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Laboratory Performance Evaluation of Hot Mix Asphalt Using Reclaimed Asphalt Pavement Material for Bituminous Concrete Layer

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Abstract
Pavement rehabilitation and reconstruction generate large quantities of reclaimed asphalt pavement (RAP). Recycling into new asphalt paving mixtures is the predominant application. The RAP contains aggregates coated with bitumen. Recently utilization of RAP in asphalt mixes has been gaining worldwide popularity. Use of RAP in asphalt mixes can reduce cost of materials (aggregates and bitumen), conserve aggregates and asphalt, save environment, and can solve problem of solid waste disposal. The present study is used to design and evaluate the performance of bitumen mix with 2 different percentage of RAP. The preliminary laboratory tests were conducted to check the quality of aggregate, bitumen and RAP. The use of different percentage of RAP (i.e. 0%, 40% and 50%) for Bituminous concrete (BC) were designed as per specifications of Ministry of Road Transportation and Highway (MoRTH). The Marshall Mix design method was utilized to design mix with different percentages of RAP. The moisture damage potential of different mixes was determined in the laboratory by estimating retained indirect tensile strength also called tensile strength ratio (TSR). The test was conducted by applying a compressive load at a rate of 50.8 mm/min and their TSR values were determined. Furthermore, the rutting performance of different types of mixes was determined in the laboratory using flow time test. The results indicate that addition of RAP increases rutting resistance. This study would be helpful for highways engineers to utilize RAP for construction of sustainable highways in India.
Keywords: *Bituminous Mixes; Marshall Mix Design; Reclaimed Asphalt Pavement (RAP); Hot Mix Asphalt.*

1. Introduction
Hot mix recycling asphalt pavements is increasingly being used as one of the major rehabilitation methods by using various highway agencies. This generally helps savings in costs, natural resources (aggregates and bitumen) and environment. Estimated world production of asphalt in 2007 is about 1.6 trillion metric tons of asphalt was produced worldwide. Out of which Asia produced 495 million metric tons of asphalt, nearly 31% of total production. [1-3] in this study attempt was made to Reuse the RAP which is obtained from deteriorated pavement with a different percentage of RAP in a virgin mix. The mixing is done in laboratory and various laboratory tests were carried out from the RAP mix to study the performances and the results are compared with the virgin mix. This would determine whether the recycled HMA pavement has performed similar to virgin mix. [4-8] it would also provide information of mix method for recycled mixture. Most states have established limit on the

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Page No: 1110-1118

maximum percentage of RAP that can be used which typically ranging between 10% to 50%. Based on the expert opinions, future specifications are expected to allow the use of RAP in higher quantity. On the other hand, many agencies are taking advantage by increasing the percentage of RAP. The design procedure and the success of using RAP will require many durability concerns related to the interaction between virgin and recycled materials. [9-12] the purpose of this study is to provide an information about use of RAP in HMA, and, mix design techniques, handling of RAP in the HMA, and performance issues.

1.1 Need of Recycling

Natural resources are conserved to reuse or salvaging of aggregates and asphalt in existing pavement. Pavement material disposal is greatly reduced or eliminated. Energy is conserved as the construction is completed or on-grade and no fuel is required for heating. [13-16] Pavement maintenance costs can be reduced. So by knowing above all advantages for the recycling of RAP, we concluded that it is more useful to reduce the cost of construction of pavement when compared with virgin mix and it also increases the age of pavement using RAP.

1.2 Objectives of the Study

The overall objective of the present study is to design and evaluate performance of bituminous mixes containing different percentage of RAP. Specifically, the objectives of present study are to

- Characterization of reclaimed asphalt pavement (RAP) collected from known source.
- Design of Bituminous Concrete (BC) with and without different percentage of RAP (0%, 40% and 50%) using Marshall Method.
- Evaluate moisture damage potential of bituminous mixes with and without RAP by Tensile Strength Ratio (TSR) test
- Evaluate the rutting resistance of bituminous mix with and without RAP, by Flow-Time test.
- Study the effect of addition of RAP in bituminous mixes.

