IMPACTS OF HOT IN-PLACE RECYCLING TECHNIQUES IN PAKISTAN

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Abstract

A hot in-place recycling (HIR) technique was employed for the first time on Lahore-Islamabad Motorway in 2005 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 of pavement.It was accomplished by comparing structural adequacy of pavement and material characterization before and after recycling.Analysis of recycled HMA wearing course indicated a reduction in modulus for a mix that was very stiff and aged prior to recycling. Relative degradation of the HMA wearing course was observed; however, it remained close to standard specifications specified by Executing Agency National Highway Authority (NHA). 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

Introduction

The Tremendous 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). The HIR technique has proven to be a viable on-site method for rehabilitation of pavements at low costs. 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 on the sections rutted to a depth of 38-50 mm.

Scope of study

The study was conducted to draw a comparative evaluation of the selected pavement sections before and after HIR. A Field work involved HMA coring before and after recycling and recording temperatures during various stages of HIR, Laboratory investigations like HMA volumetric analysis, aggregate gradation analysis, extracted asphalt properties (penetration test and DSR) and resilient modulus before and after recycling the selected pavement sections were conducted.

Materials and methods

Methodology adopted for this research before and after recycling has been given in Figure -1.

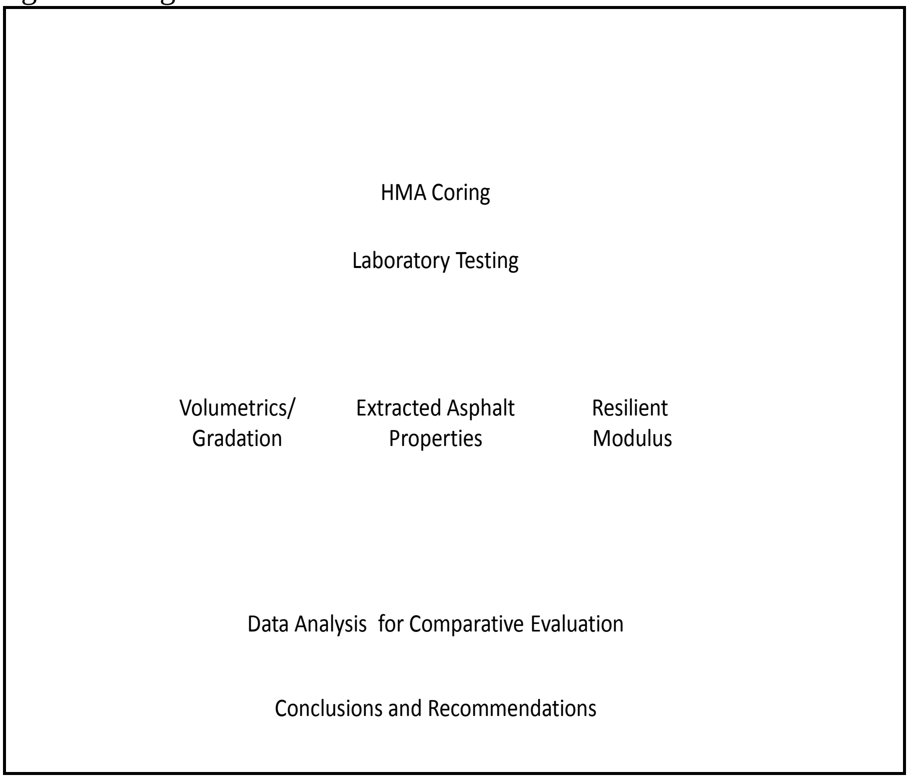


Figure -1 Evaluation method

Site selection

The selected site carriageway was divided into three sections of 150 m each separated by 10 m transition length as shown in Figure 2. The original pavement design of the test sections has been explained in Figure 3.All cores (Figure-4) were 102 mm diameter with thickness ranging between 44 mm (1.73”) to 55 mm (2.17”).

