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Characterization of Reclaimed Asphalt Pavement (RAP) for Use in Bituminous Road Construction

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Abstract

A good road network is a critical infrastructure requirement for rapid economic growth. It provides connectivity to remote areas; provides accessibility to markets, schools, and hospitals; and opens up backward regions to trade and investment. Roads play an important role in inter-modal transport development, through links with airports, railway stations, and ports. Road network in India aggregates to about 4.2 million kilometers. This extensive road network, the second largest in the world only after US, caters to about 65 per cent of the freight traffic and 87 per cent of the passenger traffic. National Highways (NH) constitute about 70,934 kilometers which is only 2 percent of the total network. However, it caters to nearly 40% of the total road traffic. State Highways (SH) and Major District Roads (MDR) together constitute the secondary system of road transportation which contributes significantly to the development of the rural economy and industrial growth of the country. The conventional method of providing bituminous surfacing on flexible pavements require significant amount of energy for production of bituminous binder from crude petroleum, drying aggregates and subsequently production of bituminous mix at hot mix plant (HMP).Hot mix recycling is the process in which reclaimed asphalt pavement materials are combined with new materials, sometimes along with a recycling agent, to produce hot mix asphalt mixtures. When properly designed, recycled mixtures can have better or similar performance to those of new conventional hot mix asphalt mixtures.
Recycling or Rejuvenating agents have been defined as organic materials with chemical and physical characteristics selected to restore properties of aged asphalt to desired specifications. In selecting the recycling agent, the viscosity characteristics of the combined aged asphalt binder and the recycling agent are the determining factors. These agents are also known as softening agents, reclaiming agents, modifiers, fluxing oils, extender oils, and aromatic oils. The choice of Recycling Agent (RA) grade will depend on the amount and hardness of the asphalt in the aged pavement. In general, the lower viscosity RA types can be used to restore aged asphalts of high viscosity and vice versa. Laboratory studies have been carried out on asphalt mixes with RAP material and rejuvenating agent and their performance has been compared with virgin asphalt mixes. Various performance tests such as Retained Stability, Indirect Tensile Strength (ITS), Creep test, beam fatigue test, resilient modulus and wheel tracking test has been carried out to compare the performance properties. This paper presents the results of all such performance tests carried out on asphalt mixes with RAP and virgin mixes. The laboratory results indicate that the asphalt mixes with RAP and rejuvenating agent provide better performance compared to virgin mixes. The paper also recommends that the Accelerated Pavement Testing Facility (APTF) should be put to use to evaluate the actual field performance of recycled pavements in a faster and effective manner.

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

Key words : Bituminous concrete;Rejuvenating Agent;Reclaimed Asphalt Pavement;Modulus;

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1. Introduction

The conventional method of providing bituminous surfacing on flexible pavements require significant amount of energy for production of bituminous binder, drying aggregates and subsequently production of bituminous mix at Hot Mix Plant (HMP). For example, approximately 6 litres of fuel is used for drying and heating one ton of aggregates, which would expand to enormously huge quantities considering lakhs of tons of aggregates that are used for road construction every year. The heating of bituminous binder, aggregates and production of huge quantities of HMA releases a significant amount of green house gases and harmful pollutants. The amount of emissions becomes twofold for every 10°C increase in mix production temperature, and increasingly, higher temperature is actually being used for the production of HMA with modified binders. Also, there is a problem of the scarcity of aggregates, which forces transportation of materials from long distance. The use of diesel for running trucks leads to emission of pollutants. Therefore, an attempt has to be made to develop and adopt alternative technologies for road construction and maintenance to reduce consumption of fuel and aggregates. Recycling of pavements, particularly HMA recycling is one such technology which may be adopted for Indian conditions (Ministry of Finance, Govt. of India, 2009).

