycling. Relative degradation of the aggregates in HMA wearing course, before and after recycling, was observed; however, it remained close to National Highway Authority (NHA) standard specifications. The research enhanced awareness of HIR among local engineers and contractors.

Keywords: (Hot in-place recycling, Resilient modulus, Volumetrics, Gradation, Dynamic shear rheometer, Performance grade)

BACKGROUND

Enormous increase in vehicular traffic, increased use of hot mix asphalt (HMA) pavements, ensuring traffic flow during execution of work, maintenance of geometrics and removal of old pavements are challenging pavement management tasks for any agency. Efficient rehabilitation techniques with minimal waste of valuable construction materials have become a necessity of the time in management of pavements at acceptable serviceability levels (AASHTO, 1993). Among the recycling techniques, hot in-place recycling (HIR) has proven to be a viable on-site method for rehabilitation of pavements at low costs with minimal use of new materials. HIR can successfully treat surface defects such as corrugation, surface rutting and longitudinal and slippage cracking to a depth of 50 mm (Kandhal and Mallick, 1997). In Pakistan, HIR technique was first used in March 2006 on the Lahore - Kala Shah Kaku section of Lahore-Islamabad Motorway (M-2) which had been in service since November 1997. The surface recycling technique of HIR was mostly performed on the sections rutted to a depth of 38-50 mm.

SCOPE AND OBJECTIVE

The objective of this study was to conduct comparative evaluation of the selected pavement sections before and after HIR. Research involved both field work and laboratory investigations. Field work involved HMA coring before and after recycling and recording temperatures during various stages of HIR. Laboratory investigations included HMA volumetric analysis, aggregate gradation analysis, extracted asphalt properties (penetration test and DSR) and resilient modulus before and after recycling the selected pavement sections.

MATERIALS AND METHODS

Methodology

The methodology adopted for this research before and after recycling is illustrated in Figure 1.

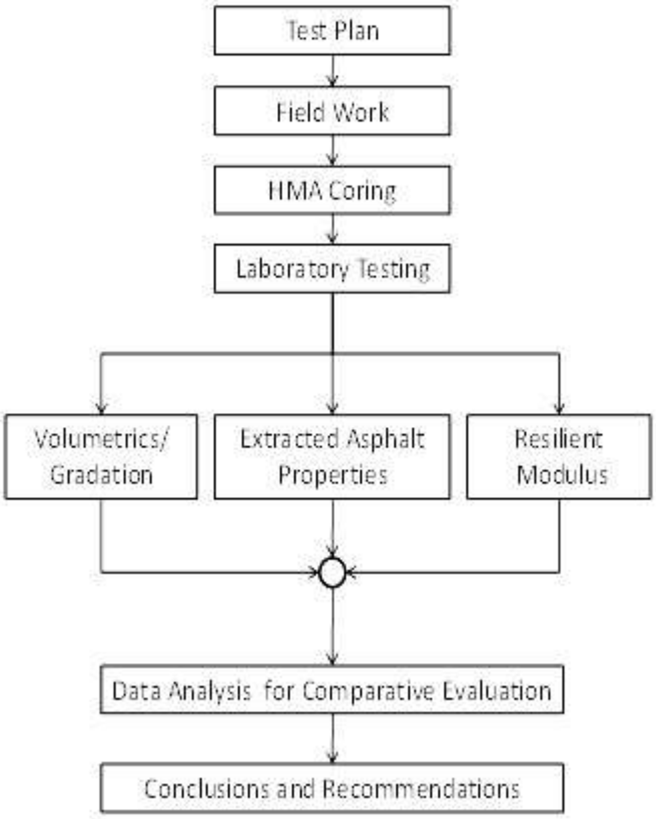

Figure 1. Evaluation methodology for the research

Site selection

The test site was selected on the south-bound carriageway of M-2, approximately 20 km from Islamabad near Chakri. It was divided into three sections of 150 m each separated by a 10 m transition length as shown in Figure 2. The original pavement design of the test sections is illustrated in Figure 3. The coring plan is illustrated in Figure 4. All cores were 102 mm diameter with thickness ranging between 44 mm (1.73”) and 55 mm (2.17”).