2. Materials Characterization

2.1 Aggregates

Aggregates are collected from Shivapur stone crushing plant near Bilagi. Sizes of aggregates collected are 6mm, 10mm, 20mm, stone dust from same quarry. Which are used for mix design by performing varies tests to determine its strength of aggregates which are shown in Table 1.

Table 1 Properties of Virgin Aggregates

Aggregate Test	Method	Result	Maximum limits
Aggregate Impact Value (%)	IS : 2386 (Part-IV)	14.65%	30 %
Los Angeles Abrasion Value (%)	IS : 2386 (Part-IV)	18.10%	30%
Combined Flakiness and Elongation Index (%)	IS : 2386 (Part-I)	37.56%	40 %
Water Absorption	IS : 2386 (Part-III)	0.90 %	2 %
Aggregate crushing value	IS : 2386 (Part-IV)	18.26%	30%

2.2 Bitumen

Viscosity grade VG10 bitumen sample was collected from bitumen concrete plant situated near agricultural college bagalkot. The VG10 grade binder is generally used for construction of flexible pavements in India as per Indian Road Congress specification which are shown in Table 2.

Table 2 Test Results of Bitumen VG 10

Test	Test Result	Limiting Value	Test Method
Softening Point, °C	52	45 to 55	IS 1205 : 1978
Ductility at 27 °C, cm	68	Min 70	IS 1208 :1978
Specific gravity	1	0.97 to 1.02	IS 1208 :1978

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Issue: 04 April 2024
Page No: 1110-1118

2.3 Recycled Asphalt Pavement (RAP)

RAP is collected from road which is a link between Bagalkot and Gaddankeri 19th cross Vidyagiri Bagalkot which is dug for the connection of water supply pipeline. The length of the road is 10 kms. The collected RAP was removed from the top surface of the pavement of thickness of 10-12cm are shown in Table 3.

Table 3 Physical Properties of RAP

Characteristics	RAP Aggregates	Maximum limit as per IRC
Aggregate crushing value	20.2%	**30%**
Aggregate Impact value	9.15%	**30%**
Flakiness Index of the aggregate	4.02%	**35%**
Elongation Index of the aggregate	5.6%	**25%**
Los Angeles	15.23%	**30%**
Specific Gravity	2.68	
Water Absorption	**2.04%**	**2%**

3. Experimental Methods

3.1 Asphalt Content in RAP

Solvent extraction or Centrifuge extraction test was conducted as per ASTM D2172. The RAP was dissolved in 200 ml of Trichloroethylene Solvent for 30 minutes and kept in centrifuge extraction machine. The centrifuge was started and continued until all solvent was forced through filter ring on outer rim of bowl. Then 200 ml additional trichloroethylene was added for second wash. This process was repeated until the solvent was clear in color. Aggregates were oven dried and weighed to determine the bitumen content in RAP. As shown in Figure 1.

Figure 1 Bitumen Extraction from RAP by Centrifuge Extractor

3.2 Marshall Mix Design of Asphalt Mixes

First approximately 1200 gm of different sizes of aggregates and filler (lime) as per the blended design gradation are taken, and heated at the temperature 170-190oC. The bitumen was then heated at 150°C. A fixed amount of bitumen quantity was then added in aggregates. [17, 18] The aggregate and binder are mixed at mixing temperature ranging from 130°C-160°. Thereafter, the mix is compacted by giving 75 blows on either side at compaction temperature ranging from 170-190°C. A compacted specimen of thickness 63.5 ± 3 mm and diameter 100 mm are prepared. The above procedure is repeated for other bitumen contents. Test Matrix for Sample Preparation for Marshall Mix Design for HMA shown in Table 4.

