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EXPERIMENTAL ANALYSIS OF RECLAIMED ASPHALT PAVEMENT ON FRESH BITUMINOUS MIXES

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Abstract: Increase in the number of high volume roads constructed to bitumen standards in the past years in india has led to a strain in the supply of scarce natural resource aggregates. Some of the existing roads have undergone reconstruction which involved removal of top asphalt concrete surfacing layer to accommodate new layers underneath. The disposal of the old asphalt concrete surfacing layer in the open spaces has led to environmental degradation. Lack of sufficient funds has led to low volume roads being left in a deplorable state. The main objective of the study was to evaluate the suitability of a mix of reclaimed asphalt concrete, virgin aggregates and a cationic emulsion as a surfacing material for the construction of low volume roads. The use of reclaimed asphalt pavement in the pavement industry in India evaluating the effects of partial and total replacements of bituminous concrete by RAP varying from 10 to 40% and virgin HMA mix on the mechanical properties of HMA mixtures. The virgin bitumen used in this study was of VG-30 grade and virgin aggregates from local quarry. The experimental process involves determination of characteristics of the materials procured. Marshall Stability, flow tests, Indirect tensile strength and Fatigue Life cycle Index were carried out on the samples prepared with both virgin and recycled mix. All the characteristics were found to be within specified specifications as per MoRT&H and IS standards.
Keywords: RAP, Bituminous concrete, Marshall Stability, Flow value, Density, Indirect tensile strength, Fatigue Life cycle Index etc.

I. INTRODUCTION

Construction of highway involves huge outlay of investment. A precise engineering design may save considerable investment as well a reliable performance of the in-service highway can be achieved. Two things are of major considerations in flexible pavement engineering–pavement design and the mix design. The heating of bituminous binder, aggregates and production of huge quantities of Hot Mix Asphalt (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.

BENEFITS OF ASPHALT RECYCLING

The following points suggest the generalized benefits:

- Reuse and Conservation of non-renewable energy sources
- Preservation of the environment and reduction in land filling
- Energy conservation and improved pavement smoothness
- Cost saving over traditional rehabilitation methods

Improved pavement physical properties by modification of existing aggregate gradation, and asphalt binder properties.

PRODUCTION OF RAP MATERIALS

Removal and reuse of asphalt layer of existing pavement is termed as RAP. However full depth reclamation (FDR) is defined as removal and reuse of hot mix asphalt layer and entire base course. RAP can be reused immediately at sites , however it may be stockpiled as the case may be. The required gradation of RAP are achieved by pulverizing the material in a crusher.

Fig 1: Demolished Asphalt Pavement

A condition of demolished flexible pavement is shown in Fig1.1 which can be reused after proper processing and crushed to required size and grading as per requirements of site condition.

II. PROPERTIES OF RAP

RAP has a higher content of fines as a result of degradation of material during milling and crushing operations. Typical physical properties of RAP are tabled below

S. No.	Parameters	Values
1	Unit Weight (Kg/m³)	1900- 2250
2	Moisture Content	Max 3- 5%
3	Asphalt Content	5- 6%

4	Asphalt Penetration(%) at 25°C	10-80
5	Compacted Unit Weight (Kg/m³)	1500- 1950
6	California Bearing Ratio (CBR)	100% RAP : 20-25%

Table 1: Typical Properties of RAP

Sources of RAP: The various possible sources of RAP are as follows-

- Generation from milling of HMA layer
- Full depth pavement removal
- Waste from HMA generated at plant

Milling is the process of scraping and removing any distressed upper layers of existing pavement to a specified depth. The process includes grinding by machine and loading of RAP into a truck for transportation.

III. MATERIALS & METHODS

AGGREGATES

For preparation of Bituminous mixes (BC) aggregates as per MORTH grading as given in Table 2 and a particular type of binder in required quantities were required as per Marshall Procedure.

Sieve size (mm)	Percentage passing
26.5	100
19	95
9.5	70
4.75	50
2.36	35
0.30	12
0.075	5

Table 2: Adopted aggregate Gradation for BC (MORTH)

Coarse Aggregates

Coarse aggregates consisted of stone chips collected from a local source, up to 4.75 mm IS sieve size. Its specific gravity was found as 2.75. Standard tests were conducted to determine their physical properties as summarized in Table 3

Fine Aggregates

Fine aggregates, consisting of stone crusher dusts were collected from a local crusher with fractions passing 4.75 mm and retained on 0.075 mm IS sieve. Its specific gravity was found as 2.6.