Many studies are available on performance evaluation with conventional asphalt mixes (mix without RAP).Therefore there is a necessity for study on mechanistic evaluation of hot recycled mixes with and without utilization of recycling agents. Among all the recycling techniques, hot mix recycling techniques have large number of advantages and is well suited for Indian conditions.(Mittal et.al,2010).Some studies indicates that utilization of certain percentage of RAP increases the performance properties of mixes (Peter E.Sebaaly,2004) and some studies indicates that incorporating certain percentages of RAP there are no significant changes in the performance of mixes (Paul,1996).Some researchers found that Recycled Mixes have good resistance to moisture damage at low RAP percentages whereas there is no significant increase in resistance to moisture damage with increase in RAP percentage in mix (Huang,2010) and some studies state that resistance to moisture damage significantly decreases with presence of RAP (Huang,2010).Some researchers found that presence of RAP increases the stiffness of the mix(Aravind.K et.al,2006) and decreases in some studies(Huang,2010).Similarly fatigue life increases (Aravind.K et.al,2006) and decreases (Mohammed et.al,2003 McDanel and shah,2003) and vary according to the temperature(Puttaguanta et.al,1997).Tensile strength increases (Puttaguanta et.al,1997)or similar to virgin mixes (Huang,2010).

2. Materials

It was necessary to undertake testing on the materials to check their suitability for use in the bituminous mixes. This section contains the details regarding the various tests conducted on the aggregates and bitumen (virgin and recovered). The details regarding the rejuvenating agent and its optimization are also described. The RAP samples were collected from a site near Delhi and its bitumen content was found to be 3.65 %.The bitumen was recovered by washing of RAP sample by centrifuge method and subjecting the solution to distillation for the recovery of solvent and further left over traces were removed by Abson recovery method. The recovered bitumen was tested and penetration was found to be 39(0.1 mm units) and softening point as 62°C.

2.1 Testing of Fresh Aggregates and Bitumen

The aggregates used in the present study were obtained from a hot mix plant located near Delhi. The results of the various tests conducted on the aggregates are reported in Table 1. The Gg-30 bitumen was used for preparing the control mix samples. The properties of the bitumen are reported in Table 2.

Table 1: Properties of mineral aggregates

Properties	Test Method	Value	Requirements as per MoRTH , 2001 Specifications
Aggregate Impact Value, %	IS 2386 (Part IV)	21.6	30 max
Water Absorption Value, %	IS 2386 (Part III)	0.7	2 max
Specific Gravity	IS 2386 (Part II)	2.66	2.5-3.0
Combined (EI + FI) Index, %	IS 2386 (Part I)	25.2	30 max
Stripping, %	IS 6241	98	Min retained coating 95

Note : El: Elongation Index, FI: Flakiness Index

Table 2. Properties of bitumen (VG-30)

Properties	Test Method	Value	Requirements as per IS 73: 2006
Penetration, (25°C, 100 g, 5s), 0.1 mm	IS 1203-1978	64	50 – 70
Softening point (Ring and Ball), °C	IS 1205-1978	48	≥ 47
Ductility at 27°C (5 cm/min)	IS 1208-1978	78	-
Specific gravity	IS 1202-1978	1.01	-
Viscosity at 60°C, Poise	IS 1206-1978	2570	≥ 2400
Viscosity at 135°C, cSt	IS 1206-1978	725	≥ 350

2.2. Determination of Dosage of Rejuvenating Agent

The bituminous rejuvenating agent which has been prepared in the laboratory was added to the recovered binder obtained from the RAP material in various dosages of 10 %, 15 %, and 20 %. For each dosage, the fail temperature of the rejuvenated bitumen was determined using Dynamic Shear Rheometer (DSR) (AASHTO T 315). The results of DSR on rejuvenated bitumen samples are given in Table 3.

Table 3. Results of DSR Testing

Property	Temperature (in °C) corresponding to $G^*/Sin\delta > 1.1$	Viscosity at 60°C, Poise
VG-30 Bitumen	65.4	2400
Recovered Bitumen	71.4	2820
10 % RA	67.3	2420
15 % RA	65.0	2070
20% RA	63.9	1740

(RA – Rejuvenating Agent)

The dosage of rejuvenating agent was fixed as 10% by weight of recovered bitumen, since at this dosage the properties of the rejuvenated bitumen are similar to that of the VG-30 bitumen. Further testing was carried out with 10% rejuvenating agent only considering it as optimum dosage. The chemical properties of the rejuvenating agent, rejuvenated bitumen and recovered bitumen are presented in Table 4

