IMPACTS OF REJUVENATOR ON PERFORMANCE AND ENGINEERING PROPERTIES OF HMA CONTAINING RECYCLED MATERIALS

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Abstract
Currently the use of recycled materials for road construction is increasing due to the ecological reasons and preserve natural resources. The present study involves the comparison of the variation in stability and durability properties of the HMA mixes containing different percentage of RAP varying from 10 to 40% and virgin HMA mix. However, these recycled materials are often highly aged and cause potential durability issue for asphaltic layers. To balance out the impact of stiff binder of recycled materials, rejuvenators have been recently evaluated. Rejuvenating agents can improve the engineering properties of asphalt mixtures containing high contents of RAP. Generally, a rejuvenator is an asphalt additive used for softening the stiffness of the oxidized asphalt mixtures. The rejuvenators typically consist of a high proportion of maltenes which balance the chemical composition of aged binder and losses the maltenes during construction and service. This study aimed to discuss the effect of using Zyco Therm as rejuvenators for restoring the properties of an aged RAP asphalt binder. The rejuvenator was incorporated with the optimum percentage of RAP. Various laboratory tests were performed to compare the performance and engineering properties of HMA mixtures without rejuvenator to those of mixtures incorporated with rejuvenators.
Index Terms: RAP, Rejuvenator and Zyco Therm

I. INTRODUCTION

The use of reclaimed asphalt pavement (RAP) materials in producing asphalt mixtures offers great benefits by reducing costs for producers and highway agencies and the environmental impact associated with the extraction, transportation and processing of natural materials. Although the use of RAP materials in asphalt mixtures can be favorable, the implementation of such mixtures is complex, since the resulted mixtures are stiff with a poor workability which makes them hard to compact in the field and ultimately leads to premature field failure. In order to moderate the stiffness of RAP-blended mixtures, a softer binder or rejuvenator can be used. Rejuvenating agents can improve the engineering properties of asphalt mixtures containing high contents of RAP. Generally, a rejuvenator is an asphalt additive used for softening the stiffness of the oxidized asphalt mixtures. This study aimed to discuss the effect of using Zyco Therm as rejuvenator for restoring the properties of an aged RAP asphalt binder. Various laboratory tests will perform to compare the performance and engineering properties of HMA mixtures without rejuvenators to those of mixtures incorporated with rejuvenators.

A. Objectives

- To characterize the RAP, that collected from field by finding the asphalt content and gradation of aggregates
- To prepare RAP (10-40%)- HMA mixes without rejuvenator and with rejuvenator (Zyco Therm) for surface course
- To suggest the optimum RAP content and rejuvenator content in HMA mix

- To evaluate and compare the performance of mixes by the use of rejuvenators for restoring the desirable properties of aged RAP binder

