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Laboratory Investigation on utilization of maximum percentage of Reclaimed Asphalt pavement material in Bituminous concrete mix (BC Grading-1) with VG-30 Grade bitumen.

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ABSTRACT
RAP is old bituminous pavement that is milled up or ripped off the roadway . This material can be reused in new bituminous mixtures because the components of the mix (the bitumen binder and aggregate) still have value. The main objective of this study aims to determine the maximum amount of reclaimed asphalt pavement material percent that can be used in BC mix with Virgin VG-30 Grade bitumen. The present laboratory investigation carried out on Bituminous Concrete (BC) mixes prepared with control mix with virgin material, and Mixes with variable % of RAP from 10 % to 80% with VG-30 Grade bitumen. The experimental process involves determination of characteristics of the materials procured. All the characteristics were found to be within specified specifications as per MoRT&H and IS standards. Firstly, the quantity of RAP and virgin aggregates are to be blended in such a way that the resultant gradation of aggregates conforms to the BC Grading-1 as per MoRT&H. The optimum Bitumen content is the percentage of bitumen corresponding to 4% of Air Voids was determined from Marshal graphs. Volumetric analysis, Marshall Stability, flow and water sensitivity tests were carried out on the specimens prepared at OBC in all mixes. Inclusion of maximum upto30% of RAP in BC with VG-30 Grade bitumen was found to be suitable for construction and rehabilitation of flexible pavement, without compromising specifications and standards as specified.
Keywords: Reclaimed Asphalt pavement, Bituminous concrete,VG-30 Grade bitumen, Marshall stability, Water sensitivity.

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I. INTRODUCTION

Recycling of bitumen pavements is a Nobel approach in terms of technical, economical, preservation of natural resources and environmental issues. These materials are generated when bituminous pavements are rehabilitated , resurfacing, removed for reconstruction, or to obtain access to buried utilities .Incorporating RAP in fresh materials has been favoured in the light of the increasing cost of bitumen, scarcity of quality aggregate, scarcity of bitumen and pressuring need to preserve the environment. RAP can be used in new hot mix bitumen concrete by several recycling techniques, such as hot mix recycling, hot in-place recycling, cold mix recycling, cold in-place recycling, and full depth reclamation. The most common method involves a process in which RAP is combined with virgin aggregate and virgin bitumen in a central mixing plant to produce new hot mix paving mixture. In the present investigation an attempt has been made to combine 10%, 20%, 30%,40% ,50%,60%,70%, and 80 % of RAP material with virgin aggregate and virgin bitumen VG-30 grade. In this investigation RAP to new aggregate ratio has been adopted as 0:100,10:90, 20:80, 30:70, 40:60, 50:50 ,60:40, 70:30, 80: 20. The major advantages of use of RAP are (a) Lower cost (b) Reduction in use of natural resources (c) Reduction of damage to other roads for transportation of materials from quarry site, (e) Less dependence on diesel due to energy crisis (f) Preservation of the Environment

1.1 Objectives of the Present Project

1. Marshall Mix design with Virgin aggregates and VG-30 Bitumen (Control mix).
2. Marshall Mix design with Virgin materials added with various proportions of the RAP from 10% to 80% with VG-30 Grade bitumen

3. Evaluation of the properties of the bituminous mix with various proportions of the RAP.
4 Maximum amount of RAP that can be used in BC-1 with VG30 bitumen was investigated
5. Cost analysis.

1.2 Scope

1. Characterization of the Virgin bitumen and aggregates.
2. Characterization of the Reclaimed bitumen and aggregate.
3. Marshall Method of mix design for virgin aggregates and determination of optimum binder content and marshall properties for control mix.
4. Laboratory investigation on Marshall Properties using the reclaimed asphalt pavement materials at variable percentages from RAP 10% to RAP 80%
5. Performance Evaluation by Moisture susceptibility

II. LABORATORY INVESTIGATION

The first step is collecting the study materials. These materials are the virgin aggregate and the RAP as well as bitumen binder

2.1 Aggregates: Aggregate samples of sizes 20mm ,16 mm, 10 mm and stone dust are collected from the Crusher site near Mederametla, Prakasam district ,AP State, India, and sampled aggregates are characterized for the following properties as per MORTH specification.

2.2 Bitumen: Source of the Bitumen used for the project work is CPCL Chennai ,Grade selected is VG-30.The bitumen is tested in the laboratory as per the procedure laid in the relevant IS codes.

2.3 Reclaimed asphalt pavement (RAP): is a reusable mixture of aggregate and bitumen binder, source of the RAP material is collected from NH-16 near Ongole.

Table-1 Physical Properties of Aggregates

Property	Test	Code of Practice	Specification Requirement as per MORT&H	Result Obtained for Virgin Aggregates	Result Obtained for RAP Aggregates
Particle Shape	Flakiness and Elongation Index (FI & EI)	IS: 2386 (P-1)	Max 35%	26%	29%
Strength	Aggregate Impact Value (AIV)	IS: 2386 (P-4)	Max 24%	16%	17.0%
	Los Angeles Abrasion Value (LAA)		Max 30%	18%	19.5%
Water Absorption	Coarse aggregates	IS: 2386 (P-3)	Max 2%	0.40%	0.49%
	Fine aggregates		Max 2%	0.97%	1.04%
Specific Gravity	Specific Gravity for Coarse aggregate	IS: 2326 (P-3)		3.068	2.921
	Specific Gravity for fine aggregate			3.006	2.903

Table-2 Physical Properties of Bitumen

Test	Code of Practice	Specification requirement as per IS-73 for VG-30 Grade bitumen	Result Obtained for Virgin VG-30 Grade bitumen	Result obtained for Residual bitumen from RAP
Softening Point	IS: 1205	Min. 47^0C	50	82
Ductility at 27^0C (cm)	IS: 1208	Min. 40 cm	> 75 cm	27 cm
Penetration at 25^0C, 100g, 5s, 0.1 mm	IS: 1203	Min 45mm	60 mm	21 mm
Specific Gravity	IS: 1202	Min. 0.99	1.04	1.05
Residual Bitumen in RAP	ASTM: D2172			4%

2.4 Individual Aggregate Gradations

Individual aggregate gradations trials were conducted for all sizes of aggregates and RAP Material and the results are summarized in the following Table 3

Table-3 Individual Gradation of Materials

IS Sieve mm	Individual % Passing of Aggregate					Specification Limits for BC Grading-1	
	RAP	20 mm	16 mm	10 mm	Stone dust	Lower Limit	Upper Limit
26.50	100.00	100.00	100.00	100.00	100.00	100.00	100.00
19.00	97.14	60.73	99.11	100.00	100.00	90.00	100.00
13.20	84.99	0.93	46.57	100.00	100.00	59.00	79.00
9.50	75.24	0.40	6.90	93.60	100.00	52.00	72.00
4.75	50.25	-	1.30	6.04	95.82	35.00	55.00
2.36	36.89	-	0.94	0.59	75.48	28.00	44.00
1.18	28.14	-	-	-	60.13	20.00	34.00
0.60	20.74	-	-	-	44.95	15.00	27.00
0.30	14.77	-	-	-	31.26	10.00	20.00
0.15	9.00	-	-	-	17.26	5.00	13.00
0.075	3.80	-	-	-	6.77	2.00	8.00

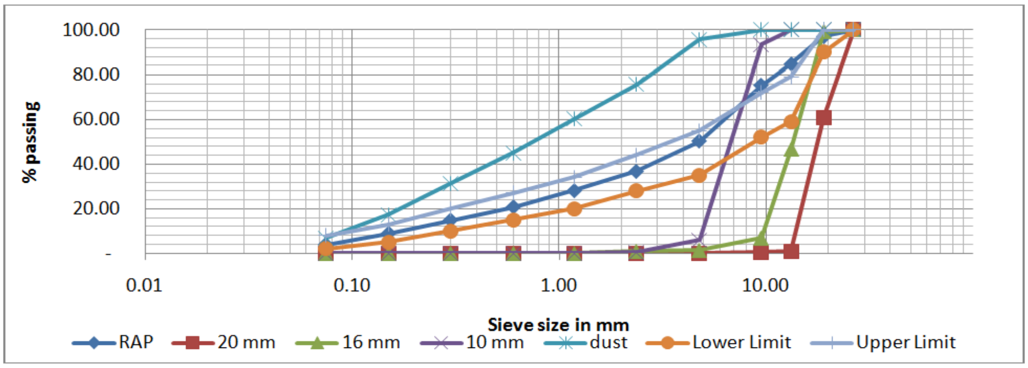


Fig-1 *Gradation curve for the Individual Material*

2.5 Combined Gradations

The Combined Gradation of virgin Aggregates and different percentage for RAP such as 10%,20%, 30%, 40%,50%,60%,70% and 80% are meeting the desired Gradation of BC Grading-1 mix as per MORT&H Table 500-17 Grading-1and the typical Grading-curve for BC mix gradation for different RAP mix is shown in Figure 2.