Table 4 Results of Chemical Analysis and Physical Properties

Sample Type	Saturates (%)	Aromatics (%)	Resins (%)	Asphaltenes (%)	Viscosity at 60°C, Poise
Recovered Bitumen	<1	30	42	27	2820
Rejuvenating Agent	<4	68	27	1	41
Rejuvenated Bitumen	<3	45	38	14	2420

3. Mix Design

The mix design for virgin and RAP mixes was carried out as per Marshall method of mix design. Grading of aggregate was adopted as per MoRTH, 2001 specifications for 50 mm thick bituminous concrete (BC) and is given in Table 5. The grading of the aggregates with 20 % RAP is given in Table 5.

Table 5. Gradation of Virgin mix and mix with 20% RAP

Sieve Size mm	Cumulative % passing for virgin mixes	Cumulative % passing for mixes containing 20% RAP	Specified Grading as per MoRTH, 2001
19.0	100	97	79-100
13.2	99	77	59-79
9.5	78	62	52-72
4.75	63	44	35-55
2.36	44	36	28-44
1.18	37	25	20-34
0.60	27	19	15-27
0.30	20	12	10-20
0.15	13	9	5-13
0.075	10	6	2-8

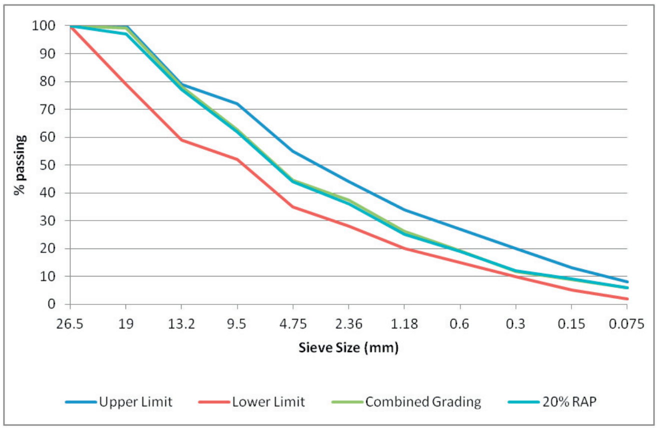

Figure 1: Aggregate Gradation Adopted for RAP Contained Bituminous Mixes

The Optimum Binder Content (OBC) for both virgin and 20 % RAP mixes was found to be 5.7 %. In case of 20 % RAP mix, the fresh binder to be added comes out to be 5.0 % compared to 5.7 % in case of virgin mix. The Marshall parameters obtained are presented in Table 6.

Table 6. Marshall Parameters for virgin and 20 % RAP mixes

Mix Type	VG-30 Binder Content (%)	Bulk Density (g/cc)	Marshall Stability (kN)	Flow (mm)	Air Voids (%)	VFB (%)
Virgin	5.70	2.358	13.50	2.30	3.57	75.0
20%	5.00	2.360	14.40	3.49	4.48	73.7

4. Performance Testing

4.1. Moisture Susceptibility

A key durability issue associated with moisture damage is commonly referred to as loss of adhesion. Stripping involves water or water vapour getting between the bitumen film and aggregates, thereby breaking the adhesive bond between the aggregate and bitumen binder film. To assess this, laboratory testing is done and the principle followed in such testing involves the determination of the strength ratio of the conditioned specimen and the controlled or unconditioned specimen, prepared as per mix design and comparing with the minimum acceptable strength ratio as given in the specifications.

4.1.1. Retained Marshall Stability

This test is conducted as per ASTM D 1075 specifications. The standard Marshall specimens of 100 mm diameter and 63.5 mm height were prepared. For conditioning purpose, the specimens were kept in water bath maintained at 60°C for 24 hours, and thereafter tested for Marshall stability value. The results are reported as the percentage of Marshall Stability determined in normal condition of the test i.e. the stability of the specimens immersed in water in a thermostatically controlled water bath at 60°C for 30 to 40 minutes. The results are presented Table.7.