Property	Test method	Value	Requirements as per MoRTH , 2013 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	35 max
Stripping, %	IS 6241	98	Min retained coating 95
Water Sensitivity	AASTHO 283	92	Retained Tensile Strength 80%

*Note: El: Elongation Index, FI: Flakiness Index

Table 3: Properties of mineral aggregates

BINDER

Here VG 30 penetration grade bitumen is used as binder for preparation of Mix, whose specific gravity was 1.01. It's important property is given in table 4

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

Table 4: Properties of bitumen (VG-30)

IV. DETERMINATION OF BINDER CONTENT

The approximate bitumen content of the combined aggregates of the target wearing coarse mixtures containing RAP were calculated from the following empirical formula:

Pb= 0.035a+0.045b+Kc+F

Where, a= % of mineral aggregate retained on 2.36mm sieve, b=% of mineral aggregate passing on 2.36mm sieve& retained on 75 µ sieve, c=% of mineral aggregate passing on 75µ sieve, K=0.15 for 11-15%passing 75µ sieve ,0.18 for 6-10 %passing 75µ sieve, 0.2 for 5% or less passing 75µ sieve, F=0-2% based on absorption of light or heavy aggregate, 0.7 for other aggregate.

RAP BITUMEN EXTRACTION:

The bitumen extraction is carried out for the target wearing coarse mixtures containing RAP by the extraction formula:

% Extraction = ((W1-W2)\W) x 100

Where

Wt of the sample (W) gm ,

Wt of the sample+ bowl (before extraction) (W1) gm,

Wt of the sample+ bowl (after extraction) (W2)

PROPORTION OF BITUMEN PRESENT IN RAP

Percentage of bitumen was determined using centrifugation method. The removal of RAP was done using excavator. The material is 3 year old. RAP being mix of base and old surface layer, the binder content found in RAP was 4.8% and the original percentage at the time of construction was 5.5%.

For this study, aggregates of 20mm, 10mm, 6.7mm and Stone Dust were used. Along with RAP material was collected from the nearby vicinity where the old road is being reconstructed. RAP here comprise of mix of old surface course and bituminous base course. The aggregates needed to be separated slightly.

Fig 2: Determination of Bitumen % of RAP on Centrifuge Extractor

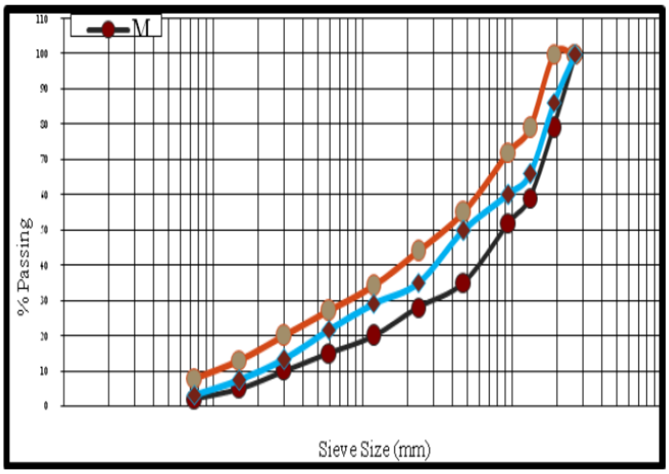
JOB MIX FORMULA FOR AGGREGATE GRADATION

The design mix was performed using job mix formula according to table 500-17 as given in MORTH (fifth revision), 2012. Following is the grading table of gradation of various aggregates and filler used for bituminous concrete of sizes 20 mm, 10 mm, 6.7 mm and stone dust.