Table -4: Combined Gradation for RAP Material and Fresh Aggregate in BC Mix

IS Sieve size in mm	Virgin Aggregates	10% RAP	20% RAP	30% RAP	40% RAP	50% RAP	60% RAP	70% RAP	80% RAP	Specification Limits
26.50	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100
19.00	92.75	92.86	92.60	92.71	92.45	92.20	91.94	91.69	92.21	90-100
13.20	71.48	70.97	71.07	70.56	70.67	71.30	71.40	72.04	74.12	59-79
9.50	62.24	61.01	61.46	60.23	60.68	61.99	62.50	63.75	66.06	52-72
4.75	42.61	42.60	42.68	42.67	42.74	42.86	43.84	43.06	43.25	35-55
2.36	32.76	32.65	32.52	32.42	32.29	32.16	32.79	31.91	31.80	28-44
1.18	25.86	25.66	25.47	25.28	25.09	24.89	25.30	24.51	24.32	20-34
0.60	19.33	19.16	18.98	18.81	18.63	18.46	18.74	18.11	17.94	15-27
0.30	13.44	13.36	13.27	13.19	13.10	13.01	13.24	12.84	12.76	10-20
0.15	7.42	7.46	7.50	7.53	7.57	7.61	7.82	7.68	7.72	5-13
0.075	2.91	2.95	2.99	3.04	3.08	3.12	3.23	3.20	3.24	2-8
Proportion***	0%, 18%, 20%, 19%,	10%, 7%, 20%, 15%,	20%, 17%, 17%, 13%,	30%, 16%, 17%, 9%,	40%, 16%, 14%, 7%,	50%, 16%, 10%, 6%,	60%, 16%, 7%, 3%,	70%, 16%, 3%, 3%,	80%, 14%, 0%, 3%,	

	43%	38%	33%	28%	23%	18%	14%	8%	3%	

Note: *** Percentages of RAP, 20mm. 16mm, 10mm and stone dust respectively

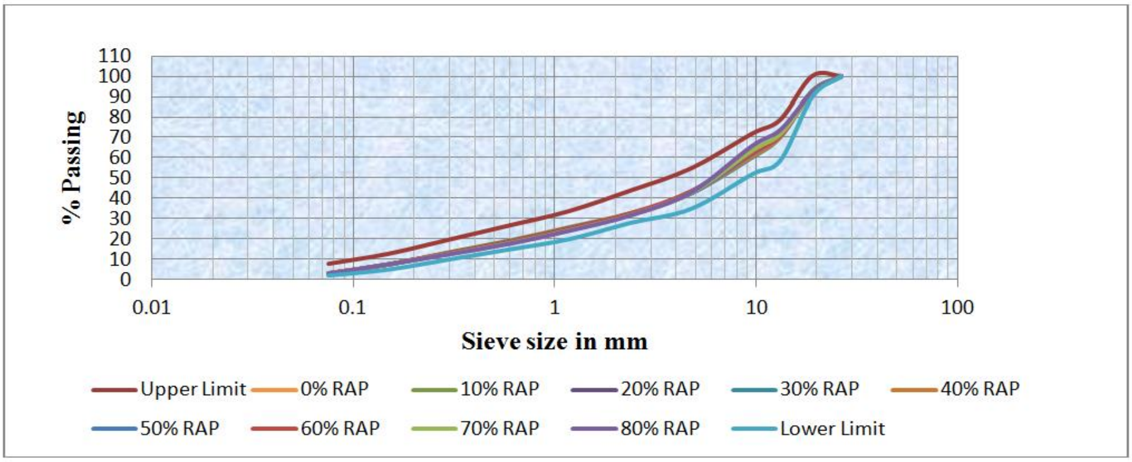


Fig –2: Gradation Curve for Combined Gradation of RAP Material and virgin Aggregates for BC Mix Grading-1

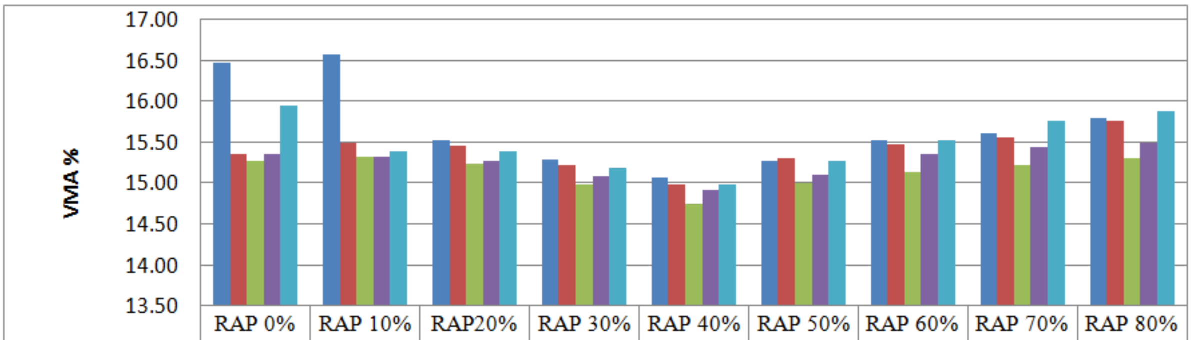
2.6 Marshall Method of Mix Design

Mixture Designs will be performed using the Marshall method by casting marshall specimens for each type of mix by varying the RAP proportion from 0 to 80 % with Bitumen content from 3.5 % to 5.5 % in each proportion with the increment of 0.5% and three specimens has been casted for each bitumen content.

2.7 Density-Void analysis , Stability - Flow Values, and Retained tensile strength of the mixes:

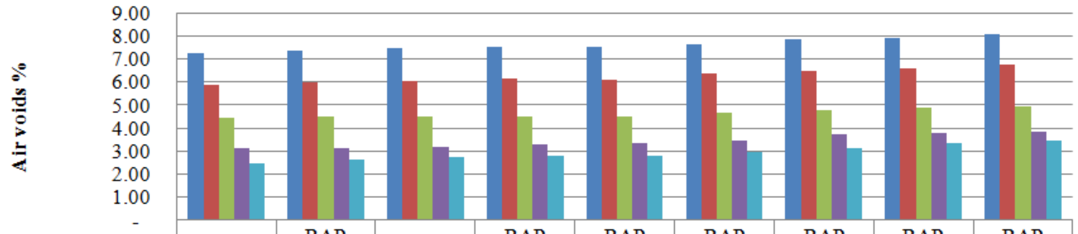
The optimum Bitumen content was chosen as the bitumen content that produced 4 % air voids. Bitumen content corresponding to all other parameters are checked for that binder content so as to confirm that whether all other parameters such as VMA, VFB, Stability and flow falls within the MORT&H specified limits. The specimens to be tested are kept immersed in water in a thermostatically controlled water bath at 60^0C for 30 minutes. The specimens are taken out one by one placed in a Marshall setup and the Marshall Stability (maximum load carried in KN by the specimen before failure) and the flow values are noted. The corrected Marshall Stability values of each specimen are calculated by applying the appropriate correction factor. Marshall Graphs were plotted for different % of RAP materials i.e.0%, 10%, 20%, 30% , 40% ,50% ,60%, 70% and 80% was obtained OBC at 4 % Air voids and then find out Properties like VMA, VFB, Density, Stability, Marshall quotient ,and flow from Marshall graphs at OBC. Water sensitivity tests were carried out on the specimens prepared at OBC in all mixes. The values along with the MORT&H Specifications are given in Table 5.

