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A Laboratory Study on Effects of Reclaimed Asphalt Pavement on Performance of Dense Bituminous Macadam

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Abstract: Now-a-days disposal of different wastes produced from different Industries is a great problem. These materials pose environmental pollution in the nearby locality because many of them are non-biodegradable. In recent years, applications of industrial wastes have been considered in road construction with great interest in many industrialized and developing countries. The use of these materials in road making is based on technical, economic, and ecological criteria. Some of the countries have already taken step to recycle the transport waste material and started using in base course, sub-base course and wearing course. The utilization of transport waste started as recycled asphalt pavement. The RAP is a useful alternative to the virgin materials because it reduces the use of virgin aggregates and the virgin bitumen. It is a great approach in terms of technical, economical, preservation of natural resources and environmental issues. Many countries who are using RAP reported that, less waste is produced, cost saving and environmentally sustainable.
Keywords: Reclaimed Asphalt Pavement, Bitumen, Aggregates and Waste Material.

1 INTRODUCTION

Recently the construction cost and pavement material cost is increasing rapidly, and in our country more than 90% of road network is paved. As we know that India is second largest country in the world in terms of road networks, and at the same time Indian government is also thinking to construct 1.5 lakh kilometre roads in every year. By this we can guess the huge quantity of material (aggregate and bitumen) is required. This influences the increase in construction costs.

But later when roads deteriorate the rehabilitation/reconstruction works should be carried out. Noticing all these things we can understand that there will be generation of lot of solid waste by the transport industry. In coming years it will become the big threat to the environment. To have sustainable transport system lot of research is needed in order to recycle the transport waste material. The use of RAP in HMA eliminates the need to dispose of old asphalt pavements and conserves asphalt binders and aggregates. This results in significant production cost savings and benefits to society.

2 OBJECTIVES AND SCOPE OF THE WORK

- The main objective of the study is to utilize the RAP in Dense Bituminous Mix in order to reduce the consumption of virgin aggregates and bitumen. It is aimed to propose the optimum content of RAP in Dense Bituminous Mix based on laboratory investigations.
- The present work is limited to study the effect of RAP on Dense Bituminous Mix with VG30 bitumen manufactured at IOCL and aggregate of nominal maximum size 26.5mm collected from quarry near chikhli. The RAP sample is collected from Rajmarg of Surat city.
- The study is pointing toward determination of Optimum RAP content in Dense Bituminous Mix based on the testing of bituminous mix performance such as Marshall Stability test, Retained Stability test, Indirect Tensile Strength test and Dynamic Creep test.

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3 METHODOLOGIES

In this study, Dense Bituminous Mix (DBM-2) has been designed for 26.5 mm nominal size of aggregate. The Aggregate used in the study is crusher Aggregate from Quarry near Chikhli and VG30 grade of Bitumen manufactured at IOCL, Surat to check the suitability of aggregates and bitumen. RAP is collected from Rajmarg road Surat city and utilized in the study with various proportion. Firstly, laboratory testing has been carried out to find the physical properties of Aggregate by conducting tests like Aggregate Impact value Test, Stripping test, Flakiness and elongation Index (combined) Water absorption and Specific Gravity Test etc. Similarly, The Bitumen tests for VG30 have been done including Penetration test at 25 °C, Softening Point test, Ductility test at 27 °C etc. to check the suitability as per IS:73-2013. Thereafter Marshall Mix design method is adopted for various content of RAP material to determine the Optimum bitumen content for. After determining the OBC, Marshall Samples are prepared at OBC to check the volumetric properties, Marshall Stability and Flow value as per MoRTH 2013 Clause 505.3.1 Specifications. Performance of DBM-2 design has been evaluated by conducting various tests on Marshall Samples including Indirect Tensile Strength test, Dynamic Creep test and Retained Stability test.

3.1 RECLAIMED ASPHALT PAVEMENT (RAP)

RAP refers to removed and reprocessed materials from existing pavements which contain useful aggregate and bituminous binder. These materials are produced when bituminous pavements are removed for resurfacing, reconstruction, and/or accessing buried substructures, RAP is obtained either by full depth reclaimed or by milling the existing pavements. With appropriate mixture design and production considerations, RAP can be reused in HMA to produce mixtures meeting normal specification requirements.