Table 7. Retained marshall stability test results

Binder content type	Marshall Stability of controlled sample at 60°C (kN)	Marshall Stability of conditioned sample at 60°C (kN)	Retained Marshall Stability %
Virgin	12.05	10.32	85.6
20% RAP	13.20	11.63	88.1

4.1.2. Tensile Strength Ratio (TSR)

This test is conducted as per ASTM D 4867 specifications. The prepared samples were divided into two subsets, one subset is maintained dry while the other subset is partially saturated with water and moisture conditioned. The potential for moisture damage is indicated by the ratio of the tensile strength of the wet subset to that of the dry subset. The dry subset is soaked in a water bath for 20 min at 25°C. For the conditioning of wet subset, the samples are placed in water bath at 60^0C for 24 hrs and placed in water bath at 25°C for 1 hour. The tensile strength of each subset is determined by the tensile splitting test. The tensile strength is calculated as given in Equation (1)

$$s_t = \frac{2P}{\pi t d} \tag{1}$$

Where:

S_t = tensile strength, P = maximum load, t = specimen height immediately before test

D = specimen diameter

The Tensile Strength Ratio (TSR) of specimen is computed by Equation (2).

$$TSR = \left(\frac{S_{tc}}{S_{tuc}}\right) * 100 \tag{2}$$

Where, S_{tc} average indirect tensile strength of conditioned specimens and S_{tuc} is indirect tensile strength of unconditioned specimen. The results which are average of 2 samples are shown in Table 8.

Table 8. Properties of BC Mixes Prepared with Varying Percentage of RAP

Property	Type of Mix		Specified Values as per MoRT&H, 2001
	Virgin	20 % RAP	
Indirect Tensile Strength (dry), kg/cm^2	6.80	6.74	-
Tensile Strength Ratio (TSR), %	81.8	84.9	≥ 80 %

4.2. Resistance to deformation

Deformation of bituminous surface at high pavement temperature is common mode of distress.The aspect of deformation at high temperature has been investigated by conducting rutting and dynamic creep tests.

4.2.1. Rut depth studies by wheel tracking test

Rutting is an important parameter for design as well as for evaluation of performance of a BC mixture. To check the rutting resistance of the BC mixtures, tests were performed using a Wheel Tracking Device (WTD). The test was conducted on slabs with dimensions 300 × 300 × 50 mm, compacted at OBC for virgin as well as for 20 % RAP mix. The test was conducted as per AASHTO 324. The test applies 20,000 passes of the rolling wheel at 45 °C and resulting rut depth was measured. The rut depths of different BC mixtures are plotted in Figure 2.

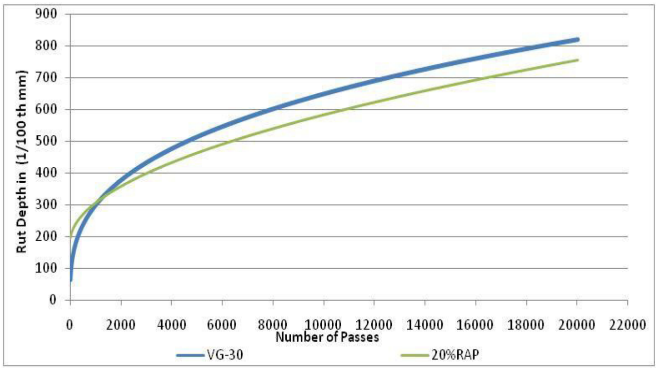

Figure 2. Rut depth Versus No of cycles of BC mixtures

4.2.2. Dynamic creep test

In the Dynamic creep test, an axial load is applied dynamically to the test specimen throughout the duration of the test. The test was conducted as per NCHRP 9-19 (unconfined). During the test, a cyclic stress of 69 kPa was applied with a seating stress of 11 kPa and haversine pulse is applied with loading width of 0.1 s followed by a rest period of 0.9 s. A maximum of 10000 load cycles were applied and accumulated permanent strain was recorded. The results for the total permanent strain (%) by taking the average of two samples are reported in Table 9

Table 9. Dynamic Creep Test Results

Type of Mix	**Total Permanent Stain (%) at a temperature of**	
	35° C	**45° C**
Virgin	0.999	1.028
20% RAP	0.717	0.827

4.3. Flexural Test

The fatigue properties are important because one of the principal modes of bituminous pavement failure is fatigue-related cracking. Fatigue cracking of pavement is considered to be more a structural problem than simply a material property. For predicting the fatigue life of bituminous layers under repeated traffic loading, repeated flexural bending test is done on bituminous beams. Results are usually plotted to show cycles to failure vs. applied stress or strain. The test may be done either in constant stress mode of loading or constant strain mode of loading. For the present study, the constant strain mode of loading was adopted. The test was done as per AASHTO T 321. The results of beam fatigue testing are presented in Table 10.