II. LITERATURE REVIEW

Brajesh Mishra (2015) analysed samples of Reclaimed asphalt pavement (RAP) materials for suitability of their usage in flexible pavements. The investigation results that 30% replacement of natural aggregate can be successfully done in base course of flexible pavements, resulting in a savings of around 25-30% in construction cost. Maulik Rao and Dr. N C Shah (2014) performed laboratory tests for using the RAP material as GSB (Granular Sub Base) after analysing and adding the missing sieve size material. The initial CBR of 0.85 was brought to 2, 3.8 and 6.8 respectively by 20, 40 and 60 % RAP mixing in black cotton soil. Also the study shows the saving of 25 % virgin material for GSB grade – II. Soohyok Im *et. al* (2014) evaluate the effect of three rejuvenators on engineering properties of asphalt mixtures containing RAP/RAS in terms of dynamic modulus, moisture damage, rutting resistance, and cracking resistance. The incorporation of rejuvenators improved the moisture susceptibility, rutting resistance and cracking resistance of the mixtures containing recycled materials. Martins Zaumanis *et. al* (2014) studied the performance properties of 100% recycled hot mix asphalt lab samples modified with five generic and one proprietary rejuvenators at 12% dose and tested for binder and mixture properties. Waste Vegetable Oil, Waste Vegetable Grease, Organic Oil, Distilled Tall Oil, and Aromatic Extract were used as rejuvenators. . Low temperature mixture cracking test results showed that five of the six rejuvenators have decreased cracking susceptibility compared to RAP mixture. Fatigue resistance of recycled mixtures at the used test parameters was higher than that of virgin mixture for all except WEO rejuvenated mixture. Workability of RAP mixture was increased by the use of all rejuvenators, but none was able to improve it to the level of the virgin binder or mixture. Aybike Ongel and Martin Hugener (2015) aimed to determine the aging behavior of rejuvenated 100% RAP binder and compare it with that of the virgin bitumen. Three types of rejuvenators were assessed in the study. The rheological tests performed at 3 aging stages: no-aging, RTFOT (Rolling Thin Film Oven Test) aging, and combined RTFOT and PAV (Pressure Aging Vessel) aging. It was shown that the aging of the virgin bitumen is slower than that of the rejuvenated bitumen. Tao Ma *et. al* (2015) focused on the diffusion and distribution of the rejuvenator in the aged asphalt of reclaimed asphalt pavement (RAP) materials during hot recycling. The viscosity, components and rejuvenator thermal stability are found to have important influences on the diffusivity and distribution of the rejuvenator in aged asphalt. During the short blending process of recycling the asphalt mixture, it is difficult for the rejuvenator to fully diffuse into the aged asphalt. Therefore, the property and distribution of the recycled asphalt tends to be no uniform in the asphalt mixture during recycling. This non uniformity can lead to poor high temperature anti-rutting performance, poor low-temperature cracking resistance and poor moisture stability of the recycled asphalt mixture. Xiaokong Yu (2014) *et. al* Studied rheological, microscopic, and chemical characterization of the rejuvenating effect on asphalt binders. Results indicated that the bulk mechanical properties (complex modulus and viscosity) of the rejuvenated binders were in between those of the virgin and aged binders. Aging and rejuvenation led to morphological changes as compared to their virgin binders; however, the rejuvenated binders did not always reproduce the microstructures of the virgin binders.

III. MATERIALS AND METHODS

In this study Hot Mix Asphalt (HMA) was designed for 13 mm nominal size of aggregates as per MoRTH specifications for Road and Bridge works-V revision (2013).

A. *RAP Aggregate*

For the study RAP was collected near Thiruvalla of SH1 in Kerala. Centrifugal extractors are used to determine the percentage of asphalt and aggregate gradation of bituminous paving materials based on the weight of an asphalt and aggregate mixture. The quantity of binder content is also determined by subtracting the weight of aggregate after extraction from the total weight of asphalt-aggregate mixture before extraction which is an average of 4.98%. For the study different samples of RAP aggregate separated from the centrifugal extractor were subjected to sieve analysis .Fig. 3.1 shows the gradation chart of RAP.

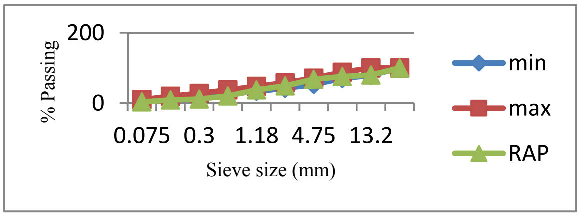

Fig.1.Gradation of RAP Aggregate

B. Virgin Aggregate

Gradation of the virgin aggregate is fixed as per the specification given by MoRTH 2013 (5th Revision). Midpoint gradation for 13 mm wearing course was selected for study.

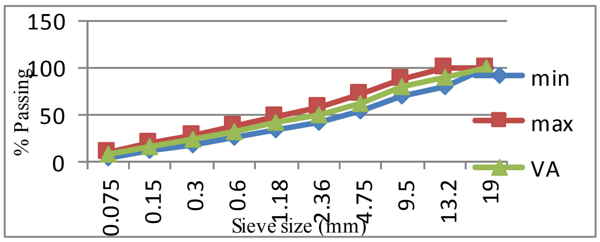

Fig. 2 Gradation of Virgin Aggregate

C. Characterization of RAP and Virgin Aggregate

The aggregate used for pavement construction should be of sufficient quality. To ensure this basic laboratory tests were conducted for both RAP and virgin aggregates and results are shown in Table 1

Table 1 CHARACTERISATION OF RAP AND VIRGIN AGGREGATE

Tests performed	**Results**		Requirement as per MORTH, 2013 Specifications
	Virgin Aggregate	RAP Aggregate	
Aggregate Impact value, %	26.35	24.3	Max. 30
Los Angeles Abrasion value, %	29.7	28	Max. 40
Combined (EI+FI) Index, %	20	29	Max. 35
Aggregate crushing value	27	29	Max.30
Specific gravity	2.67	2.65	2.5-3

D. Zyco Therm

Zycotherm is an organosilane additive to bitumen binder, to be added before bitumen is mixed with aggregates to produce HMA. Zycotherm makes the pavements resistant to moisture, as it promotes chemical bonding at the aggregate interface. This additive also facilitates consistent compaction while paving. Zycotherm provides 100% coating of aggregates.