3.1.1 SAMPLING OF RAP

RAP can be sampled from the road way (by coring before the pavement is milled), from a stockpile, or from haul trucks. The process for stockpile or haul truck sampling is similar to the sampling process used for aggregates.

Milling and processing operations breakdown some of the aggregate in the RAP producing finer gradations with increased percentages passing the 0.075 mm (#200) sieve. Since a representative sample of the RAP will be used directly in the mixture design process, it is critical that the RAP samples obtained for HMA mixture design be representative of the RAP that will be used in the mixture. For this reason, the recommended sampling location for RAP is from stockpiles of the RAP after final processing. It is important to get samples that accurately reflect the material that is available for use.

3.1.2 SAMPLE SIZE

The size of the sample needed depends on the purpose of the sampling. If sample is used only for RAP aggregate gradation and bitumen content then the sample size required is less than the sample size required for Marshall Specimens. Normally 10Kg is sufficient for gradation and bitumen content determination. For Marshall Tests about 25Kg is sufficient according to NCHRP 9-33 manual.

3.1.3 EXTRACTION AND RECOVERY OF RAP BINDER AND AGGREGATES

It is important to know how much bitumen binder is present in the RAP material. So that it can be accounted for in the mix design process. It is also important to know some physical properties of the RAP aggregates. These can be done by doing an Extraction on the RAP to measure the bitumen content and obtain the bare aggregates for testing. ASTM 1856-09 code is used to extract the bitumen from the RAP, the bitumen extractor is shown in the **Figure 1**. And then the bitumen is recovered by the distillation process according to ASTM D2171-05.

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Figure 1 Centrifugal Extractor and Abson Recovery Apparatus

3.1.4 DETERMINATION OF BITUMEN CONTENT OF RAP

It is important to determine the bitumen content of RAP. The further proceedings, all the calculations and decisions are highly depending on the bitumen content of RAP. It is done precisely to get correct result. The sampling is done as discussed earlier and then extraction and recovery test is done. The test Results are shown in **ANNEXURE C**. The results can be determined as shown below,

Before extraction,
a = Weight of RAP material
b = Weight of bowl
c = Weight of plate + filter paper
After extraction,
d = Weight of recycled material + bowl
e = Weight of plate + filter paper (fines are added)
The Recycled material after extraction = (d + e) - (b + c) = f
Then the recycled material should be kept in oven for 24hrs, in order to remove the trichloro-ethylene.
g = Weight of the recycled aggregate after oven drying
Now, the bitumen content = (a-g)/a = **3.3%**

3.2 BITUMEN TESTS

Bitumen is often referred to as visco-elastic materials, behaving as elastic solids at low temperature and viscous liquids at high temperature. The physical properties of bitumen have determined by the test methods shown in **Table 3-2** and **Table 3-3** along with the Specifications of IS 73:2013 for VG-30 grade bitumen. Similarly the physical properties of recycled bitumen also determined.

Table 3-1 Properties of Virgin Bitumen of grade VG 30

Property	**Test Method**	**Test Results**	**Repeatability**	**Requirements as per IS 73:2013 for VG 30**
Penetration 25°C ,100 g, 5 s, 0.1mm	IS 1203:1978	56	3%	Min 45
Softening point (R&B),°C	IS 1205:1978	48	1°C	Min 47
Absolute viscosity at 60°C, Poises	IS 1206 (Part 2):1978	2678	7%	2400-3600
Tests on residue from rolling thin film oven test				
Viscosity ratio at 60°C, Max	IS 1206	3.51	-	4

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	(Part 2):1978			
Ductility at 25°C, cm, Min	IS 1208:1978	48	-	40

Table 3-2 Properties of Recycled Bitumen

Property	**Test Method**	**Test Results**
Penetration 25°C ,100 g, 5 s, 0.1mm	IS 1203:1978	24
Softening point (R&B),°C	IS 1205:1978	68
Ductility Test, 25°C, cm	IS 1208:1978	41

3.3 AGGREGATE TESTS

The physical properties of aggregate has determined for the binding coarse DBM - 2 by the test methods shown in **Table 3-4** and **Table 3-5**, which includes the MoRTH 2013 specifications. In the same manner the tests for recycled aggregates also conducted, and results are shown in **Table 3-6**.