Mix Properties for Virgin materials and varying different % of RAP



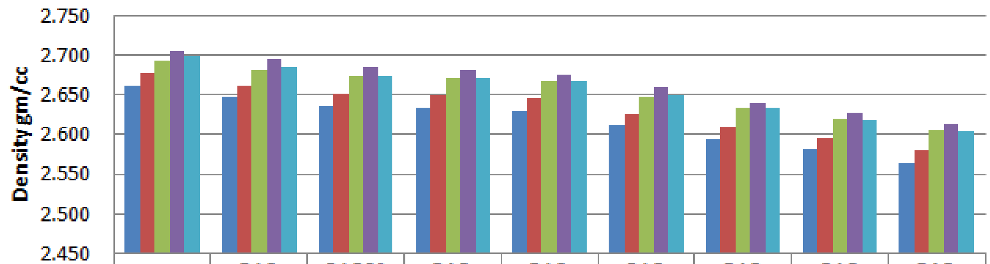
	RAP 0%	RAP 10%	RAP20%	RAP 30%	RAP 40%	RAP 50%	RAP 60%	RAP 70%	RAP 80%
Bitumen 3.5 %	16.47	16.57	15.52	15.28	15.07	15.28	15.52	15.61	15.80
Bitumen 4 %	15.35	15.48	15.45	15.22	14.98	15.31	15.47	15.55	15.76
Bitumen 4.5 %	15.27	15.32	15.23	14.98	14.75	15.00	15.13	15.21	15.31
Bitumen 5 %	15.35	15.32	15.27	15.09	14.91	15.10	15.36	15.44	15.50
Bitumen 5.5 %	15.95	15.38	15.40	15.19	14.99	15.27	15.52	15.75	15.87

Fig-3 Comparison of VMA % for different percentage of RAP Mixes for varying Binder Content with VG-30 Grade bitumen



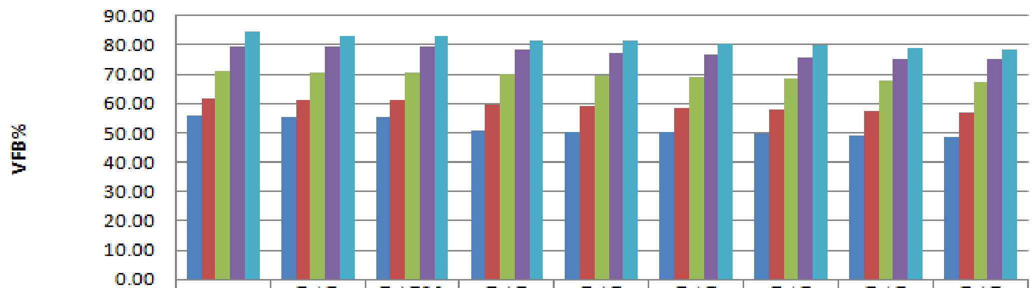
	RAP 0%	RAP 10%	RAP20%	RAP 30%	RAP 40%	RAP 50%	RAP 60%	RAP 70%	RAP 80%
Bitumen 3.5 %	7.28	7.35	7.45	7.51	7.54	7.62	7.83	7.92	8.08
Bitumen 4 %	5.87	6.00	6.06	6.13	6.12	6.35	6.47	6.56	6.75
Bitumen 4.5 %	4.43	4.48	4.48	4.52	4.53	4.68	4.79	4.87	4.95
Bitumen 5 %	3.16	3.12	3.16	3.30	3.36	3.46	3.71	3.80	3.84
Bitumen 5.5 %	2.48	2.62	2.74	2.81	2.80	2.95	3.12	3.34	3.43

Fig-4 Comparison of Air voids % for different percentage of RAP Mixes for varying Binder Content with VG-30 Grade bitumen



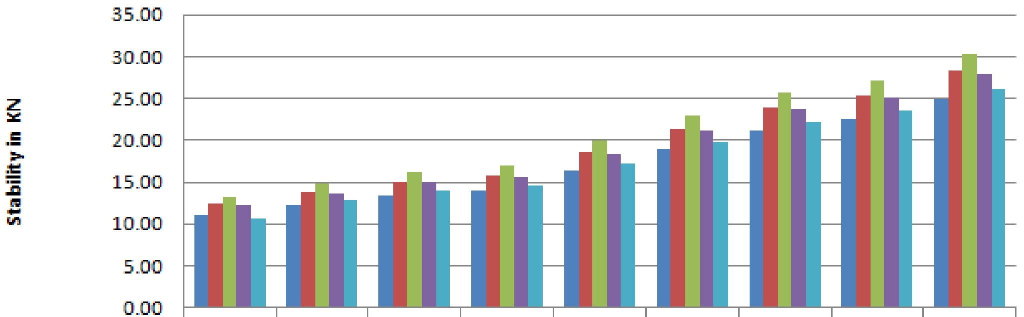
	RAP 0%	RAP 10%	RAP20 %	RAP 30%	RAP 40%	RAP 50%	RAP 60%	RAP 70%	RAP 80%
Bitumen 3.5 %	2.661	2.647	2.636	2.633	2.629	2.612	2.594	2.581	2.565
Bitumen 4 %	2.677	2.662	2.652	2.649	2.646	2.625	2.609	2.596	2.579
Bitumen 4.5 %	2.693	2.681	2.673	2.671	2.667	2.648	2.633	2.620	2.607
Bitumen 5 %	2.705	2.695	2.686	2.681	2.676	2.659	2.640	2.627	2.615
Bitumen 5.5 %	2.700	2.685	2.674	2.671	2.668	2.650	2.634	2.617	2.604

Fig-5 Comparison of Bulk density of compacted mix values for different percentage of RAP Mixes for varying Binder Content with VG-30 Grade bitumen



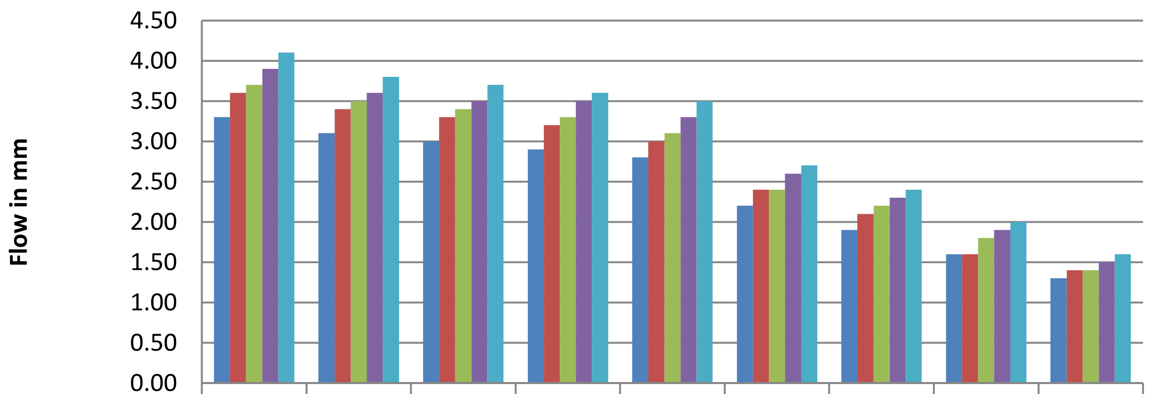
	RAP 0%	RAP 10%	RAP20 %	RAP 30%	RAP 40%	RAP 50%	RAP 60%	RAP 70%	RAP 80%
Bitumen 3.5 %	55.83	55.64	55.64	50.84	50.00	50.10	49.53	49.27	48.86
Bitumen 4 %	61.78	61.27	61.27	59.75	59.15	58.50	58.16	57.80	57.15
Bitumen 4.5 %	70.98	70.78	70.78	69.83	69.31	68.78	68.38	67.96	67.66
Bitumen 5 %	79.44	79.65	79.65	78.16	77.45	77.09	75.86	75.36	75.20
Bitumen 5.5 %	84.46	82.94	82.94	81.48	81.29	80.71	79.91	78.77	78.38

Fig-6 Comparison of VFB % for different percentage of RAP Mixes for varying Binder Content with VG-30 Grade bitumen



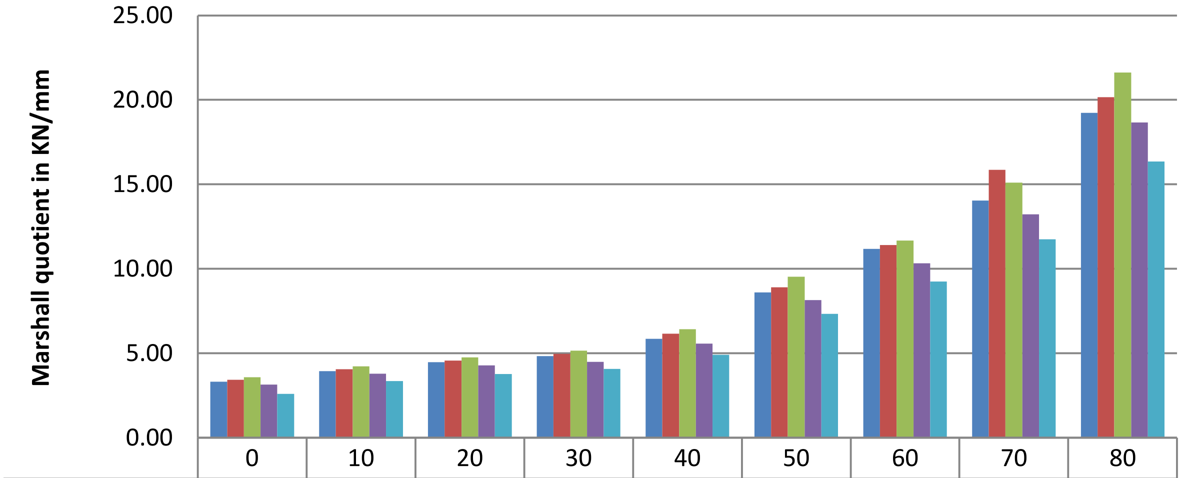
	0	10	20	30	40	50	60	70	80
Bitumen 3.5 %	10.95	12.21	13.40	14.00	16.40	18.92	21.23	22.46	25.00
Bitumen 4.0 %	12.36	13.79	15.10	15.90	18.50	21.36	23.97	25.37	28.23
Bitumen 4.5 %	13.25	14.79	16.20	17.00	19.90	22.90	25.70	27.20	30.27
Bitumen 5.0 %	12.25	13.67	15.00	15.70	18.40	21.17	23.76	25.15	27.98
Bitumen 5.5 %	10.65	12.78	14.00	14.70	17.20	19.79	22.21	23.50	26.16