IV. EXPERIMENTAL SETUPS

A. Mix design

1.) Combined Gradation

From the RAP aggregate gradation it was found that aggregates with some of the sizes are very less. By fixing the mid-value of cumulative percentage passing as per MoRTH specifications the remaining quantity of virgin aggregate was selected.

2.) Marshall Mix design

Considering the simplicity, reliability and ease of performance it was decided to use Marshall method to determine optimum binder content and performance prediction. The Marshall samples were prepared where binder content is varied from 4% to 7% with an increment of 0.5% for each RAP mixture (0-40%) and for control mix. Approximately 1200gm of aggregate is heated to a temperature of 150 – 165 ^{0}C and bitumen is heated to a temperature of 150 − 170^{0}C. The heated aggregates and bitumen are thoroughly mixed at a temperature of 150 − 165^{0} C. The percentage of RAP binder was deducted from the total weight of bitumen needed for mix. It is assumed that the RAP binder blends with the virgin binder. The specimen was compacted with 75 gyrations using gyratory compactor. The Optimum Binder Content for control and RAP specimens were found by conducting Marshall Stability tests.

iii) Marshall stability tests for Rejuvenator added RAP mixes

Even the RAP specimen's stability values conforms to the required stability values since we are using aged aggregate and binder the long term performance of the RAP mix is expected to be week. In order to withstand or retain the drawbacks of aged binder rejuvenator has been used. Therefore Zycotherm of 0.1 and 0.15 % by weight of bitumen binder (including RAP binder) is added to virgin binder and Marshall stability tests were conducted. From these tests the best RAP and rejuvenator combination were identified.

B. Retained Stability Test

This test determines the retained Marshall stability of Marshall compacted specimens after curing for 24 hours in a water bath at 60^0C. The test results are the indication of moisture susceptibility of the mix.

C. Indirect Tensile Strength Test

The values of IDT strength may be used to evaluate the relative quality of bituminous mixtures in conjunction with laboratory mix design testing and for estimating the potential for rutting or cracking. The results can also be used to determine the potential for field pavement moisture damage when results are obtained on both moisture-conditioned and unconditioned specimens. The tensile characteristics of bituminous mixtures are evaluated by loading the Marshall specimen along a diametric plane with a compressive load at a constant rate acting parallel to and along the vertical diametrical plane of the specimen through two opposite loading strips.

D.Indirect Tensile Stiffness Modulus test

The Indirect Tensile Stiffness Modulus (ITSM) test is a non-destructive method of measuring the stiffness modulus of asphaltic paving materials at a selected horizontal deformation. During this test, the specimen is subjected to five load pulses. During the ITSM test, the load and deformation pulses were captured by the data acquisition system. Each load pulse was analysed by the software and determined the maximum load.

V.RESULTS AND DISCUSSION

A. Marshall Stability

Optimum binder content at the various percentages of the RAP material is determined corresponding to MoRTH specifications. . It was found that the OBC determined was 6.33 for the control mix, 6.17 for 10% RAP, 5.67 for 20% RAP, 5.50 for 30% RAP and 5.33 for 40% RAP in percentage by weight of mix respectively. OBC values have been on the decreasing trend with increasing RAP bitumen. To get exact properties, Marshall stability tests were conducted for each RAP percentage with OBC. Table 2 gives the mix properties of OBC added virgin materials and RAP materials.