Table 4 Total No of Moulds for All Test

Percentage of bitumen used	No of moulds for 0% RAP	No of moulds for 40% RAP	No of moulds for 50% RAP
4%	3	3	**3**
4.5%	3	3	**3**
5%	3	3	**3**
5.5%	3	3	**3**
6%	3	3	**3**
Total	15	15	**15**
Moisture damage	6	6	**6**
Rutting Test	**5**	**5**	**5**

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Page No: 1110-1118

3.3 Evaluation of Moisture Damage by Indirect Tensile Strength Test

From the Table 5 moisture damage potential of HMA mixes with different percentages of RAP (0%, 40% and 50%) were evaluated using retained tensile strength (TSR) test. This test is conducted by applying a compressive load at a rate of 50.8 mm/min. Two different types of samples (i) conditioned (ii) unconditioned, were prepared. The conditioned samples were placed in water bath maintained at a temperature of 60°C for 24 hour prior to testing. Similarly, unconditioned sample were kept in water at 60°C for 30-40 min prior to testing. The ratio of failure load of conditioned and unconditioned samples is reported as a TSR value. A high TSR value indicates a good water resistance mix and vice versa. The MORTH recommends a minimum TSR value of 0.80 for a mix to ensure moisture resistant mix. The indirect tensile strength (S) is determined by Eq. (3.1) The TSR is calculated by Eq. (3.2).

$$S=2000P/\Pi Dt \qquad \text{Equation 3.1}$$

Where,

S= Indirect tensile strength, kPa P = Peak load at failure, N, t = thickness of sample, mm D = diameter of sample, mm

$$TSR= (N)/ (P) * 100 \qquad \text{Equation 3.2}$$

Where,

N is the average indirect tensile strength of wet conditioned specimens, N P is the average indirect tensile strength of dry unconditioned specimens, N

Table 5 Test Matrix for Sample Preparation for Moisture Damage test

Mix Type	Test	RAP (%)	No of Specimen	
			Conditioned	Unconditioned
HMA +RAP	Tensile Strength Ratio (TSR)	0	3	3
		40	3	3
		50	3	3

3.4 Evaluation of Rutting Performance by Flow Time Test

Rutting is one of the major distresses in a flexible pavement which can lead to early failure. The rutting is caused due to application of repeated loads which results in densification and lateral plastic flow under the wheel path. The flow time has been recognized as one of the important tests to evaluate rutting performance of asphalt mixes. In this test, a static load of selected magnitude is applied for 10,000 s to a cylindrical sample of 100 mm diameter and 150 mm height. The test is generally conducted a higher temperature to simulate rutting behavior of a pavement. The permanent deformation is measured with time. The plot of permanent deformation versus time has three different zones: primary zone (reflecting initial densification stage), secondary zone (indicate long time densification), and tertiary zone (shear failure) which is shown in Figure 2. A flow time is defined as a time where zone shifts from secondary to tertiary. A flow time is an indication of rutting performance of a mix. A higher flow time value indicates stronger mix and vice versa. The rutting performance of asphalt mixes containing different percentages of RAP (i.e., 0%, 40% and 50%) were evaluated in the laboratory.

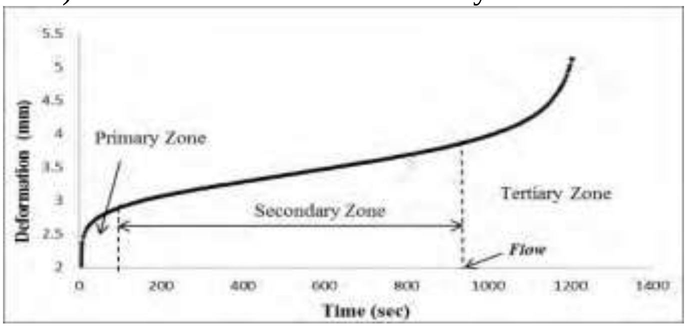

Figure 2 Different Zones of Rutting in Flow Time Test

3.4.1 Sample Preparation for Flow Time Test

The samples of 100 mm diameter and 150 mm in height were prepared in the laboratory using Marshall Sample compactor. Approximately 2700 gm of aggregates and filler were heated at170-190°C.The bitumen was heated at 150°C, and then mixed with aggregates. Thereafter the mix was placed in Marshall Mould and compacted by 150 to

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Volume: 02
Issue: 04 April 2024
Page No: 1110-1118

170 blows on either side by targeting air void in range of 6±0.5% in compacted samples. The height of the rammer was 457.2 mm, weight was 4.5 kg and diameter was 98.2 mm are shown in Table 6& 7.