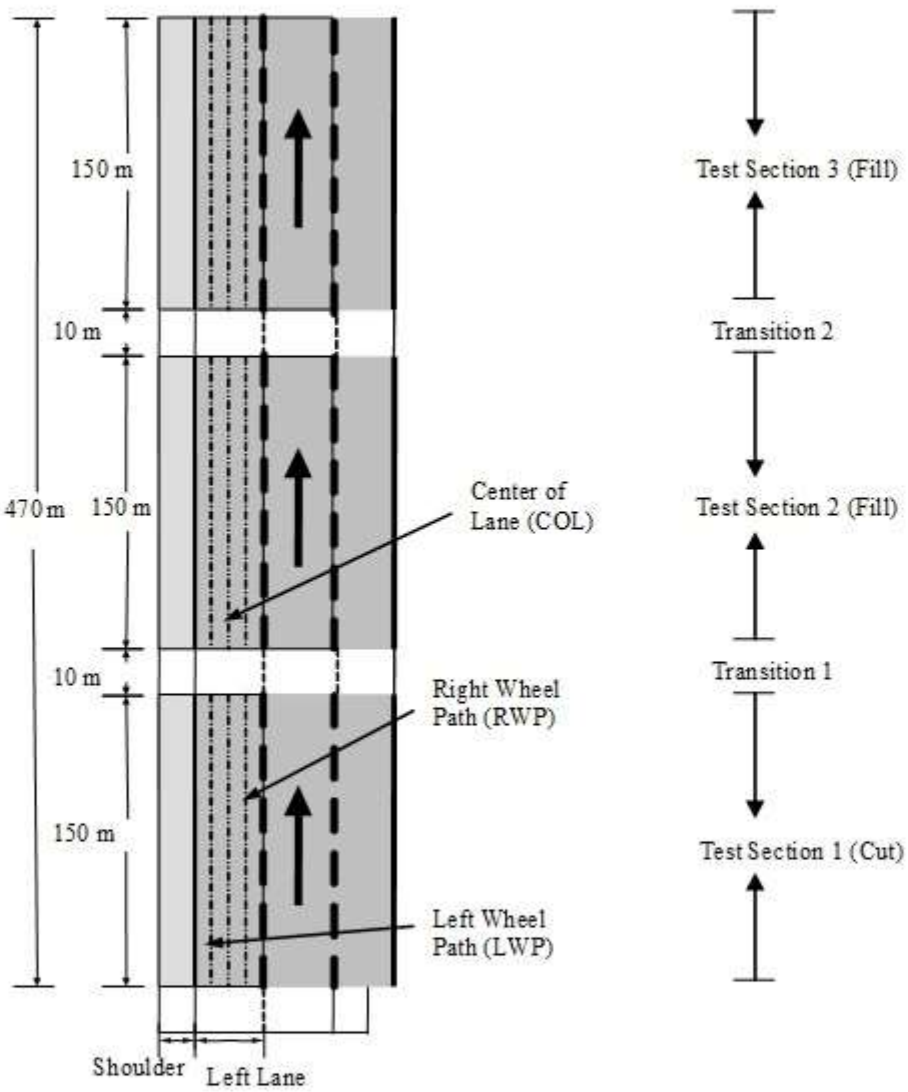

Figure 2. Division of test site into sections

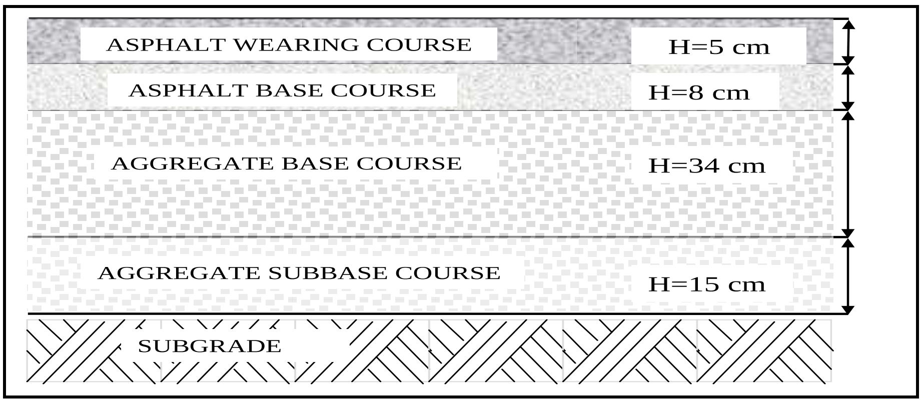

Figure 3. Cross section details of test sections

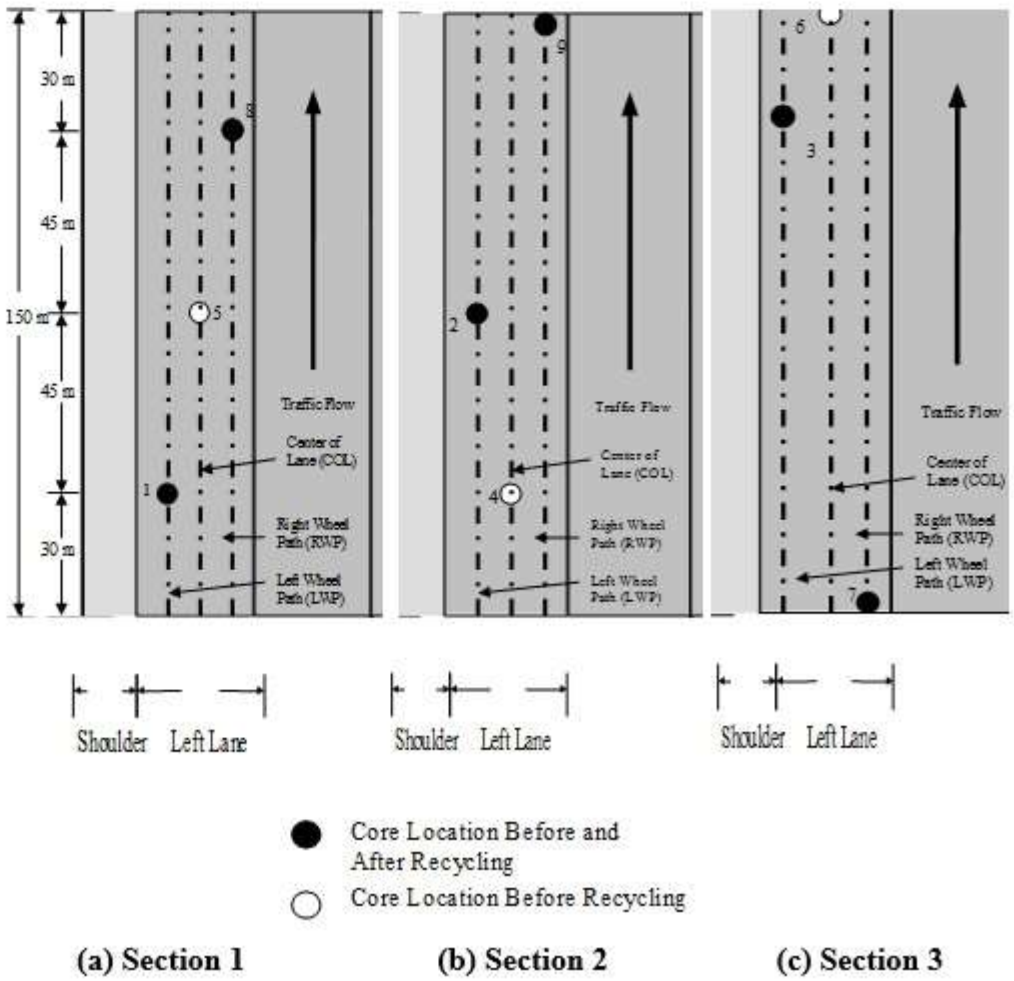

Figure 4. Coring plan within a test section

HIR equipment

The recycling unit used on this project is a German made, hot recycling unit by Wirtgen. The unit consists of two main parts, i.e. Panel heating machine HM 4500 and Remixer RX 4500. The units are shown in Figure 5, 6 and 7.

Technical specifications of the panel heating machine HM 4500 and Remixer RX 4500 units are tabulated in Table 1 and 2. HM 4500 heats pavement gently by infrared heater elements up to 60 mm of depth.

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

Figure 5. Pre-heating unit

Figure 6. Scarifying and heating unit

Figure 7. Remixing unit

Field testing

The coring plan is illustrated in Figure 4. A total of 9 HMA wearing course cores (3 cores from each section) before recycling and 6 HMA wearing course cores (2 cores from each section) after recycling were extracted for further laboratory testing and evaluation.