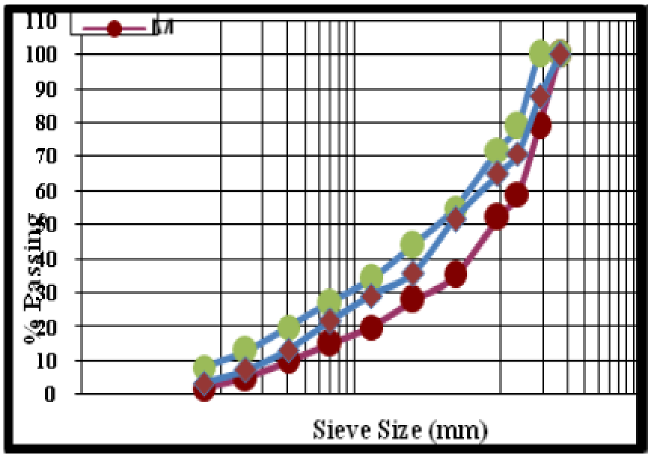
JOB MIX FORMULA FOR BC VIRGIN MIX

Sieve size	% passing (required)	% passing IS 19mm	% passing 13.2mm	% passing 6.7mm	% passing stone dust	Cement	Grading of mix
19mm	100	98.6	100	100	100	100	99.86
13.2mm	79-100	10.2	100	100	100	100	91.02
9.5mm	70-88	1	87	99.4	100	100	86.87
4.75mm	53-71	0	1	42.4	99.3	100	55.55
2.36mm	42-58	0	0	6.4	90.3	100	44.78
1.18mm	34-48	0	0	2.2	68.9	100	34.40
600µ	26-38	0	0	2.2	51.3	100	26.48
300µ	18-28	0	0	2.2	37.1	100	20.09
150µ	12-20	0	0	1.7	19.6	100	12.12
75 µ	4-10	0	0	1.7	10.5	100	8.03
Ratio		0.1	0.24	0.18	0.45	0.03	

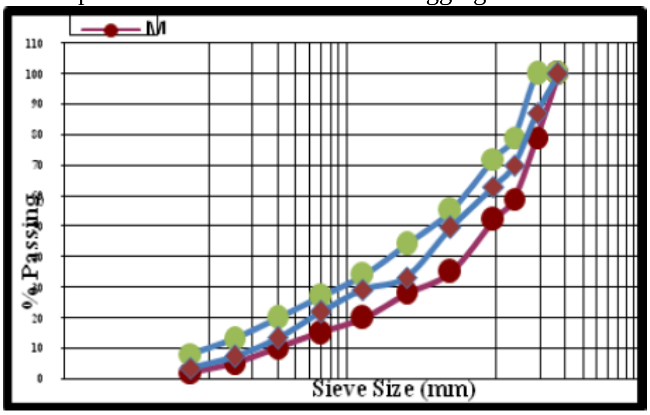
Table 5: Gradation table for virgin mix



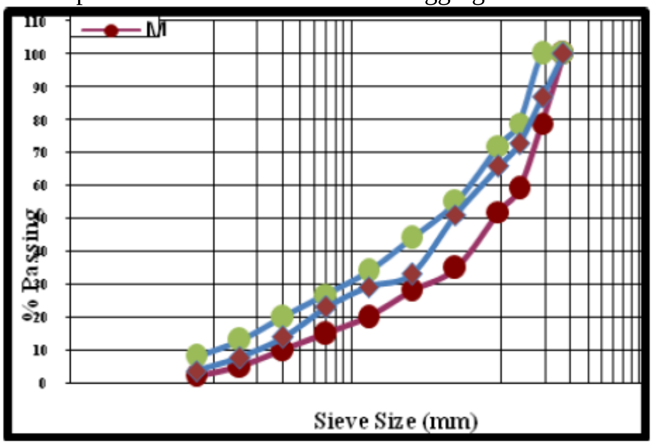
Graph 1: Gradation curve for Virgin aggregates



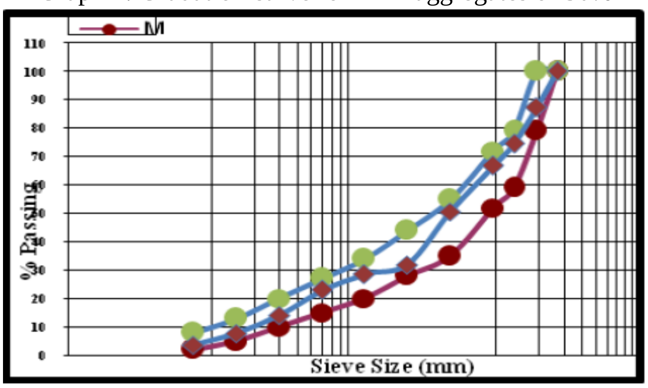
Graph 2: Gradation curve for RAP aggregates of 10%