3.4.2 Fabrication of Instruments

ITS Test Apparatus-Figure 3 shows that ITS Test Apparatus used to determine moisture damage potential.

Figure 3 ITS Test Apparatus

Moulds- Figure 4 shows that mould used for casting specimen. Mould has dimension of 4’’ diameter and 6’’ height to prepare Flow Time specimen.

Figure 4 Fabrication of Mould

4. Results and Discussion

4.1 Gradation of Aggregates

Table 6 Optimum Percentage of Materials used in BC- Grade-1 Mixes for Different Percentage of RAP

Type of Mixes	Percentage of materials for BC-grade-1					
	Coarse (20 mm)	Fine (10 mm)	Stone Dust	Filler (Lime)	RAP	Total
BC-G1-0	33	20	45	2	0	**100**
BC-G1-40	13	12	33	2	40	**100**
BC-G1-50	**7**	**8**	**33**	**2**	**50**	**100**

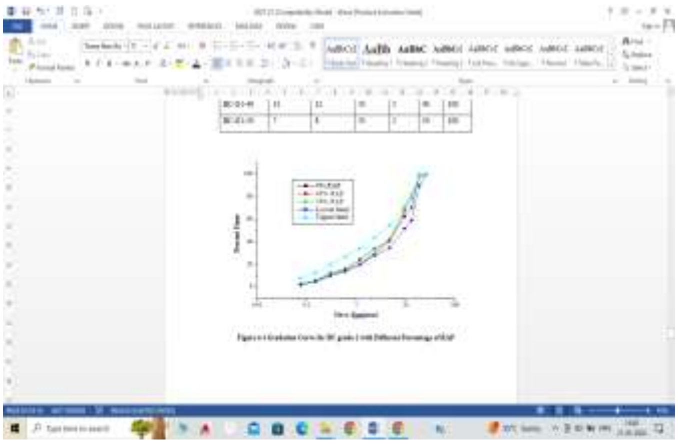

Figure 5 Gradation Curve for BC Grade-1 with Different Percentage of RAP

Table 7 Aggregate Gradation of BC-Grade-1 with Different Percentage of RAP

Sieves Size (mm)	Specified Limits for BC-grade-1 (MoRTH)					
	0% RAP	40% RAP	50% RAP	LL	UL	MV
26.5	100	100	100	100	100	100
19	94.16	98.6	98.05	90	100	95
13.2	77.35	78.91	82.34	59	79	69
9.5	57.23	67.89	70.73	52	72	62
4.75	23	40.97	43.34	35	55	45
2.36	7.49	29.23	30.18	28	44	36
1.18	2.84	20.36	20.84	20	34	27
0.6	0.94	13.46	13.76	15	27	21
0.3	0.49	10.55	10.82	10	20	15
0.15	0	5.29	5.44	5	13	9
0.075	0	2.93	3.02	2	8	5

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e ISSN: 2584-2854
Volume: 02
Issue: 04 April 2024
Page No: 1110-1118

4.2 Asphalt Content in RAP

The asphalt content in collected RAP material was determined using two different methods: chemical extraction using centrifuge device and ignition oven. The asphalt content in RAP determined from chemical extraction using centrifuge device was found to be 4.5%. The reported results are the average of five samples. In this study. The AC content is RAP is relatively high, indicating that the RAP is rich in asphalt content and hence a significant cost saving can be expected. The AC content in RAP helps to determine quantity of neat binder to be added in the mix. Bitumen content in RAP is shown in Table 8.

Table 8 Bitumen Content in RAP

Test Method	Bitumen Content (%) Average of 5 Samples
Centrifuge Extraction	**4.5**

4.3 Mix Design of HMA-RAP Mix

Marshall Stability and flow values are tabulated in Table 9 and design parameters are explained in Figure 5. The optimum binder content (OBC) is calculated as the average of binder content corresponding to maximum stability, maximum unit weight and 4% air voids in accordance with MORTH specification.