During the application of the HIR process on March 5, 2007, temperatures were measured at various stages of recycling. Surface temperatures recorded at different times during various stages of the HIR process are tabulated in Table 3. There were three panels in front and one on rear of panel heating machine HM 4500. According to Table 6-4 of Roberts et al. (2009), minimum laydown temperature for 5 cm (2”) with base temperature greater than 32^{o}C (90^{o}F), should be around 126^{o}C (260^{o}F). Temperatures recorded at different times during various stages of the HIR process indicated that they were well below the guidelines provided by Roberts et al. (1996), even though in HIR laydown temperatures are lower than conventional HMA. About 1% fresh asphalt binder (penetration grade 60-70) was added during the recycling process. Virgin aggregate and new HMA was not added during HIR on test sections.

Laboratory testing

Resilient modulus testing

The cores removed from test sections before and after recycling as illustrated in Figure 4 were brought back to the laboratory for further testing. The wearing course was separated from HMA cores. Resilient modulus testing was performed on HMA wearing course cores (102 mm diameter) according to ASTM D 4123 and the laboratory testing procedure by Barksdale et al. (1997). A universal testing machine (UTM-5P) by Industrial Process Control Global-IPC (IPC*)* was used for the tests. A total of 9 asphalt concrete wearing course cores (3 cores from each section) before and 6 asphalt concrete wearing course cores (2 cores from each section) after recycling with thickness ranging between 44 mm (1.73”) and 55 mm (2.17”) were tested. Barksdale et al. (1997), suggest load ranges of 30, 15, and 4% of tensile strength measured at 25°C to be used in conducting the test at temperatures of 5 ± 1, 25 ± 1, and 40 ± 1°C, respectively. The indirect tensile strength of asphalt cores was determined by using a Marshall loading frame based on *TXDOT Designation: Tex-226-F*. A Haversine load duration of 0.1 sec with rest period of 0.9 sec (frequency, 1Hz) was used for resilient modulus testing as recommended by Barksdale et al. (1998). Poisson's ratio values used during the resilient modulus testing were as recommended by Von Quintus et al. (2002). Temperature, loads, preconditioning cycles and Poisson's ratio used for resilient modulus testing of HMA wearing course cores before and after recycling are tabulated in Table 4. The summary of resilient modulus test results of HMA wearing course cores before and after recycling is tabulated in Table 5. Core designation includes whether the core is taken before or after recycling (BR/Before Recycling, AR/After Recycling), location (L/Left Wheel Path, C/Center of the Lane, and R/Right Wheel Path), test section number, and core number.

Table 3. Temperatures (°C) during various stages of HIR process

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

Table 4. Test procedure parameters for resilient modulus testing

Temperature (°C)	Load (N) before Recycling	Load (N) after Recycling	Cycles (No.)	Poisson's ratio
5	1250	1100	100	0.25
25	625	550	100	0.30
40	150	150	50	0.40

Table 5. HMA wearing course resilient modulus test results

Sample No.	Modulus (MPa)			Bulk Specific Gravity
	5^0C	25^0C	40^0C	
Before recycling				
BRL-1-1	15662	10724	3975	2.44
BRC-1-5	16479	7390	3397	2.44
BRR-1-8	18558	10553	3040	2.46
Average	16900	9556	3471	2.45
BRL-2-2	21246	8348	2436	2.46
BRC-2-4	25801	11535	2891	2.46
BRR-2-9	16429	7806	2328	2.46
Average	21159	9230	2552	2.46
BRL-3-3	16172	6585	1427	2.46
BRC-3-6	16673	10880	2219	2.44
BRR-3-7	12813	4447	1040	2.32
Average	15219	7304	1562	2.41
Overall Average	17759	8696	2528	2.44
Std Dev	3766	2385	923	0.05
CoV	21%	27%	36%	2%
After recycling				
ARL1-1	11536	3253	802	2.28
ARR1-8	9054	3437	940	2.34
Average	10295	3345	871	2.31
ARL2-2	10547	4718	953	2.33
ARR2-9	8447	2318	672	2.28
Average	9497	3518	813	2.30
ARL3-3	9405	2059	550	2.26
ARR3-7	9586	2646	625	2.27
Average	9496	2352	588	2.27
Overall Average	9763	3072	757	2.29
Std Dev	1109	965	168	0.03
CoV	11%	31%	22%	1.50%

Volumetrics and gradation testing

Bulk specific gravity of asphalt concrete core specimens was tested in accordance with AASHTO T 166-07. Extraction procedures for removing asphalt from aggregates in an asphalt mixture followed 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 British Standard, BS 598. Volumetric properties of asphalt wearing course cores before, and after recycling are tabulated in Table 6. The gradation envelopes of HMA wearing course before and after recycling are illustrated in Figure 8 and 9.