Graph 3: Gradation curve for RAP aggregates of 20%



Graph 4: Gradation curve for RAP aggregates of 30%



Graph 5: Gradation curve for RAP aggregates of 40%

PREPARATION OF MIXES

The mixes were prepared according to the Marshall procedure specified in ASTM D1559. For BC the coarse aggregates, fine aggregates and filler were mixed according to the adopted gradation as given in Table 2. First a comparative study is done on BC by taking four percentage of RAP material i.e. 10%, 20%, 30% and 40%. Here Optimum Binder Content (OBC) was found by Marshall Test where binder content is very from 0% to 6%. The mineral aggregates with binders were heated separately to the prescribed mixing temperature. The temperature of the mineral aggregates was maintained at a temperature 10°C higher than the temperature of the binder. Required quantity of binder was added to the pre heated aggregate mixture and thorough mixing was done manually till the color and consistency of the mixture appeared to be uniform. The mixing time was maintained within 2-5 minutes. The mixture was then poured in to pre-heated Marshall Moulds and the samples were prepared using a compactive effort of 75 blows on each side. The specimens were kept overnight for cooling to room temperature. Then the samples were extracted and tested at 60°C according to the standard testing procedure.

V. TESTS ON MIXES

Marshall Mix design is a standard laboratory method, which is adopted worldwide for determining and reporting the strength and flow characteristics of bituminous paving mixes. In India, it is a very popular method of characterization of bituminous mixes.

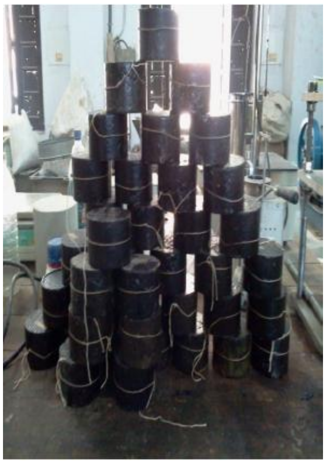



Fig 3: Marshall Sample

Fig 4: Marshall Test In Progress

Marshall Graphs were plotted for air voids, VMA, VFB, Stability flow and density and Optimum binder content was determined for all the four cases of particle index. As per the guidelines of MS-2 Bitumen content corresponding to median of air voids percentage (4.5%) is read from the graph and all other parameters are checked for that binder content so as to confirm that whether all other parameters such as VMA, VFB, Stability and flow falls within the MORT&H specified limits. From the Experimental investigations for four different % of RAP materials i.e. 10%, 20%, 30% and 40% was obtained at Bitumen % of 5.4, 5.6, 5.8 and 6.0 and then we find out the air voids, stability, VMA, VFB. A total of 9 Marshall Specimens, 3 specimens each were prepared at OBC for RAP materials 10%, 20%, 30% and 40% and tested for bulk density, stability, flow, air voids, VFB and VMA.

Properties	VG-30				
	5.2	5.4	5.6	5.8	6.0
Bulk density (gm/cc)	2.361	2.370	2.367	2.364	2.362
Stability (kg)	1271	1381	1402	1461	1416
Flow (mm)	2.4	3.7	3.9	4.4	5.1
Air Voids (%)	5.68	4.58	4.12	3.3	2.44
VMA (%)	16.41	16.54	17.24	17.62	17.97
VFB (%)	65.38	72.31	76.11	81.26	86.4

Table 6: Physical properties of BC mix for Virgin material

JOB MIXES FORMULA FOR BC USING RAP- 10 %, 20%, 30% & 40%

IS Sieve size	% passing (required)	Grading of mix with RAP 10 %	Grading of mix with RAP 20%	Grading of mix with RAP 30%	Grading of mix with RAP 40%
19mm	100	97.96	97.58	97.21	96.84
13.2mm	79-100	83.25	81.88	80.51	80.03
9.5mm	70-88	77.00	74.94	72.85	72.08
4.75mm	53-71	56.96	56.07	55.18	56.12
2.36mm	42-58	55.25	46.34	46.07	46.84
1.18mm	34-48	36.07	35.97	35.86	36.48
600µ	26-38	27.96	27.91	27.87	28.39
300µ	18-28	21.40	21.41	21.42	21.84
150µ	12-20	13.05	13.1	13.14	3.41
75 µ	4-10	8.34	8.55	8.57	8.72
Ratio		6%,8%,15%, 43%, 25% and 3%	5%,7%,13%,42 %, 30% and 3%	4%, 6 %, 11%, 41%, 35% and 3%	2%, 3%, 11%, 41%, 40% and 3%

*NOTE: % of 20mm, 10mm, 6.7mm, stone dust, cement and RAP respectively.