TABLE 2. MIX PROPERTIES FOR CONTROL AND DIFFERENT % OF RAP MIXES

RAP %	Optimum Binder content, %	Stability, kN	Flow, mm	Air voids, %	VMA, %	VFB, %	Unit weight (g/cc)
0	6.33	16.91	3.92	3.99	17.41	67.5	2.45
10	6.17	14.98	4.23	4.01	17.38	69.6	2.43
20	5.67	17.41	3.68	4.02	17.31	69.9	2.42
30	5.5	18.58	3.88	4.06	16.79	67.5	2.39
40	5.33	15.98	3.73	4.15	17.53	69.9	2.34

From the Marshall tests, it was observed that there has not much variation between the stability values for control mix and RAP mixes. Mix properties of all the mixes upto 40% RAP are conforms to the MoRTH specification. Even the RAP specimen's stability values conforms to the required stability values since we are using aged aggregate and binder the long term performance of the RAP mix is expected to be week. In order to withstand or retain the drawbacks of aged binder rejuvenator has been used. Therefore Zycotherm of 0.1 and 0.15 % by weight of bitumen binder (including RAP binder) is added to virgin binder and Marshall stability tests were conducted. For control, 30% and 40% RAP mixes the addition of 0.1% dosage Zycotherm improves their stability by 0.41, 2.26, 0.19% respectively. For 10 and 20% RAP mix addition of this percentage of Zycotherm has not improved their stability. For control, 10%, 20%, 30% and 40% RAP mixes the addition of 0.15% dosage Zycotherm improves their stability by 0.47, 0.20, 1.49, 11.95 and 8.07% respectively. The best improvement was shown by the addition of 0.15% dosage of zycotherm with 30% RAP.

From these tests the best RAP and Zycotherm combination were identified. Different Marshall properties of 0.15% of Zycotherm added mixes are shown in tables 3.

TABLE 3. MIX PROPERTIES FOR 0.15 % ZYCOTHERM ADDED RAP MIXES

RAP %	Optimum Binder content, %	Stability, kN	Flow, mm	Air voids, %	VMA, %	VFB, %	Unit weight (g/cc)
0	6.33	16.99	3.61	4.1	15.26	73.9	2.34
10	6.17	15.01	4.43	3.85	17.31	69.8	2.37
20	5.67	17.67	3.89	4.3	15.23	71.4	2.41
30	5.5	20.8	3.56	3.99	17.36	65.4	2.43
40	5.33	17.01	4.01	3.76	16.88	74.4	2.39

The best stability values were obtained for the combination of 30% RAP and 0.15% Zycotherm. Therefore retained stability and Indirect Tensile Strength and Indirect Tensile Stiffness Modulus tests were conducted for control mix, 30% RAP mix and 0.15 % Zycotherm added 30% RAP mix.

B. *Retained Stability test*

Marshall stability of the compacted specimen was determined at 60^0 C for 24 hr prior to the testing. This test is conducted to know that the mix should be susceptible to moisture damage or not. The static immersion test was conducted as per the procedure in ASTM D 1075. The results obtained are as given in Table 4.

TABLE 4. MARSHALL IMMERSION VALUE

Description	Conditioning time	Stability ((kN)	Marshall stability ratio	Desired value
Control mix	40 min	16.91	87.7%	>75% as per MoRTH ((Fifth revision)
	24 hr	14.83		
RAP 30 % mix	40 min	18.58	71.85%	
	24 hr	13.35		
30% RAP + Zycotherm mix	40 min	20.80	81.54%	
	24 hr	16.96		

It is observed that 30% RAP mix shows only 72% Marshall stability ratio which is less than the required value as per MoRTH. There is a 9.69 % increase in retained stability ratio by the addition of 0.15% dosage of Zycotherm. These results indicate that 30% RAP mix are susceptible to moisture damage. But the addition of Zycotherm provides resistance to moisture damage to the RAP.

C. *Indirect Tensile Strength test*

The first group of specimens were immersed in a water bath at 60˚C, for a period of 24 hours (conditioned sample). The samples are then removed from the water bath and kept at a temperature of 25˚C for a period of 2 hours. Other set of samples (unconditioned sample) are kept at a temperature of 25˚C for a period of 2 hours without soaking. These specimens are then mounted on the conventional Marshall testing apparatus and loaded at a deformation rate of 51mm/min and the load at failure is recorded at each case. Then the tensile strength of water conditioned as well as unconditioned specimen for each additive stabilized mixture is determined which is shown in Table 5.

TABLE 5. ITS AND TSR RESULTS

Description	Sample type	ITS (kN)	TSR (%)	Desired value
Control mix	Dry	16.89	85.43	Min. 80% as per MoRTH (AASHTO T 283)
	Soaked	14.43		
RAP 30 % mix	Dry	18.53	70.04	
	Soaked	12.98		
30% RAP + Zycotherm mix	Dry	19.23	79.32	
	Soaked	15.25		

C. Indirect Tensile Stiffness Modulus Test

The ITSM test requires specimen dimensions, temperature of specimen and Poisson's ratio are to be provided in the software. As the test progress, real time display of graphs will appear on screen. Temperature correction factors are included in the software. The test results obtained from the ITSM test is shown in the Table 6. By the inclusion of Zycotherm the ITSM values is increased by 18.15% compared to RAP mix without zycotherm.