Fig-7 Comparison of Stability values for different percentage of RAP Mixes for varying Binder Content with VG-30 Grade bitumen



	0 % RAP	10	20	30	40	50	60	70	80
Bitumen 3.5%	3.30	3.10	3.00	2.90	2.80	2.20	1.90	1.60	1.30
Bitumen 4.0%	3.60	3.40	3.30	3.20	3.00	2.40	2.10	1.60	1.40
Bitumen 4.5%	3.70	3.50	3.40	3.30	3.10	2.40	2.20	1.80	1.40
Bitumen 5.0%	3.90	3.60	3.50	3.50	3.30	2.60	2.30	1.90	1.50
Bitumen 5.5%	4.10	3.80	3.70	3.60	3.50	2.70	2.40	2.00	1.60

Fig-8 Comparison of Flow values for different percentage of RAP Mixes for varying Binder Content with VG-30 Grade bitumen

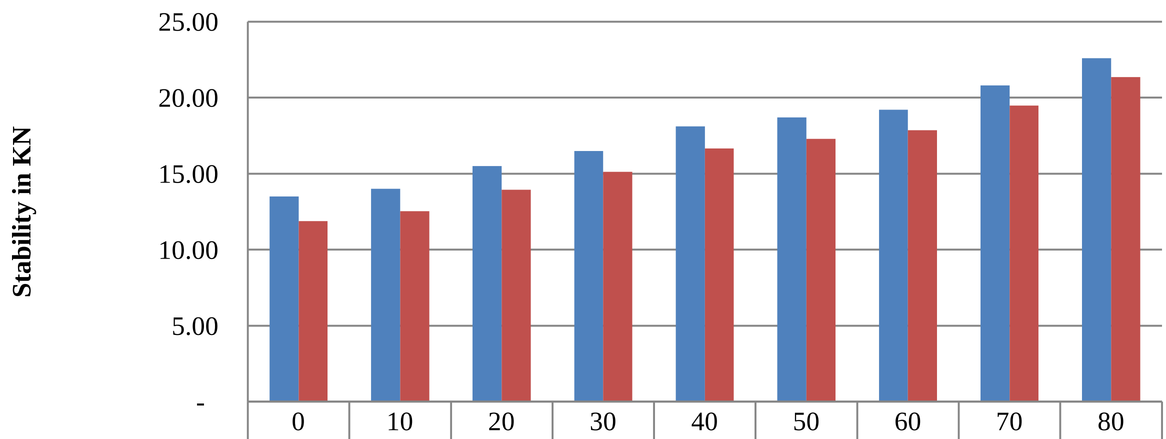


	0	10	20	30	40	50	60	70	80
Bitumen 3.5 %	3.32	3.94	4.47	4.83	5.86	8.60	11.17	14.04	19.23
Bitumen 4.0 %	3.43	4.06	4.58	4.97	6.17	8.90	11.41	15.85	20.16
Bitumen 4.5 %	3.58	4.22	4.76	5.15	6.42	9.54	11.68	15.11	21.62
Bitumen 5.0 %	3.14	3.80	4.29	4.49	5.58	8.14	10.33	13.23	18.66
Bitumen 5.5 %	2.60	3.36	3.78	4.08	4.91	7.33	9.25	11.75	16.35

Fig-9 Comparison of Marshall quotient values for different percentage of RAP Mixes for varying Binder Content with VG-30 Grade bitumen.

2.8 Retained Tensile strength Test: Retained tensile strength test, which was used to measure mix durability by evaluating the resistance of the investigated mixes to moisture damage. This test is intended to measure the loss of stability resulting from the action of water on compacted bitumen mixtures by comparing the stability of dry specimens which have been immersed in water bath at 60 C for certain times, 0.5 and 24 hours

- . Water Sensitivity (Retained Tensile Strength)



	0	10	20	30	40	50	60	70	80
Stability 30 min	13.50	14.00	15.5	16.5	18.1	18.7	19.2	20.8	22.6
Stability 24 Hours	11.88	12.53	13.95	15.13	16.65	17.30	17.86	19.47	21.36

Fig-10 Comparison of Stability values at 60o C in 30 min and 24 hours for different percentage of RAP Mixes for varying Binder Content with VG-30 Grade bitumen

III. ANALYSIS OF TEST RESULTS AND DISSCUSSION

3.1 Comparison of Marshall Properties at different RAP Percentages at OBC

After finding the OBC at 4 % Air voids at the various percentages of the RAP material i.e.10%, 20%, 30% ,40%,50%,60%,70%,and 80% .the percentage reduction in the bitumen content is 0.397%,0.794%,1.191%,1.588%,1.983%,2.378%,2.772 %, and 3.167% respectively.

3.2 Analysis of Marshall Test Results. Table 5 shows the results of Marshall test of the investigated mixes.

Table-5 Mix Properties for Virgin materials and varying different % of RAP @ 4 % Air Voids with VG-30 Grade Bitumen

Parameter	RAP%									Criteria as per MORT&H
	0	10	20	30	40	50	60	70	80	
Aggregate Bulk Specific Gravity (Gsb)	3.036	3.024	3.011	3.000	2.988	2.975	2.963	2.952	2.939	
Apparent Specific Gravity of Aggregate (Gsa)	3.098	3.087	3.075	3.063	3.052	3.040	3.029	3.017	3.006	
Aggregate Effective Specific Gravity (Gse)	3.065	3.051	3.040	3.039	3.035	3.016	3.000	2.987	2.972	
Bitumen specific Gravity Gb	1.04	1.041	1.042	1.043	1.043	1.044	1.045	1.046	1.046	
Maximum theoritical Specific Gravity of loose mixture(Gmm)	2.814	2.808	2.794	2.799	2.795	2.781	2.768	2.756	2.752	
Bulk Specific Gravity of Compacted Mixture (Gmb)	2.697	2.685	2.678	2.673	2.670	2.652	2.638	2.623	2.610	
Optimum Binder Content (%) by total weight of mix	4.650	4.680	4.695	4.725	4.750	4.800	4.900	4.950	5.000	Min 5.2% *
% of Residual bitumen in RAP by Weight of total mix	-	0.397	0.794	1.191	1.588	1.983	2.378	2.772	3.167	
% of Virgin bitumen VG-30 Grade by Weight of total mix	4.650	4.283	3.901	3.534	3.163	2.817	2.523	2.178	1.833	
Absorbed Binder (Pba) (%)	0.329	0.306	0.330	0.448	0.539	0.472	0.434	0.418	0.386	
Effective Binder (Pbe) (%)	4.337	4.388	4.381	4.298	4.236	4.351	4.487	4.552	4.633	
Dust-Binder Ratio	0.626	0.631	0.638	0.642	0.648	0.650	0.659	0.647	0.649	0.6 to 1.2
Voids in Mineral Aggregate (VMA) (%)	15.20	15.20	15.20	15.10	14.80	15.10	15.30	15.40	15.60	Min 12
Voids Filled with Bitumen (VFB) (%)	73.00	73.00	73.00	73.00	73.00	73.00	74.00	74.00	74.50	65-75
Stability (KN at 60^0C, 30 minutes)	13.00	14.40	15.80	16.60	19.30	22.20	24.70	26.00	28.80	Min 9 KN

Flow (mm at 60^{0}C, 30 minutes)	3.750	3.600	3.450	3.400	3.300	2.500	2.300	1.850	1.500	2-4 mm
Marshall Quotient	3.47	4.00	4.58	4.88	5.85	8.88	10.74	14.05	19.20	2-5
Water Sensitivity (Retained Tensile Strength) (%)	88.00	89.50	90.00	91.70	92.00	92.50	93.00	93.60	94.50	minimum 80%

*As per IRC: 111-2009, Cl: 3.5.2, Note-2 and Foot note of Clause 507.2.5 of MORT&H , The bitumen content specified corresponds to Specific gravity of aggregate being 2.7 ,In case of aggregate specific gravity more than 2.7,the minimum bitumen content can be reduced proportionately