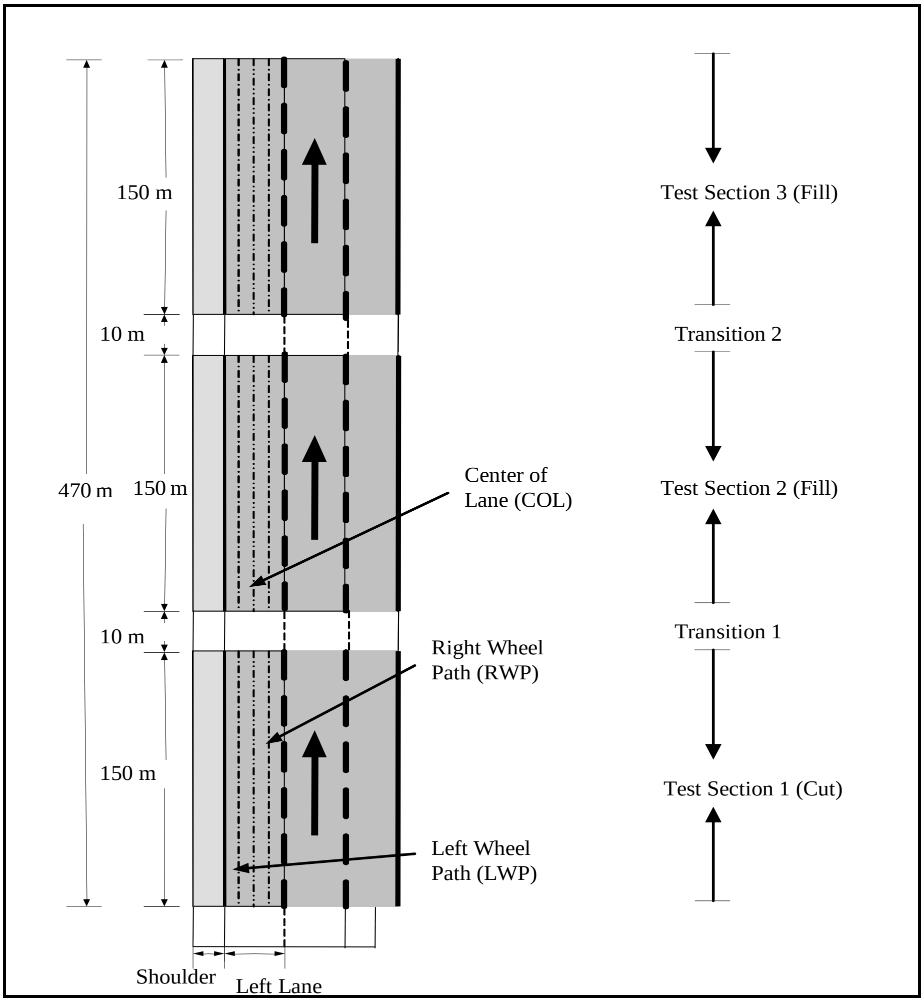


Figure -2 Different sections of Selected Site

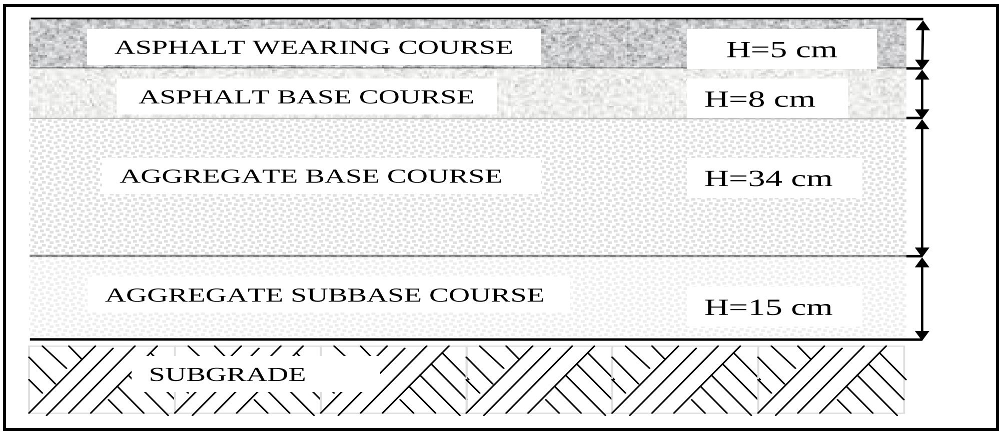
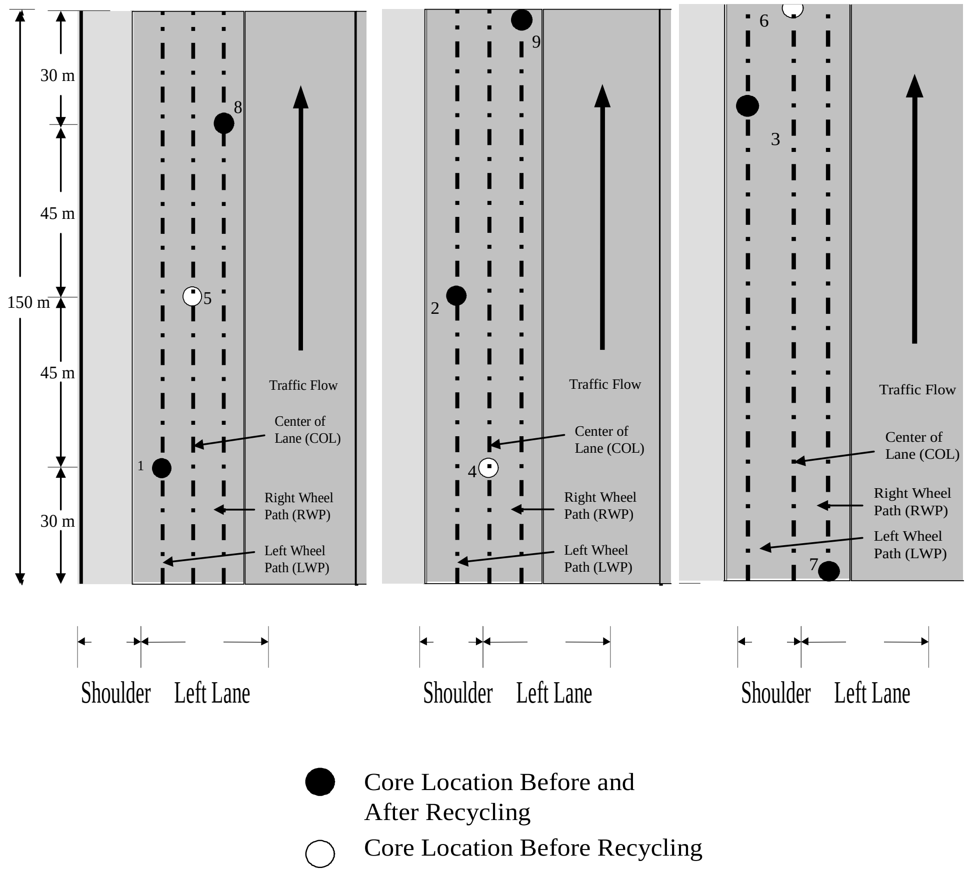


Figure- 3 Cross section of original pavement



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

Figure- 4 Coring plan of selected section

HIR Equipment

Technical specifications of the panel heating machine HM 4500 and Remixer RX 4500 units (Figure-5,6,&7) are tabulated in Table 1 and 2. HM 4500 heats pavement gently by infrared heater elements up to 60 mm of depth.

Table- 1 Specifications 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

Source-Website

Table -2 Specifications 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

Source-Website

Figure- 5 Pre-heating unit

Figure- 6 Scarifying and heating unit

Figure -7 Remixing unit

Field Tests

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 HIR process, temperatures were measured at various stages of recycling. Surface temperatures recorded at different times during various stages of the HIR process have been tabulated in Table-3. There were three panels in front and one on rear of panel heating machine HM 4500. The 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) Roberts et al. (2009).Temperatures recorded at different times during various stages of HIR process indicated that they were well below the prescribed guidelines 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.

Resilient modulus Test

The cores removed from selected sites before and after recycling (Figure-4) were brought to the laboratory. 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 laboratory testing procedure by Barksdale et al. (1997). 