Table 3-3 Properties of Virgin Aggregates for DBM-2

Property	**Test Method**	**Test Results**	**MoRTH, 2013 Specifications**
Aggregate Impact Value	IS 2386 (Part IV):2002	10.25	27% max
Flakiness and Elongation Index	IS 2386 (Part I):2002	27.85	35% max
Stripping Value Test	IS 6241:1971	98%	Minimum retained coating 95%

Table 3-4 Specific gravity and Water absorption test results of Virgin Aggregates for DBM-2

IS Sieve Size (mm)	Specific Gravity	**MoRTH, 2013 Specifications** IS 2386 (Part III):2002	Water absorption	**MoRTH, 2013 Specifications** IS 2386 (Part III):2002
26.5	2.76	2.5-3	0.99	2% max
19	2.74		1.16	
13.2	2.68		1.44	
4.75	2.68		1.50	
2.36	2.68		1.60	
0.300	2.68		1.56	
0.075	2.72		1.48	
Pan	2.78		1.35	

Table 3-5 Properties of Recycled Aggregates

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Property	Test Method	Test Results	MoRTH, 2013 Specifications
Aggregate Impact Value	IS 2386 (Part IV):2002	16.77	27% max
Flakiness and Elongation Index	IS 2386 (Part I):2002	23.51	35% max

3.5 BITUMINOUS MIX DESIGN

In order to determine OBC, Marshall Method of mix design is adopted as per Asphalt Manual Series No 2 (MS 2). The Marshall Test procedures have been standardized by the American Society for Testing and Materials. Procedures are given by ASTM D1559, Resistance to plastic Flow of Bituminous Mixtures Using Marshall Apparatus.

And for the **RAP mix**, to determine OBC, the same method is applied but the RAP material is heated to a temperature of 110^0 C for a period of less than 2 hour and next moment it should be used for the mix as specified by the NAPA Quality improvement series 124.

3.5.1 DESIGN REQUIREMENTS

As per the MoRT&H (2013) specifications for DBM-2 mix, when the specimens are compacted with 75 blows on either face, the designed DBM-2 mix should fulfil the following requirements are given in **Table 3-7 and Table 3-8**.

Table 3-6 Design requirements for Bituminous Mixes (DBM-2) using VG Graded Bitumen as per MoRTH (2013)

Property	Specified Value
Compaction level	75 blows on either side
Minimum stability, (kN) at 60°C	9.0
Marshall flow (mm)	2 – 4
Marshall Quotient (Stability/Flow)	2-5
% Air Voids	3 – 5
% Voids Filled with Bitumen (VFB)	65 – 75
Coating of aggregate particle, minimum	95%
Tensile Strength ratio, minimum	80%
Loss of stability on immersion in water at 60°C	> 75 %

Table 3-7 Minimum Percent Voids in Mineral Aggregates (VMA)

Nominal Maximum Particle Size (mm)	Minimum VMA, % Related to Design Air Voids, %		
	3.0	4.0	5.0
26.5	11	12	13

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37	10	11	12

3.5.2 SAMPLE PREPARATION SCHEDULE

The maximum allowable RAP % is determined as discussed in **chapter 3.1.6**.

Table 3-8 Sample preparation schedule

Sr. No	Type of Test	Remarks				
		0% RAP	**10% RAP**	**20% RAP**	**30% RAP**	**40% RAP**
1	Marshall test for OBC	15	15	15	15	15
2	Marshall test at OBC	3	3	3	3	3
3	Retained Stability	3	3	3	3	3
4	Indirect Tensile Strength Test (Dry And Wet)	6	6	6	6	6
5	Dynamic Creep Test	3	3	3	3	3
Total Samples		**30**	**30**	**30**	**30**	**30**

4 ANALYSIS OF TEST RESULS

4.1 GENERAL

Laboratory test results have been evaluated to predict the effect of different RAP content on volumetric properties, Marshall Stability and flow.

Results of an Optimum binder content has been analysed while comparing with stability, bulk density, Air voids, flow value and voids fill with bitumen.

4.2 AGGREGATE GRADATION SELECTION FOR DBM MIXES

Sieve analysis has been carried out for the aggregate to be tested for their physical properties and Grading of aggregate is determined for Mix design for 26.5 mm nominal size of aggregate.