3.2.1 Analysis of Optimum Bitumen Content Results

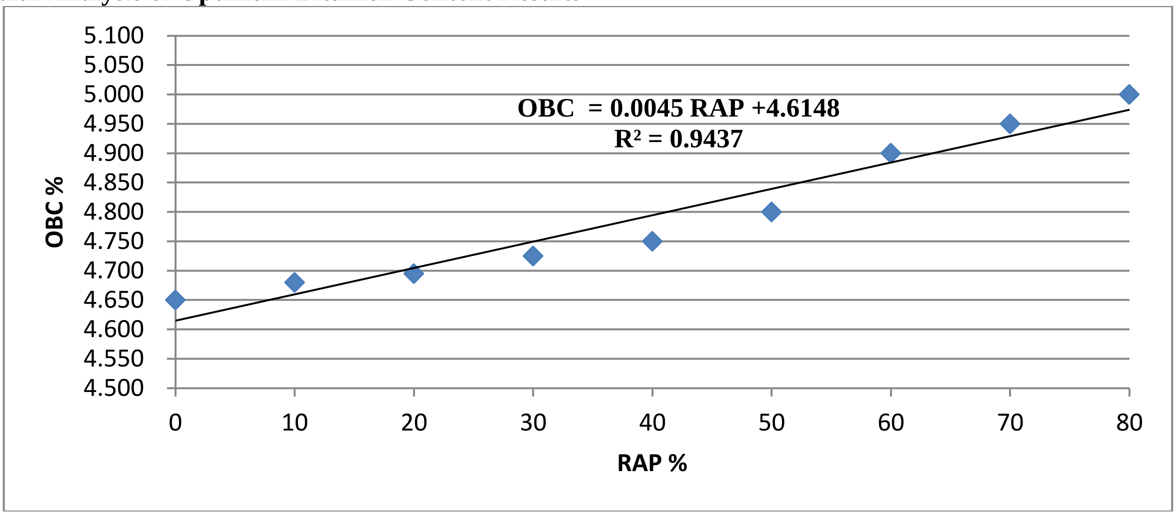


Fig-11: Relationship between % of RAP Vs OBC %

Aggregate gradation is directly related to OBC. The finer the mix gradation, the greater the surface area of aggregate and the greater the binder that will be required to uniform coat the particles.Fig-11 is plotted Based on Marshall test results presented in table (5) to show the optimum bitumen content percent for the investigated mixtures. From the fig-11 it can be noticed that the optimum bitumen content is slightly increased as the RAP percent increases. The relationship between optimum bitumen content % (O.B.C) and RAP % in mix is as follows:

OBC = 0.0045 RAP +4.6148

3.2.2 Analysis of Bulk density Results

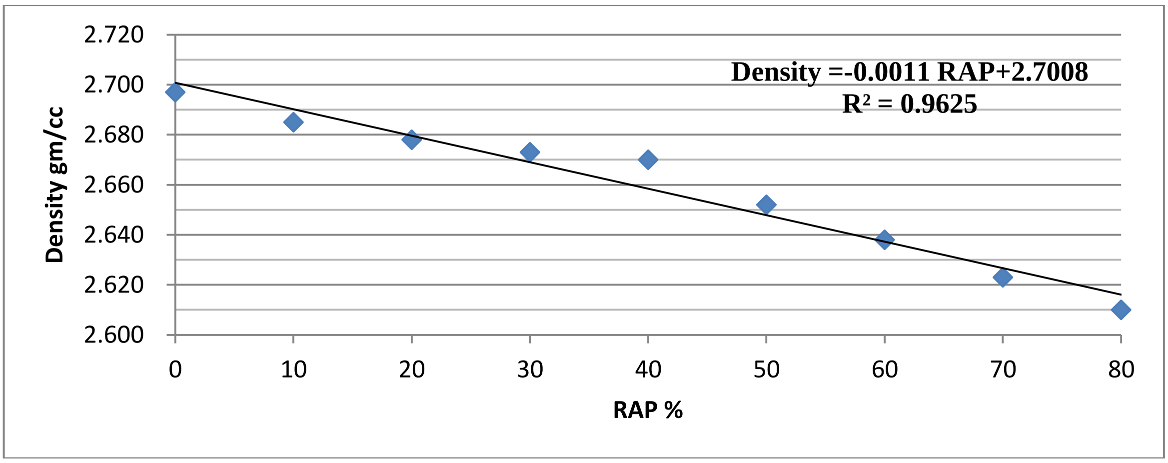


Fig-12: Relationship between % of RAP Vs Density at OBC

Investigating the effect of using RAP on the density of bitumen mixtures. RAP has unpronounced effect on the mix unit weight. However unit weight is decreased as reclaimed percent increases. It must be noticed that, increasing RAP percent from zero to 80% reduce the unit weight by only 3.225%. To examine the relationship between mix density content and RAP percent figure (12) was plotted. The relationship between mix density content and RAP % in Mix is as follows:-

Mix Density = – 0.0011 RAP+2.7008

3.2.3 Analysis of Mix Stability Results

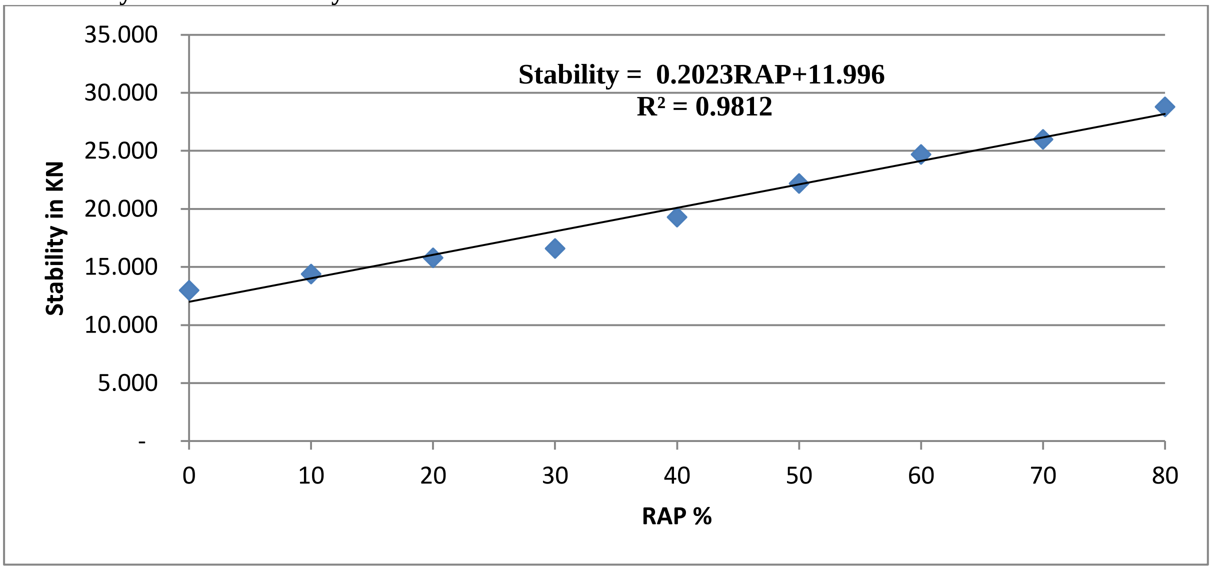


Fig-13: Relationship between % of RAP Vs Stability at OBC

One of the most important properties of bitumen mix is the stability. The mix stability is an important indicator for resisting pavement distresses. The stability of the investigated mixtures is presented in the table 5. Referring to the table it can be noticed that, the mix stability is increased as RAP percent increases. It can be also noted that, increasing RAP percent from zero to 30% increase the stability value from 13 KN to 16.6 KN i.e. increased by about 27.69%. ,when the RAP percent increases from 30% to 80% the increase in the stability value from 16.6 KN to 28.8 KN i.e. increased by about 73.49%. To deduce the relationship between mix stability and recycled aggregate percent figure (13) was plotted. The relationship between mix stability and RAP percent in mix is as follows:

Stability = 0.2023 RAP+11.996

3.2.4 Analysis of Mix Flow Results

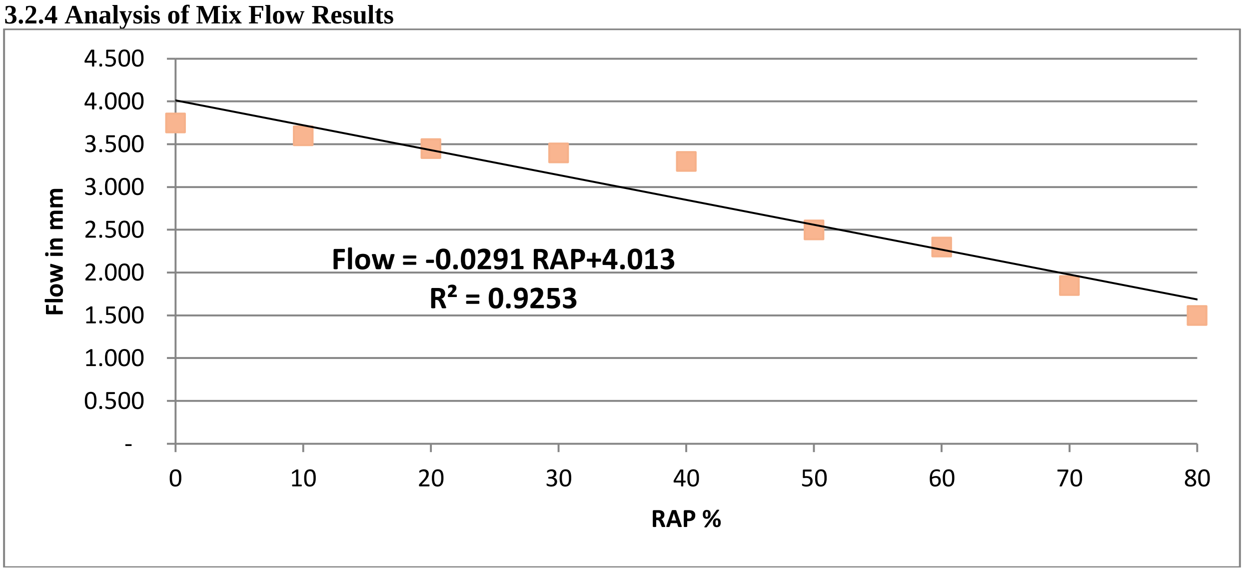


Fig-14: Relationship between % of RAP Vs Flow at OBC

Mix flow value gives an indicator for the resistance to permanent deformation. Based on the flow values obtained for all the investigated mixtures, table (5) was prepared. The mix flow is decreased as the RAP percent increases. When RAP percent increases from zero to 40%, the flow value

decreases from 3.75 mm to 3.3 mm.i.e. decreased by about 12%.When the RAP percent increases from 40%,50%,60%, 70% and 80% the decrease in the flow values of mix are 3.3,2.5,2.3,1.85 and 1.5 mm respectively, decreases of flow value from 40% RAP to 80 % RAP by about 54.54%.It must be noted that the mix flow reaches a value of 1.85 as the RAP percent reaches to 70%. This flow value is out of specification limits. To derive the relationship between mix flow and RAP percent, fig-14 was plotted. The relationship between mix flow and RAP % in Mix is as follows.
Mix flow = -0.0291 RAP+4.013

3.2.5 Analysis of Marshall Quotient of Mix Results

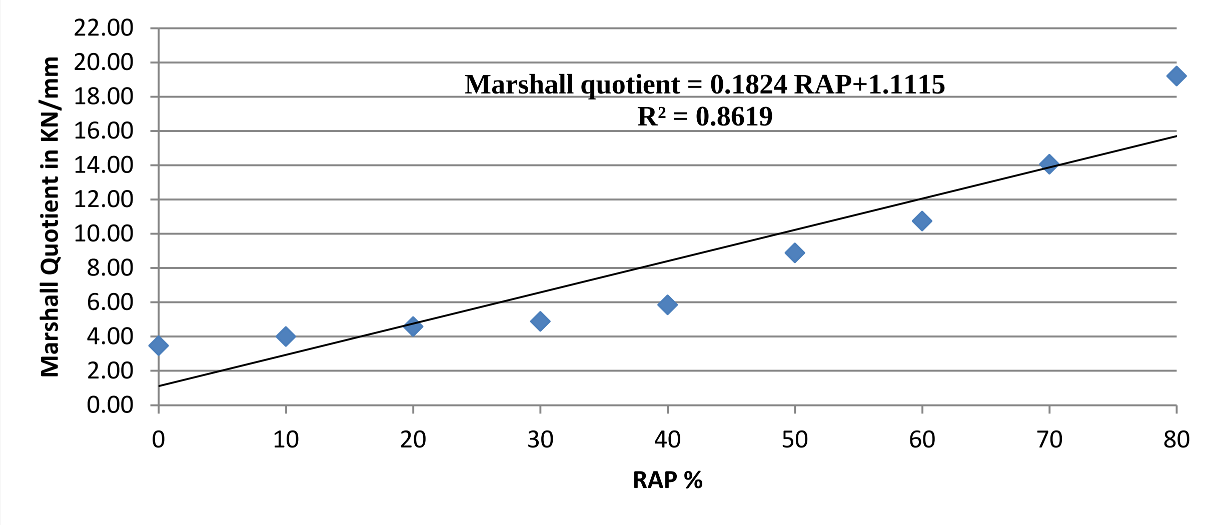


Fig-15: Relationship between % of RAP VsMarshallQuotient at OBC

Marshall Quotient (MQ) also known as rigidity ratio is the ratio of stability to flow value of the mixture and the Marshall Quotient values of Bituminous concrete mix with different RAP contents are shown in Fig.15. It is observed that Marshall Quotient (MQ) increases with increase of RAP content. It can be also noted that, increasing RAP percent from zero to 30% increase the Marshall Quotient (MQ) value from 3.47 KN/mm to 4.88 KN/mm i.e. increased by about 40.63%. ,when the RAP percent increases from 30% to 80% the increase in the Marshall Quotient (MQ)value from 4.88 KN/mm to 19.2 KN/mm i.e. increased by about 293%..It must be noted that the mix Marshall Quotient value reaches a value of 5.85 KN/mm as the RAP percent reaches to 40%. This value is out of specification limits. **Therefore, it is recommended to use RAP up to the percent of 30 only with VG-30 Grade bitumen in Bituminous concrete mix**.. To derive the relationship between Marshall Quotient (MQ) and RAP percent, fig-15 was plotted. The relationship between mix Marshall Quotient (MQ) and RAP percent in Mix is as follows.
Marshall Quotient = 0.1824 RAP+1.1115

3.2.6 Analysis of Air voids results

The air voids is an important factor that must be considered when designing bitumen Concrete mixture. The air voids limits are in the range 3-5 % of the total mix volume. When air voids lower than 3% bleeding of bitumen will occur specially with higher temperature. On the other hand for air voids percent greater than 5% of the mix, the pavement will be weak and unstable. For these considerations the bitumen binder is a very sensitive element in pavement design. It is observed that from Fig-4 the Air Voids value goes on slightly increased while increasing the RAP content. Analysing the data in the Fig-4, it can be seen that virgin bitumen may not perfectly blended with the RAP binder as its percentage increases. This may be due to the ineffective old bitumen in the aggregate pores which prevent partly the virgin bitumen from occupying deeply the aggregate pores
The results of the investigated mixes are shown in table-5 were Based on the 4 % air voids.

3.2.7 Analysis of Voids in Mineral Aggregate Results

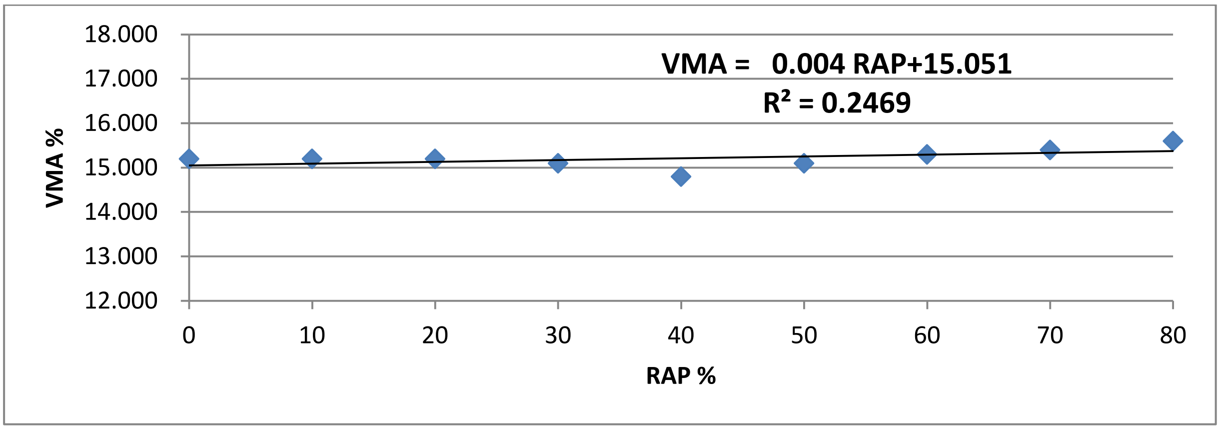


Fig-16: Relationship between % of RAP Vs VMA at OBC

VMA must be high enough to achieve an adequate bitumen film thickness ,which results in a durable pavement. Bituminous mixes with below minimum VMA values will have thin film of bitumen and will provide bituminous pavement with low durability. Table (5) presents the voids in mineral aggregate for all the investigated mixes. VMA is satisfying in all mixes of Variable % of RAP from 0 to 80% and it's value is more than the minimum value of 12 as specified. From the table it can be noted that, the VMA of mix is 15.2%upto 20% of RAP there after it is reducing to 14.8% when RAP reached to 40% again it is increasing to 15.6% as the RAP percent increases to 80%. No change is noted in VMA upto 20% of RAP, The decrease in VMA is of low rate up to RAP % of 40% i.e. decreased by about 2.63%. when the RAP % increases from 40% to 80% the VMA is slightly increased by about 5.4%. To derive the relationship between the voids in mineral aggregate and the RAP% in mix, figure (16) was plotted and the relationship is as follows: VMA =0.004 RAP+15.051