Table 7: Table for grading of BC using RAP 10%, 20%, 30% & 40%

MARSHALL STABILITY TEST FOR BC CONTAINING RAP

The experimental results (average) of different parameters of Marshall Stability Test for BC containing RAP 10%, 20%, 30% and 40% at optimum binder content (OBC) 6 are given in table 8

RAP percentage	Fresh Mix (Virgin)	RAP 10%	RAP 20%	RAP 30%	RAP 40%
Density (g/cc)	2.369	2.357	2.361	2.364	2.358
Volume of Bitumen, Vb%	13.74	13.671	13.565	13.254	13.145
Volume of aggregates VA%	81.86	82.61	84.099	85.65	86.78
Voids in mineral Aggregate (VMA)%	16.27	17.11	18.45	17.22	17.442
Voids filled with bitumen(VFB) %	84.47	79.90	82.953	80.048	78.413
Measured stability,(kN)	1461	1189	1376	1376	1308
Flow value (mm)	2.9	3.8	4.43	3	3.5
Marshall quotient (Stability/Flow)	5.03	3.12	3.694	4.77	3.73
S.G of mix, S_T	2.726	2.687	2.681	2.675	2.667

Table 8: Average results of Marshall Stability test at optimum binder content for bituminous mix containing different percentages of RAP

Fig 5: Marshall Stability testing of bituminous concrete specimen

INDIRECT TENSILE STRENGTH TEST

Indirect tensile test is used to determine the indirect tensile strength (ITS) of bituminous mixes. In this test, a compressive load is applied on a cylindrical specimen (Marshall Sample) along a vertical diametrical plane through two curved strips the radius of curvature of which is same as that of the specimen. A uniform tensile stress is developed perpendicular to the direction of applied load and along the same vertical plane causing the specimen to fail by splitting.

FATIGUE LIFE CYCLE FOR DIFFERENT PARTICLE INDEX:

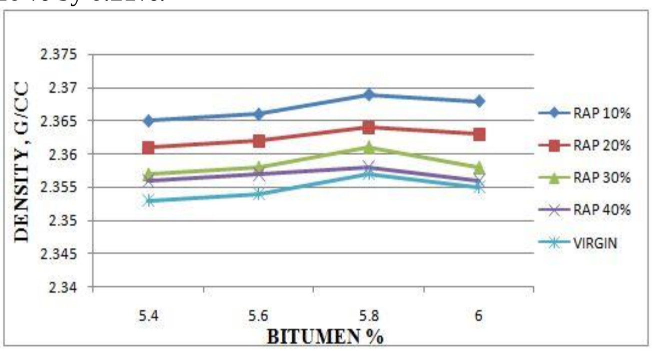
The flexural fatigue test is used to characterize the fatigue life of HMA at intermediate pavement operating temperatures. This characterization is useful because it provides estimates of HMA pavement layer fatigue life under repeated traffic loading.

VI. RESULTS

RESULTS OF MARSHALL STABILITY TEST

DENSITY Vs BITUMEN %

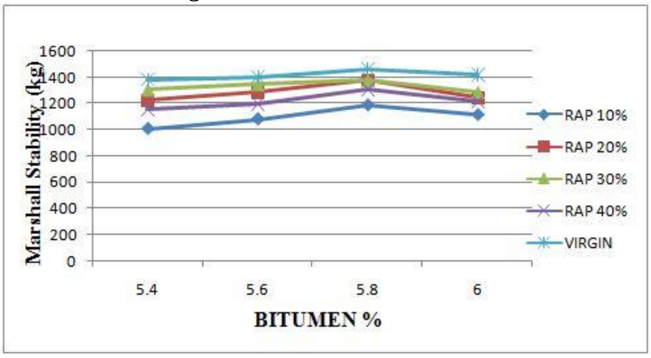
After the laboratory investigation it is observed that fresh bituminous mix has the maximum density of all RAP percentages at all bitumen percentages. It is also seen that the Optimum Binder Content was not changed in any of RAP mixes and remains the same as fresh bituminous mix i.e at 5.8%. This indicates that the binder in RAP materials perfectly blended with fresh binder. At 5.8% binder content density of fresh bituminous mix is found to be 2.365 as compared to 2.364 which is maximum value determined corresponding to content 20% this difference is negligible. The overall variation of maximum Density is between 2.357 to 2.364 which are again slightly more than density of RAP 20 % by 0.21%.