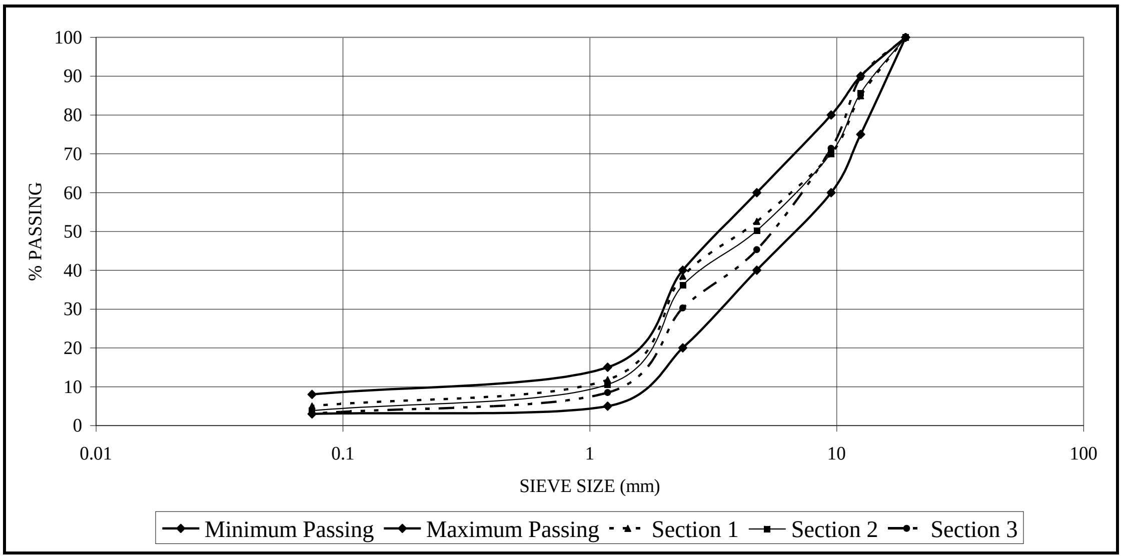

Figure 8. Gradation analysis of HMA wearing course cores before recycling

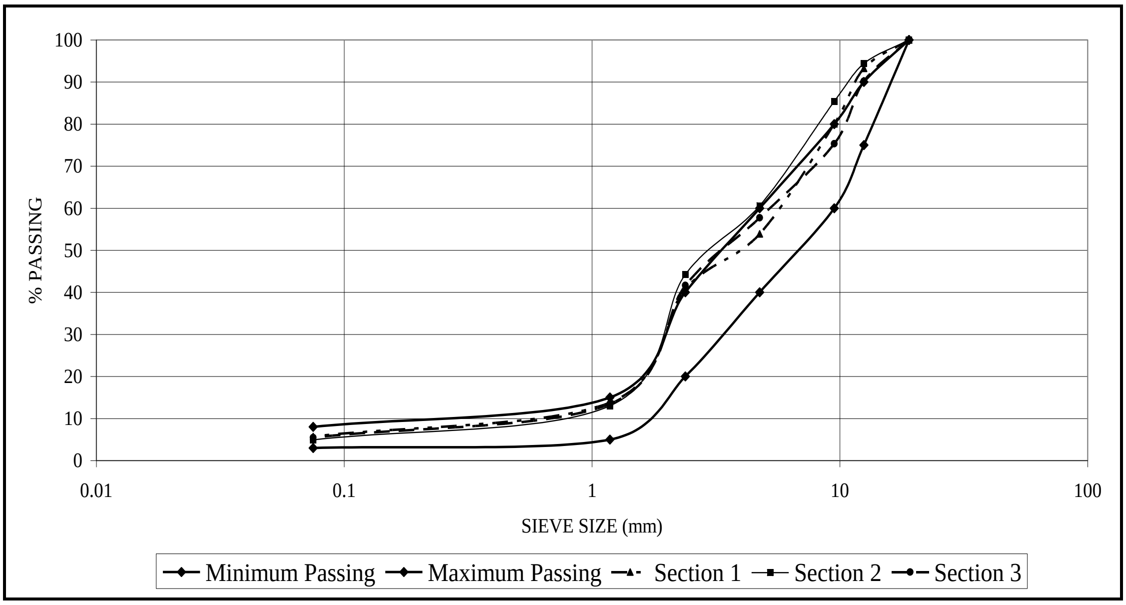

Figure 9. Gradation analysis of HMA wearing course cores after recycling

Table 6. Volumetric properties of HMA wearing course

Sample No.	Agg %	Asphalt %	Weight (gm)			(b)-(a)	Bulk Specific Gravity (Gmb)	Asphalt Gs	Gse of Agg	Max Theoretical Gs (Gmm)	% Air Voids	Voids in Mineral Aggregate (VMA) %	Voids Filled with Asphalt (VFA) %
Before recycling wearing course cores													
BRR-1-8	95.1	4.9	789.8	469.2	790.8	321.6	2.46	1.03	2.76	2.55	3.70	14.2	73.9
BRL-2-4	94.9	5.1	867.4	515.5	868.4	352.9	2.46	1.03	2.76	2.54	3.32	14.3	76.8
BRC-3-6	94.8	5.2	836.5	495.9	833.3	337.4	2.44	1.03	2.76	2.54	2.33	13.6	82.9
Average	95	5.0					2.46				3.12	14.0	77.9
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

Note: Agg stands for Aggregate

Reclaimed asphalt binder testing

The penetration grade as well as the performance grade (PG) of recovered asphalt binder from asphalt cores before recycling was determined. Penetration grade was determined according to ASTM D 5-06 e1. Penetration grades of recovered asphalt binder before recycling ranged between 55 and 57 whereas after recycling they ranged between 58 and 60.

The PG (higher temperature only) was determined by Dynamic Shear Rheometer (DSR) according to AASHTO T 315-06. The RAP binder was tested in the DSR at a high temperature as if it was original, unaged binder (McDaniel and Anderson, 2001). Performance grades of recovered asphalt binder before recycling ranged between 58 and 64 whereas after recycling ranged between 52 and 58.

RESULTS AND DISCUSSION

Analysis of resilient modulus data