3.2.8 Analysis of Voids Filled with Bitumen Results

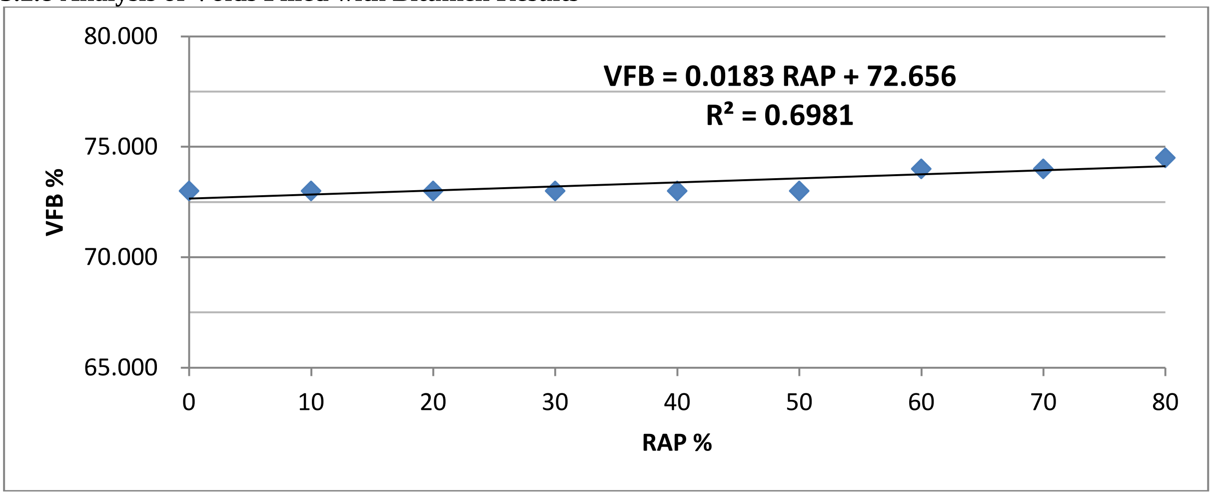


Fig-17: Relationship between % of RAP Vs VFB at OBC

VFB criteria helps to avoid those mixes that would be susceptible to rutting in heavy traffic situation. The main effect of the VFB criteria is to limit maximum levels of VMA, and subsequently, maximum levels of Bitumen content. VFB is used to ensure proper asphalt film thickness in the mix, if it is too low the mix will have poor durability or if it is too high, the mix can be unstable. Table (5) presents the voids filled with the bitumen for all the investigated mixes. VFB is satisfying in all mixes of Variable % of RAP from 0 to 80% and it,s value is in the range of 73 to 74.5% at OBC. From the table it can be noted that, the VFB of mix is 73% upto50% of RAP there after it is slightly increasing to 74.5% when RAP reached to 80%. No change is noted in VFB values upto50% of RAP, when the RAP % increases from 50% to 80% the VFB is slightly increased by about 2.05%. To derive the relationship between the voids filled with bitumen and the RAP% in mix, figure (17) was plotted and the relationship is as follows: VFB =0.0183RAP+72.656

3.2.9 Analysis of Retained Tensile Strength Test Results

The loss of stability test was conducted on bitumen concrete specimens prepared at the optimum bitumen content obtained in Marshall test. This test is considered an important measure of mix durability by evaluating the resistance of the investigated mixes to moisture damage. The results of the Retained tensile strength test are presented in table (5) and it can be noted that Retained tensile strength is satisfying in all mixes of Variable % of RAP from 0 to 80% and its value is more than the minimum value of 80% as specified. It is clear that increasing of recycled material percent decreases the loss of stability of mix. It is noticed that, increasing RAP percent from zero to 30% resulted decrease in loss of stability value from 12 % to 8% i.e by about 33.3 % of its original value. But when the RAP percent reaches from 30% to 80%, the decreasing in loss of stability value reaches from 8% to 5%; i.e. by about 37.5% .To derive the relationship between the Retained Tensile Strength and the RAP percent, figure (18) was plotted and the relationship is as follows

Retained Tensile strength =0.0008 RAP+0.8864

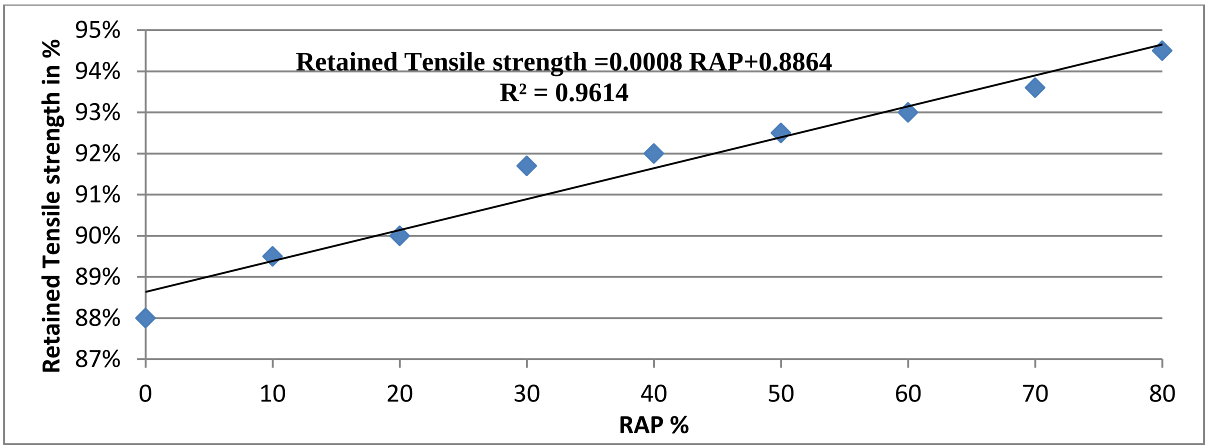
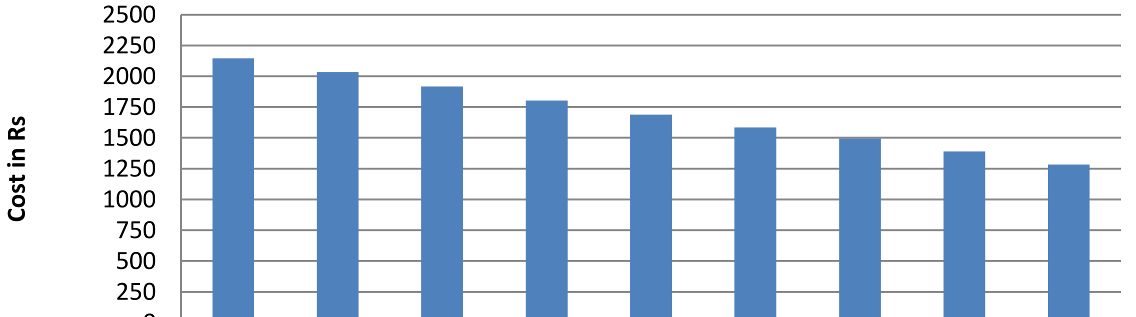


Fig-18: Relationship between % of RAP VsRetained tensile strength at OBC

IV. COST ANALYSIS

The primary saving in central hot mix recycling comes from savings in the cost of virgin bitumen materials and aggregates. Fig-19 shows cost of mix per MT by using Variable percentages of Reclaimed bitumen pavement (RAP) with VG-30 Grade bitumen. Based on AP SSR Rates 2016-2017 it is obtained Average rate of Virgin aggregates is Rs 660 per MT and the rate of VG-30 Grade bitumen is Rs 32600 per MT , the cost of a 100 percent virgin mix with OBC at4.65percentbitumen the material cost worked out to Rs 2145 per MT of Mix. The cost of milling machine and hauls the RAP back to the Central hot mix plant, the total cost for RAP is worked out to Rs 708/MT



	0%	10%	20%	30%	40%	50%	60%	70%	80%
Cost per MT	2145	2,033	1,916	1,803	1,689	1,584	1,494	1,389	1,284