Table 9 Marshall Stability and Flow Value for HMA at Optimum Bitumen Content

% of Bitumen	Avg Vv	Flow value (mm)	Marshall stability	VFB %	% VMA
4	5.2	3.8	25	35	**18**
4.5	5.7	4	26	40	**18**
5	5.7	4.5	31	55	**17**
5.5	5.3	4.5	28	50	**12**
6	1.1	9	21	81	**9**
6.5	**2.5**	**10**	**19**	**82**	**8**

4.4 ITS Test Results

The moisture damage potential is determined by conducting indirect tensile strength. The ITS test results for different percentage of RAP (0%, 40% and 50%) are shown in Figure 6 as per MoRTH min TSR should be 80%

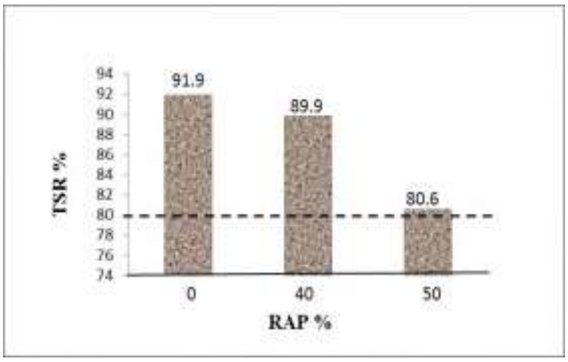

Figure 6 ITS results for Different Percentage RAP

The moisture damage potential of RAP mixes (i.e. 0%, 40% RAP and 50%) was determined in the laboratory by estimating TSR value. The TSR value of virgin mix without RAP was found to be 91.9% which is higher than the minimum required value of 80%, and hence the mix passes moisture resistance test. TSR value of 40% RAP is 89.9% which is higher than minimum requirement of 80% as per MORTH specification. TSR value for 50% RAP is 80.6% which is higher than the minimum requirement of 80% as per MORTH specification.it started decreasing, indicating, higher RAP content may result in a poor mix as far as moisture damage potential is concerned, therefore a careful attention should be given for designing mix with higher percentage of RAP.

4.5 Flow time Results

The rutting performance of different types of RAP mixes is presented in Figures 7. The addition of RAP increases flow time. A high value of flow time indicates a stronger mix, and better rut resistance. Bar chart for different % RAP shown in Figure 8 .

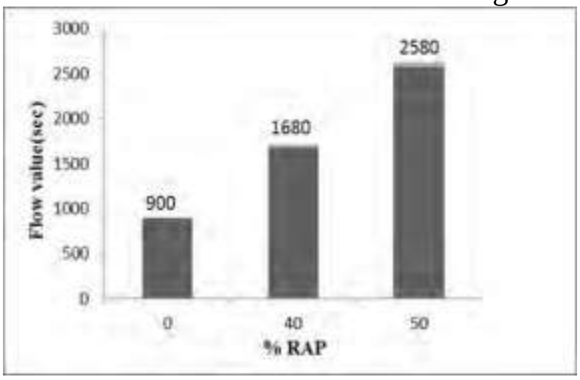

Figure 7 Flow Time for Different Percentages of RAP Mix

The Flow time results obtained for 0% RAP is 900 sec and addition of 40%, and 50% RAP resulted in an increase in flow time from 1680 seconds and 2580 seconds flow time, respectively. The increase in rut resistance of a mix with addition of RAP can be due to the addition of aged and stiffer binders.