Graph 6: Density v/s Bitumen percentage

MARSHALL STABILITY Vs BITUMEN %

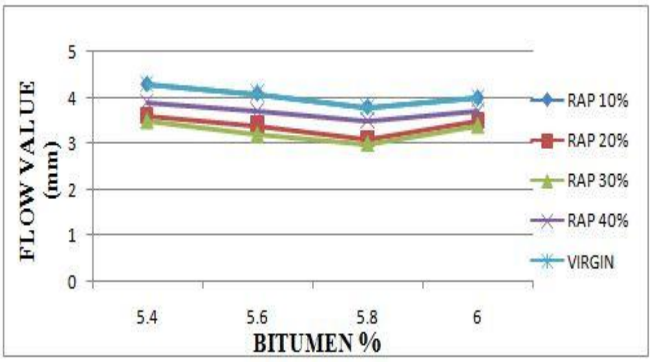
From the test results performed it is observed that the Marshall Stability values for virgin bituminous mix are more than any of RAP mixes. RAP 30% has values nearly equal to that of fresh bituminous mix and has best density values amongst other RAP mixes. At 5.8% binder content the Marshall Stability value of fresh bituminous mix was found to be 1461 kg as compared to 1431 kg which was the maximum value determined correspondingly to RAP content 20%. This difference is negligible. The overall variation of maximum stability was between 1189 kg to 1431 kg, which again is not a huge difference. Also all the stability values of RAP mixes and fresh bituminous mix were above the minimum required range (minimum 9kN) which is specified in table 500-11 in “SPECIFICATIONS FOR ROAD AND BRIDGE WORKS”, MORTH (fifth revision), published by Indian Roads Congress



Graph 7: Marshall Stability v/s Bitumen percentage

FLOW VALUE

It is observed that RAP 10 % had the maximum flow values followed by RAP 40%, RAP 20%, RAP 30 % and fresh bituminous mix. Fresh bituminous mix had minimum values out of all mixes. At 5.8% binder content the flow value of fresh bituminous was found to be 2.9 mm as compared to 3 mm which was the minimum value determined correspondingly to RAP content 20%. This difference is very less. Also all the flow values of fresh bituminous mix and RAP mixes except for RAP 40 were within the required range (2mm - 4mm) as specified in table 500-11 in “SPECIFICATIONS FOR ROAD AND BRIDGE WORKS”, MORTH (fifth revision), published by Indian Roads Congress.



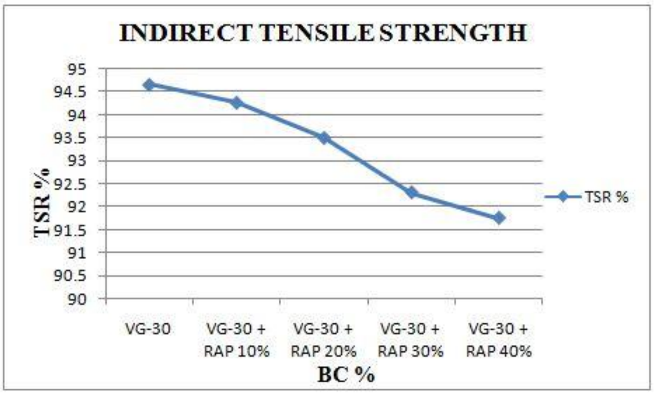
Graph 8: Flow Value v/s Bitumen percentage

INDIRECT TENSILE STRENGTH TEST

Test was conducted for Virgin and varying % of RAP with OBC of 5.8% which was found after Marshall Stability testing. The ASTM T283 code specifies 80 percent should be the minimum value of Indirect Tensile Strength ratio. The Results were tabulated in table 9.

Type of mix	Average Indirect tensile strength, Mpa		TSR%
	Unconditioned	Conditioned	
VG-30	0.656	0.621	94.66
VG-30 + RAP 10%	0.681	0.642	94.27
VG-30 + RAP 20%	0.693	0.648	93.50
VG-30 + RAP 30%	0.716	0.661	92.31
VG-30 + RAP 40%	0.728	0.668	91.75

Table 9: Indirect tensile strength test results



Graph 9: Indirect tensile strength test

FATIGUE LIFE CYCLE TEST

Test was conducted for different stress ratios 0.6, 0.7 and 0.8 for Virgin and different % of RAP. The concepts of fatigue life cycle tests are presented in previous chapter. The results of this test are tabulated in table 10.