TABLE 6. INDIRECT TENSILE STIFFNESS MODULUS VALUES

Type of mix	Indirect Tensile Stiffness Modulus (MPa)		
	Along diameter 1	Along diameter 2	Average
Control sample	2796	2759	2778
30% RAP sample	2234	2349	2292
30% RAP+ Zycotherm mix	2718	2698	2708

The results indicate that TSR value of 30% RAP mix not conform to the limit as per MoRTH. But with the addition of Zycotherm TSR value is improved by 13.25 %.

VI . CONCLUSIONS

- From the Marshall stability test values it was observed that 10, 20, 30 and 40 % RAP inclusion has not decreased the stability values.
- By the addition of Zycotherm at dosage 0.15% by weight of binder, it was observed that the marshall stability values of RAP mixes increased.
- 30% RAP with 0.15% Zycotherm was identified as the best combination from Marshall values.
- To evaluate and compare the performance of mixes by the use of Zycotherm for RAP Retained stability tests and Indirect Tensile Strength tests have been conducted for 30% RAP mix, 30% RAP with 0.15% Zycotherm and contol mix. Performance test results of 30% RAP are not conformed to the MoRTH specifications.
- But there is a 9.69 % increase in retained stability ratio by the addition of 0.15% dosage of Zycotherm. Thus Zycotherm enables RAP mixture resistant to moisture susceptibility. With the addition of Zycotherm TSR value is improved by 13.25 % and ITSM values are increased by 18.15% compared to RAP mix without zycotherm.

From the observations it can be concluded that 30% RAP with 0.15% Zycotherm by weight of binder is an optimum combination for HMA mix that can be used in surface course.

REFERENCES

[1] Charles Grady and Jim Brownridge (2000)," The Role of an Asphalt Rejuvenator in Pavement Preservation Use and Need for Asphalt Rejuvenation".

[2] Robert E Boyer (2000)," Asphalt Rejuvenators -Fact or Fable"

[3] Stephen J. Cooper (2011),"Asphalt Pavement Recycling with Reclaimed Asphalt Pavement (RAP)", NWPMA, 18th Annual Fall Pavement Conference.

[4] Soohyok Im, Fujie Zhou, Robert Lee, Tom Scullion (2014)," Impacts of rejuvenators on performance and engineering properties of asphalt mixtures containing recycled materials", *Journal of Construction and Building Materials,* Vol. 53, pp. 596–603.

[5] Maulik Rao and Dr. N C Shah (2014), "Utilisation of RAP (Reclaimed Asphalt Pavement) Material Obtained By Milling Process: With Several Options in Urban Area at Surat, Gujarat, India", *International Journal of Engineering Research and Applications,* Vol. 4,pp.1-4

[6] Martins Zaumanis , Rajib B. Mallick , Lily Poulikakos and Robert Frank, " Influence of six rejuvenators on the performance properties of Reclaimed Asphalt Pavement (RAP) binder and 100% recycled asphalt mixtures", *Journal of Construction and Building Materials* , Vol. 71, pp. 538-550

[7] Brajesh Mishra (2015), "A Study on Use of Reclaimed Asphalt Pavement (RAP) Materials in Flexible Pavements", *International Journal of Innovative Research in Science, Engineering and Technology,* Vol. 4, pp. 12170-12177

[8] Xiaokong Yu , Martins Zaumanis , Salomé dos Santos ,Lily D. Poulikakos (2014), "Rheological, microscopic, and chemical characterization of the rejuvenating effect on asphalt binders", *Journal of Fuel*, Vol. 135, pp. 162-171

[9] Aybike Ongel , Martin Hugener (2015),"Impact of rejuvenators on aging properties of bitumen", *Journal of Construction and Building Materials*, Vol. 94, pp. 467-474.

[10] Jun-Feng Su, Erik Schlangen, Ying-Yuan Wang (2015)," Investigation the self healing mechanism of aged bitumen using microcapsules containing rejuvenator", *Journal of Construction and Building Materials*, Vol. 85, pp. 49 – 56.