Fig-19: Comparison of Cost in RS per 1 MT of Mix materials for different percentage of RAP with VG-30 Grade bitumen

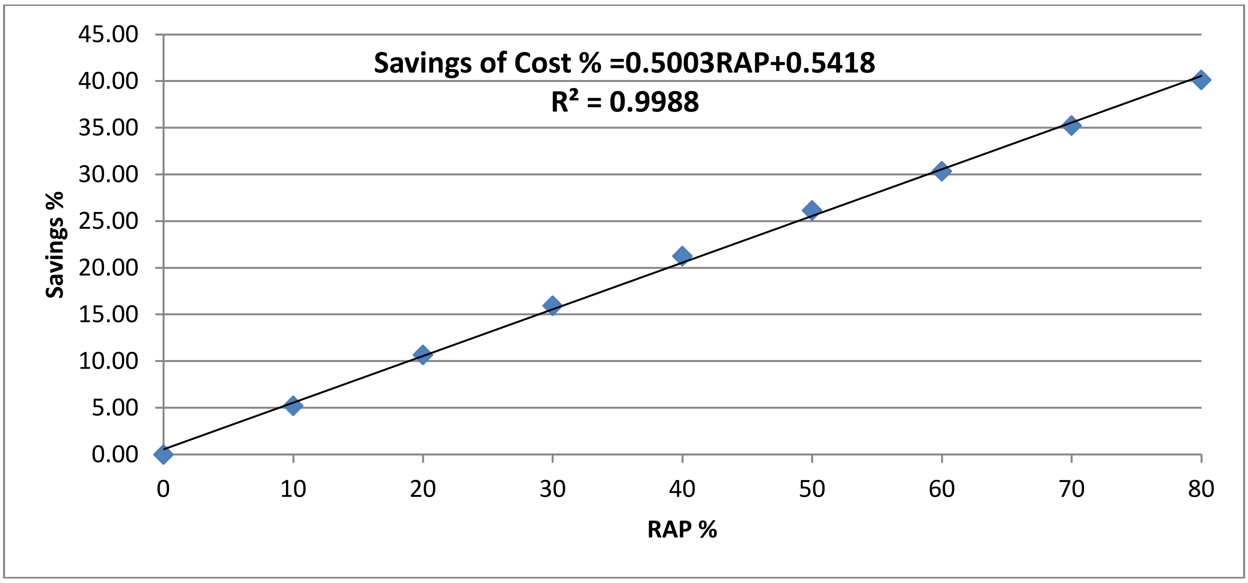


Fig-20: Savings % by using diffrent percentages of RAP with VG-30 Grade bitumen

V. CONCLUSIONS

The following conclusions were determined based upon the experimental results obtained from a laboratory investigation of mixes of Control mix with Virgin materials (0% RAP) and mixes with Variable % of RAP from 10 to 80% which contain both RAP and Virgin Material on Bituminous Concrete Grade-I.

The results obtained showed that there were no significant difference in Volumetric Properties of mix, between Control mix with Virgin materials (0% RAP) and mixes with Variable % of RAP from 10 to 80%. But there are significant effect on the Marshall stability, flow of mix, Marshall quotient and water sensitivity test values were noted.

5.1 The optimum binder content for Control Mix was at 4.65% bitumen, OBC for RAP 30% Mix is 4.725%. It was also observed that the optimum binder content for RAP mixes was slightly increased as the RAP percent increases. This may mainly due to decrease of bulk specific gravity of compacted mix as the percentage of increasing RAP, and the mix gradation is very slightly finer when increasing of RAP causing the slightly increasing the surface area of aggregate and the greater the binder that will be required to uniform coat the particles.

OBC = 0.0045 RAP+4.6148

5.2 At optimum binder content the density of Control mix (RAP 0%) was 2.697 g/cc which is slightly higher than that of RAP 30% which had density 2.673 g/cc by 0.89 % Increasing RAP has unpronounced effect on the mix unit weight. However, increasing RAP from zero to 80% decreases the mix density by 3.225 % only,

Mix Density =– 0.0011 RAP + 2.7008

5.3 At optimum binder content the Marshall Stability value of control mix was 13 KN found to be less than RAP 30% 16.6 KN by 27.69%. Mix stability increases as the RAP percent increases. However, the increasing stability of bitumen mix is more significant when the percent of RAP is higher than 30 %.,increases of RAP from zero to 30% the mix Stability increases by27.69 %,whereas from increase of RAP from 30% to 80% the increases in the mix Stability by73.49 %

Stability =0.2023 RAP + 11.996

5.4. At optimum binder content the mix flow value of control mix was 3.75 mm found to be more than RAP 30% 3.4 mm by 9.33%.At optimum binder content flow value of RAP mixes were lesser than the control mix.The mix flow decreased as the RAP percent increased. However, the decreasing flow of bitumen mix is more significant when the percent of RAP is higher than 40 %.,increases of RAP from zero to 40% the mix flow decreases by12 %,whereas from increase of RAP from 40% to 80% the decrease in the mix Flow by54.54 %

Mix flow = -0.0291 RAP +4.013

5.5 At optimum binder content the mix Marshall Quotient of control mix was 3.47KN/mm found to be less than RAP 30% 4.88 KN/ mm by 40.63%.It is observed that Marshall Quotient (MQ) increases with increase of RAP content.It can be also noted that, increasing RAP percent from zero to 30% increase the Marshall Quotient (MQ) value by about 40.63%. ,when the RAP percent increases from 30% to 80% the increase in the Marshall Quotient (MQ)value from 4.88 KN/mm to 19.2 KN/mm i.e. increased by about 293%.It must be noted that the mix Marshall Quotient value reaches a value of 5.85 KN/mm as the RAP percent reaches to 40%. This value is out of specification limits. Mixes having Marshall Quotient (MQ) value more than 5 KN/mm are not acceptable because pavements with such mixes tend to be less durable and prone to cracking prematurely under heavy volumes of traffic. Therefore, it is recommended to use RAP up to 30% only with VG-30 Grade bitumen in bituminous concrete Grading-1. The relationship between mix Marshall Quotient (MQ) and RAP percent in mix is as follows.

Marshall Quotient =0.1824 RAP + 1.1115

5.6 Specimen prepared with Control Mix (0% of RAP) sample has less Air Voids value than specimen prepared with RAP mixes it indicates that Air Voids value goes on slightly increased while increasing the RAP content. It can be seen that virgin bitumen may not perfectly blended with the RAP binder as its percentage increases. This may be due to the ineffective old bitumen in the aggregate pores which prevent partially the virgin bitumen from occupying deeply the aggregate pores. The results of the investigated mixes are shown in table-5 were Based on the 4 % air voids.

5.7 At optimum binder content the VMA of control mix was 15.2 % found to be slightly more than RAP 30% 15.1 % by 0.65%. VMA is satisfying in all mixes of Variable % of RAP from 0 to 80%. No change is noted in VMA upto 20% of RAP, The decrease in VMA is of low rate up to RAP % of 40% i.e. decreased by about 2.63%. When the RAP % increases from 40% to 80% the VMA is slightly increased by about 5.4%.

VMA = 0.004 RAP + 15.051

5.8. It was found that VFB at optimum binder content for control mix was 73%. It was also observed that at optimum binder content for RAP mix 30% was same as that of Control mix. No change is noted in VFB values upto50% of RAP at OBC, when the RAP % increases from 50% to 80% the VFB is slightly increased by about 2.05%

VFB = 0.0183 RAP + 72.656

5.9. At optimum binder content Retained tensile strength of control mix was 88 % found to be less than RAP 30% mix value of 91.7% by 4.2%.Increasing of RAP percent decreases the loss of stability of bitumen mix and there by increases the percentage of Retained Tensile strength. it can be noted that Retained tensile strength is satisfying in all mixes of Variable % of RAP from 0 to 80% and its value is more than the minimum value of 80% as specified

% of Retained tensile strength=0.0008 RAP + 0.8864

In this present paper, based on the laboratory studies it was concluded that upto maximum 30% RAP with VG-30 Grade bitumen was satisfied the Volumetric properties of compacted mix, stability, Flow, Marshall quotient ,and Retained tensile strength than the other mixes Hence Maximum upto 30% RAP can be used in the Bituminous concrete mix with VG-30 Grade Bitumen. It was also noted that the use of 30% RAP in Bituminous concrete will save 16 % of mix initial cost.

VI. SCOPE FOR FURTHER STUDY

6.1 A large scale study can be carried out taking into considerations of several parameters like age of RAP materials, Residual binder content, availability of RAP, viscosity of binder etc and corrections also need to be established with respect to age of RAP and other factors example residual binder, percentages etc.

6.2 Performance based test methods can be carried out are Static or Creep, Dynamic loading and Rutting tests to provide accurate and realistic relationship under the actual traffic loading and environmental conditions.

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