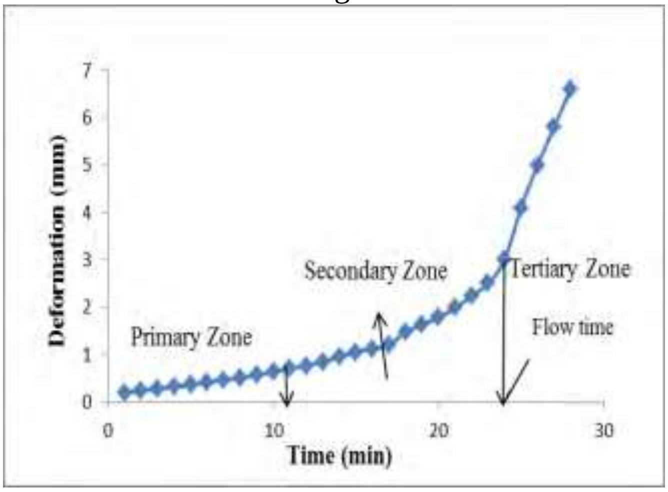

Figure 8 Different Zones of Rutting in Flow Time Test for 0% RAP

5. Summary and Conclusions

5.1 Summary

The construction of highways with RAP materials is not as popular in India as it expected to be, due to lack of laboratory and field performance data. Furthermore, agencies and contractors are not enough trained and confident on quality of RAP materials and to design mixes containing RAP. Generally it is thought that RAP is a poor grade material which may negatively impact quality of pavements and consequently wastage of significant amount of money. Nonetheless, studies conducted over the years in different parts of the world showed that performance of bituminous mixes containing RAP can be equal and better than the performance of virgin bituminous mix. The RAP is beneficial to increase rutting resistance of asphalt mixes, therefore, can results in a long lasting pavement. The present study was undertaken to design and evaluate performance of bituminous mixes containing different percentages of RAP. For this purpose, RAP is collected from road which is a link between Bagalkot and Gaddankeri 19th cross Vidyagiri Bagalkot which is dug for the connection of water supply pipeline. The length of the road is 10 kms. The collected RAP was removed from the top surface of the pavement of thickness of 10-12cm. The preliminary laboratory tests on the collected RAP such as aggregate quality, gradation and bitumen content were conducted to ensure its quality. The bituminous concrete (BC) with different percentages of RAP (i.e., 0%, 40% and 50%) were design as per the standards and specifications provided by Ministry of Road Surface and Transportation (MoRTH). The selected BC in this study generally used in a base course of a flexible pavement in India. The Marshall Mix design method was utilized to design mix with different percentages of RAP. The moisture damage potential of different mixes was determined in the laboratory by estimating retained indirect tensile strength also called tensile strength ratio (TSR). The conditioned and unconditioned samples were compacted in the laboratory and their TSR values were determined. Overall, addition of RAP increases TSR value of a mix, indicating that RAP helps in enhancing moisture damage potential of a mix. The rutting performance determined using flow time test. The samples of 100 mm diameter and 150 mm height were compacted in the laboratory. In flow time test, a static load of 500 kPa is applied for 10,000 seconds and vertical deformation is recorded. The test was carried out at 55ºC. It is expected that this research project would be helpful for highways engineers to utilize RAP for construction sustainable highways in India.

Conclusions

The following conclusions can be drawn from the results and discussion presented in this study. The asphalt content in collected RAP was determined from chemical extraction using centrifuge device, 4.5%, was considered for design of mixes containing different percentages of RAP. The Optimum bitumen content of RAP mixes was found to be 6% by Marshall Mix design. The volumetric properties of mixes at OBC satisfy design requirements. The addition of 40% and 50% RAP may result in saving quantity of binder.

e ISSN: 2584-2854
Volume: 02
Issue: 04 April 2024
Page No: 1110-1118

Moisture Damage Potential: HMA-RAP Mix

- The TSR value of virgin mix without RAP was found to be 91.6% which is higher than the minimum required value of 80%, and hence the mix passes moisture resistance test.
- TSR value of 40% RAP is 89.9% and TSR value for 50% RAP is 80.6% which is higher than the minimum requirement of 80% as per MORTH specification. It is seen from the results that moisture damage potential started decreasing with indicating, higher RAP content which may result in a poor mix, therefore a careful attention should be given for designing mix with higher percentage of RAP.

Rutting Resistance of HMA-RAP Mix

- The Flow time results obtained for 0% RAP is 900 sec and addition of 40%, and 50% RAP are 1680 seconds and 2580 seconds respectively. From this it can be concluded that an increase in RAP will increases the rutting performance of the mixes, Increase in rut resistance of a mix with addition of RAP may be due to the addition of aged and stiffer binders.

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