S. No	Materials	Stress level in %	No of cycle
1	Virgin materials	60	1406
		70	985
		80	719
2	10% RAP	60	1317
		70	893
		80	661
3	20% RAP	60	1305
		70	875
		80	645
4	30% RAP	60	1301
		70	870
		80	639
5	40% RAP	60	978
		70	701
		80	478

Table 10: Fatigue cycle results for Virgin and different % of RAP

COST COMPARISON

Following analysis shows a cost comparison between a fresh bituminous mix and mix prepared with RAP 30% for BC

- Cost of laying fresh Bituminous Concrete (BC) = Rs 10,500 /m³
- Reduction in cost by aggregates by using 35 % RAP = Rs 200 /m³
- Reduction in cost by bitumen since RAP contained 4.8 % bitumen = Rs 5106 /m³
- Total reduction in cost = Rs 5106 /m³ + Rs 200 /m³ = Rs 5306 /m³
- Cost of laying BC using 30 % RAP = Rs 10,500 /m³ - Rs 5306 /m³ = Rs 5194 /m³

From the above analysis it can be understood that using RAP makes the project more economical.

VII. CONCLUSIONS

BC WITH DIFFERENT % OF RAP

As per MORTH Specification mix design requirements of bituminous mix is given in table 9

PROPERTY	VALUE
Marshall stability (KN at 60°C)	>9KN
Flow Value (mm)	2-4
Air Void (%)	3-6
VFB (%)	65-75
OBC (%)	5-6

Table 11: MORTH Specification mix design requirements of bituminous mix

- The bituminous concrete made of from RAP 30 % satisfies above requirements we can use them for fresh construction. The results is conforming to the requirement of “Specifications for road and bridge works”, MORTH (fifth revision), published by Indian Roads Congress.

- Densities of virgin mix at 5.4%,2.388 gm/cc, at Bitumen content 5.6%,2.421gm/cc, at Bitumen content 5.8%,2.443 gm/cc, at Bitumen content 6.0%,2.432gm/cc and Bitumen content 6.2%,2.424 gm/cc similarly density with RAP 10%, 2.359 gm/cc, RAP 20%, 2.402 gm/cc, RAP 30%, 2.434gm/cc and RAP 40%, 2.416 gm/cc. The density of RAP 30%,2.434 gm/cc is very closer to density at OBC 5.8% ,2.443 gm/cc of virgin mix.
- The Marshall Stability values of virgin mixes were found at different binder content is Bitumen percent 5.4%, 902.12 Kg, Bitumen percent 5.6%, 1071.74, Bitumen percent5.8%, 1232.70kg, Bitumen percent6.0%1008.38kg, Bitumen percent 6.2%, 905.33Kg. Simelarly with different percentage with RAP, RAP10%,882.12kg, RAP20%,1043.35kg, RAP30%,1148.85kg and RAP40%,979.03Kg. The stability at 5.8% OBC is 1232.70kg and with RAP30% is 1148.85Kg, the difference is very closer with others and the results is acceptable. The minimum required stability is 900 kg as table 500-11 as specified in "SPECIFICATIONS FOR ROAD AND BRIDGE WORKS", MORTH (fifth revision), published by Indian Roads Congress.
- The matured bitumen has shown the available paving material at different percentages of the virgin binder. There has been consistent increase in the physical properties (Penetration, Ductility, softening point etc) of the old bitumen when invigorated with Virgin VG-30.
- The proportioning of the aggregates with reclaimed aggregates at all specified percentages of 10, 20, 30 and 40 have given correct blending of the aggregates meeting the specification requirements.
- It is observed that by using 30% RAP the project cost was reduced by 46.44%.
- Time period for mixing was similar in all the cases.
- In this present project work, based on the laboratory studies it can be concluded that more than 30% RAP can be suitable to adopt in making the new roads with the RAP. These percentages of the RAP will differently provide an insight to a researcher or field persons to adopt effectively with proper technical alignments for Milling, Mixing, Transporting, Laying and Compacting.

Overall from this study it was concluded that RAP 30 % showed results similar to that of virgin bituminous mix at their OBC and its performance was best amongst other RAP percentages. Also with the use of RAP 30 % the cost of project was reduced by 46.44 % and the result is qualifying the all requirements of "SPECIFICATIONS FOR ROAD AND BRIDGE WORKS", MORTH (fifth revision), published by Indian Roads Congress.

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