Table 10. Result of Beam Fatigue Test

Mix Type	Initial Flexural Stiffness (MPa)	Termination Flexural Stiffness (MPa)	No of Cycles to Failure
Virgin	1515	606	55,000
20% RAP	2311	1153	92,000

4.4. Resilient modulus (M_R) test

A material's resilient modulus is actually an estimate of its modulus of elasticity. The repeated loading indirect tensile test on compacted bituminous mixtures was performed as per ASTM D 7329. The test was conducted by applying the compressive load in the form of haversine wave at 25°, 35°, and 45°C for two BC mixtures. The specimens were conditioned for 5 hr in the environmental chamber at the given temperature and then subjected to repeated loading pulse of 0.1 s duration and 0.9 s rest period. The results which are average of three samples are shown in Table 11.

Table 11. Resilient Modulus (MPa) Test Results

Temperature (°C)	Resilient Modulus values	
	Virgin	20% RAP
25	3807	3943
35	1448	1478
45	582	631

5. Discussion of test results

5.1. Moisture Susceptibility

Values obtained for 20 % RAP mixes are higher as compared to the virgin mixes which clearly indicates that mix made with RAP is less susceptible to moisture damage as compared to the virgin mixes. Higher viscosity of rejuvenated binder ensures greater affinity of binder with aggregates and renders it less prone to stripping. The results further confirm the increased resistance of RAP mixes towards moisture damage.

5.2. Dynamic creep test

The accumulated permanent strain at the end of 10000 cycles was found to be less for 20 % RAP mixes compared to the virgin mixes at both the temperatures of 35 °C and 45 °C. This indicates that mixes with 20 % RAP have more potential to resist permanent deformation compared to the virgin mix. This behaviour is attributed to the hardened bitumen in RAP that possesses higher bitumen viscosity

5.3. Rutting test

It can be seen from the figure that the rut depth for virgin mix was obtained as 8.20 mm, whereas for 20 % RAP mix, it was 7.6 mm only after 20,000 passes. This indicates that the rut depth for 20 % RAP mix is less compared to the virgin mix. This substantiates that the addition of RAP improves the rutting resistance of the mix. The RAP containing mixes become stiffer compared to the mix without RAP and thus has better resistance to permanent deformation.

5.4. Fatigue Characteristics

Improvement in the fatigue life of BC mix with addition of RAP was observed as compared to the virgin mix. The average percentage increase in fatigue life of the RAP mixes was found to be 67.2% compared to the virgin mix.Therefore, the increased fatigue life implies that the mix prepared with addition of RAP is more durable than the mix without RAP.

5.5. Resilient modulus Test, M_R

The resilient modulus test indicates the improvement in the resilient modulus values of bituminous mix on using RAP. This increase in stiffness values might be attributed to the rejuvenation between virgin and RAP binder. As the stiffness of RAP binder is considerably higher than that of virgin VG-30 binder, the specimens with RAP have higher stiffness values.

6. Conclusions

Based on the laboratory testing work carried out on virgin mixes and mixes with 20 % RAP, it was found that addition of RAP improves all the properties of the bituminous mixes. This indicates that mixes with 20 % RAP would perform better than the virgin mixes under similar conditions.

Based on the findings of the study, it is concluded that it is possible to design acceptable-quality bituminous mixes with RAP that meets the required volumetric, mechanical properties and desired performance criteria. However, for actual field performance evaluation of RAP mixes, Accelerated Pavement Testing Facility (APTF) available at CSIR-CRRI may be put to use to get the results in a shorter time period.

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