Wearing course layer moduli show that the material is stiff; however, the variation of modulus was in a medium range. Average values of 17759 MPa at 5^{o}C, 8696 MPa at 25^{o}C and 2528 MPa at 40^{o}C (Table 5) can be taken as representative values. Test Section 1 contained a stiffer HMA layer as compared to other test sections at 25^{o}C and 40^{o}C. Section 2 has highest modulus values at 5^{o}C. Overall average specific gravity of 2.44 and low VMA (14%) shows that the material has become too dense and compacted with age which is also a cause of high modulus. This is also reflected in low air void results reported in Table 8 and wearing course high modulus values measured by Falling Weight Deflectometer (FWD) of the same sections given by Qureshi et al. (2010) for the same sections.

The results for wearing course layer moduli show that the material is of medium stiffness after hot in-place recycling. Average values of 9763 MPa at 5^{o}C, 3072 MPa at 25^{o}C and 757 MPa at 40^{o}C (Table 5) can be taken as representative values. Section 2 contains a stiffer HMA layer as compared to other test sections at 25^{o}C whereas Section 1 contains stiffer HMA at 40^{o}C and at 5^{o}C. Average specific gravity of 2.30 shows that density of the HMA wearing course layer has significantly reduced. This will cause the pavement to become more susceptible to rutting and moisture related damage but better resistant to fatigue cracking. Based on the above results, analysis can be summarized as follows:

- The average reduction in modulus of test sections is 45%, 65% and 70% at 5^{o}C, 25^{o}C and 40^{o}C respectively. This reduction is probably due to the fact that HMA pavement was stiff before recycling, softened after recycling and low laydown temperatures during recycling. The average reductions in wearing course modulus, measured by FWD, of test Sections 1, 2 and 3 were 25%, 30% and 38% respectively, at a normalized temperature of 23^{o}C. (Qureshi et al., 2010).
- The reduction in stiffness of the HMA layer is probably due to addition of fresh asphalt and reduced density.

- The significant reduction of modulus at 40ºC will increase the pavement susceptibility to rutting and moisture related damage of HMA wearing course.