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 (3 cores from each section) before and 6 asphalt concrete wearing course(2 cores from each section) after recycling with thickness ranging between 44 mm (1.73”) to 55 mm (2.17”) were tested. Barksdale et al. (1997), suggest load ranges of 30, 15, and 4% of tensile strength measured at 25^{o}C to be used to conduct the test at temperatures of 5 ± 1, 25 ± 1, and 40 ± 1^{o}C, respectively. The indirect tensile strength of asphalt core was determined by using 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 test as recommended by Barksdale et al. (1998). Poisson’s ratio values used during the resilient modulus test was as recommended by Von Quintus et al. (2002). Temperature, loads, preconditioning cycles and poison’s ratio used for resilient modulus test of HMA wearing course before and after recycling are tabulated in Table-4. The summary of resilient modulus test results of HMA wearing course before and after recycling are 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 (^oC) variation at different stages of HIR process

Section	Time (hrs)	Panel Heating Machine Front			Panel Heating Machine Rear	Mix under Screed	After compaction
1	1000	81.8	92.5	127.0	136.0	92.0	66.0
1	1200	90.0	102.0	150.0	155.0	97.0	70.0
2	1300	100	117.0	170.0	175.0	102.0	74.0
2	1400	85.0	96.0	135.0	145.0	95.0	69.0
3	1600	94.0	107.0	160.0	160.0	101.0	72.0
Average		90	103	148	154	97	70

Source; Field work

Table- 4 Resilient modulus test procedure

Temperature (^oC)	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

Source; Field work

Table -5 HMA Wearing Course Resilient Modulus Test Results

Sample #	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%

Source; Field work

Volumetric and gradation testing

Bulk specific gravity of asphalt concrete core specimen 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 before, and after recycling (Table-6) and the gradation envelops of HMA wearing course before and after recycling has been given in Figure 8 and 9.