Analysis of volumetrics and gradation

The recovered asphalt binder, air voids and bulk specific gravity before recycling ranged between 4.9 and 5.2 %, 2.33 and 3.70 %, 2.44 and 2.46 (Table 6), respectively. Average air voids of 3.12% along with average bulk specific gravity of 2.46 before recycling shows that the HMA wearing course layer has become denser with age. The HMA wearing course layer important volumetric parameters were measured to be average asphalt content (5%), average VMA (14%) and average VFA (77.9%), all within reasonable limits.

The recovered asphalt binder, air voids and bulk specific gravity after recycling range between 5.5 and 5.8 %, 6.32 and 8.95 %, 2.26 and 2.34 (Table 6), respectively. Average air voids of 7.8% along with average specific gravity of 2.30 after recycling shows an increase in air voids and reduction in density as compared to volumetric data before recycling. Insufficient compaction seems to be one of the causes of the reduction in density, even after fresh asphalt was added to the pavement. HMA wearing course layer important volumetric parameters show a trend of increase in asphalt content (5.5%) and VMA (19.2%) and decrease in VFA (59.3%) but all within reasonable limits. It is assumed that reduction in stiffness in the HMA wearing course layer is due to a combination of higher asphalt content, finer gradation, lower density and increased VMA. This follows the finding of a study carried out by Roque et al. (2002) that mixes with higher VMA exhibited lower stiffness.

The gradation envelopes of HMA wearing course before and after recycling are illustrated in Figure 8 and 9. The gradation of HMA wearing course before recycling (Figure 8) was well within the gradation envelope of NHA “Class B” specification. The degradation of the aggregates in HMA wearing course due to scarification (after recycling) was observed as illustrated in Figure 9. However it remained within the limits of NHA “Class B” asphalt wearing course specifications.

Based on personal observation of the writer, visible fractured aggregate in Figure 6, low laydown temperatures of recycled HMA, relatively low densities achieved in the field, it seems that heat could not penetrate the whole 5 cm depth of wearing course. The fast speed of the HIR train to achieve a target of 1 km in 9 hours seems to be one of the causes of insufficient heat penetration in the wearing course. Compaction was done with normal procedure of break down rolling by vibratory roller, intermediate rolling by Pneumatic-tired roller (PTR) and then finish rolling by vibratory roller (without vibration).

Analysis of reclaimed asphalt data

Based on the results, analysis can be summarized as follows:

- Binder has softened, but not significantly, after recycling as indicted by penetration results given in Section: “Reclaimed asphalt binder testing” above. The softening of asphalt binder is probably due to addition of fresh asphalt and low temperatures during the recycling process. Increase in penetration showed that the effect of infra-red heating was relatively gentle and its effects on age hardening were negligible. Based on the limited number of samples used for extracting binder, it is recommended to further investigate the effects HIR has on binder properties.

- There is no significant change in PG after recycling given in Section: "Reclaimed asphalt binder testing" above. This further highlights the need for further investigation of studying the effects of HIR on binder.

CONCLUSIONS

Based on the results of the field, laboratory investigations and data analysis conducted during the investigation of hot in-place recycling effects on HMA wearing course on Lahore-Islamabad Motorway, the following conclusions are inferred

The M-2 test sections contained stiff and aged HMA layer with presence of medium level rutting. The penetration and performance grade of binder showed that effect of infra-red heating was gentle and binder has softened minutely, probably due to addition of fresh asphalt. Recycled wearing course seems to be structurally sound on the basis of resilient modulus test results whose values were in medium range. Insufficient heat penetration was inferred in the wearing course due to fast speed of HIR train. In-place air voids of recycled wearing course are lower probably due to lower mix temperature and insufficient compaction.

RECOMMENDTIONS

In order to expand and further validate this research, a proper mix design procedure for hot in-place recycling (HIR) should be developed and validated by project specific studies and refined through experience in Pakistan. This HIR mix design procedure should ensure the proper design requirements of asphalt and aggregate. Proper mixing and laydown temperature, of pavements to be recycled, should be maintained at site to ensure long service life and better performance. Rheological properties of binder after HIR should be further studied with consideration for the local climate in Pakistan. A detailed study should be made on effect of different rejuvenators on performance of Binder in local environments to maximize the gain from HIR wearing course.

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