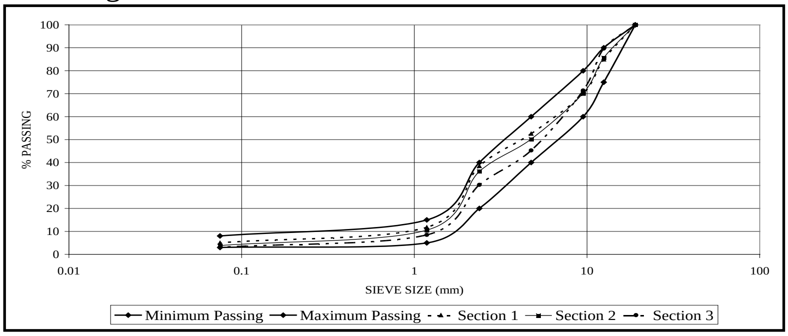


Figure -8 Gradation analysis of HMA wearing course before recycling

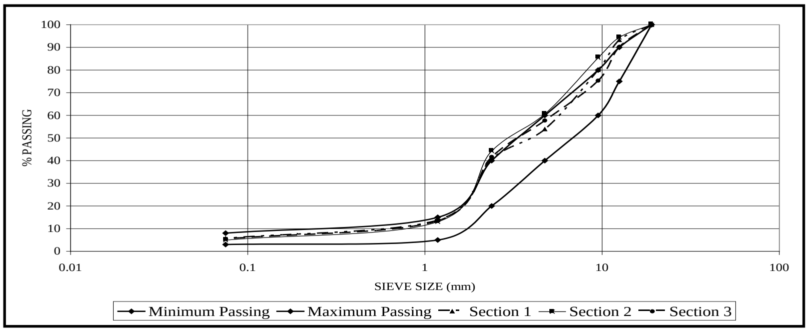


Figure -9 Gradation analysis of HMA wearing course before recycling

Table- 6 volumetric properties of HMA wearing course

Sample#	Agg %	Asphalt %	Weight (gm)			(b)-(a)	Bulk Specific Gravity (Gmb)	Asphalt Gs	Gse of Agg	Max Theoretical Gs (Gmm)	% Air Voids	VMA %	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

Source; Field work

Reclaimed asphalt binder test

The penetration grade as well as the performance grade (PG) of recovered asphalt binder from asphalt cores before recycling was determined according to ASTM D 5-06. Penetration grades of recovered asphalt binder before recycling ranged between 55 and 57 whereas after recycling 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 (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 shows that material has become too dense and compact with age that may be a cause of high modulus. This has also been reflected in low air void results reported in Table-8 and wearing course high modulus values measured by Falling Weight Deflect meter (FWD) of the same sections given by Qureshi et al. (2010) of 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}Cand 757 MPa at 40^{o}C (Table-5) can be taken as representative values. Section-2 contains 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 also prune to fatigue cracking. Based on the above results, analysis can be summarized as follows:

- The reduction in stiffness of HMA layer is probably due to addition of fresh asphalt and reduced density.
- The significant reduction of modulus at 40^{o}C will increase the pavement susceptibility to rut 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 volumetrics parameters were measured to be average asphalt content (5%), average VMA (14%) and average VFA (77.9%), all remained within reasonable limits.

The recovered asphalt binder, air voids and bulk specific gravity after recycling ranges 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 volumetrics parameters shows 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 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 of HMA wearing course before recycling (Figure 8) was well within gradation envelop of NHA “Class B” specification. The degradation of the aggregates in AC wearing cores due to scarification (after recycling) was observed(Figure-9).However it remained within the limits of NHA “Class B” asphalt wearing course specifications**.**

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 6.3. The softening of asphalt binder is probably due to addition of fresh asphalt. 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.
- There is no significant change in PG after recycling given in Section 6.3.

Conclusion

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 test sections contained very 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 observed 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.

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