The controlled gradation has been carried out to match the gap that occurred because of RAP material. The detailed calculation and the final gradation is given in **ANNEXURE C**.

4.3 MARSHALL MIX DESIGN

Marshall Test include preparation of Marshall samples at Bitumen content ranges from 3.5%-5.5% by weight of specimen (1280gm) at 0.5% increment, three samples are prepared at each bitumen content and Optimum Bitumen Content (OBC) is found out for 0%, 10%, 20%, 30% and 40% RAP content. Marshall Stability and Flow is found out for each sample.

4.3.1 MAXIMUM SPECIFIC GRAVITY AND EFFECTIVE SPECIFIC GRAVITY

The maximum specific gravity is determined according to the procedure illustrated by ASTM D2041 – 03a. And then the effective specific gravity of combined aggregate can be determined using the formula from MS-2. Maximum specific gravity and the Effective specific gravity keep on changing with varying the proportion of RAP content. The results are shown in **Table 4-1.**

Table 4-9 G_{se} and G_{mm} of particular RAP content

Maximum Specific Gravity (G_{mm})					
% Binder Content	% RAP Content				
	0	**10**	**20**	**30**	**40**

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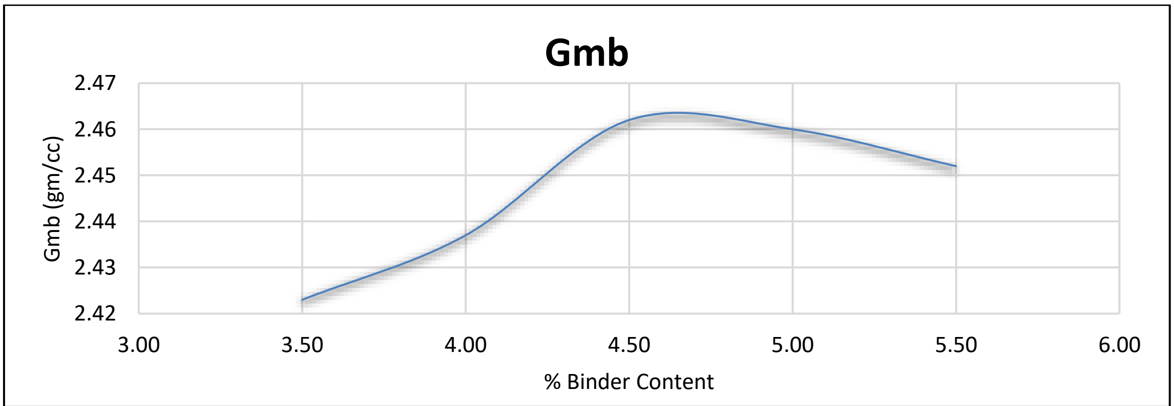
3.5	2.608	2.595	2.582	2.569	2.557
4.0	2.587	2.574	2.562	2.549	2.537
4.5	2.567	2.554	2.542	2.530	2.517
5.0	2.547	2.535	2.522	2510	2.498
5.5	2.527	2.515	2.503	2.491	2.479
G_{se}	2.761	2.746	2.732	2.717	2.702

4.3.2 VOLUMETRIC ANALYSIS AND MECHANICAL TEST OF THE MARSHALL SPECIMENS

The volumetric analysis includes calculation of Bulk Density, Percent Air voids, Percent Voids in Mineral Aggregates (VMA), Percent Voids Filled with Bitumen (VFB). The Mechanical test includes finding the Marshall Stability and Flow value of Marshall Specimens. At each binder content three specimens are made. The average bulk density of three specimens is found out in terms of gm/cc. The detailed bulk density calculations are shown in **ANNEXURE D**. Based on average bulk density, volumetric analysis is carried out and is shown in **ANNEXURE E**. Correction has to be made for non-standard specimen. So volume calculation for the same is shown in **ANNEXURE F**. Marshall Stability and Flow calculations for different type of gradations are shown in **ANNEXURE G**. Stability and Flow value are taken as average of three samples to find out Optimum Binder Content (OBC).

0% RAP CONTENT

It is similar to conventional DBM-2 mix. Here no RAP is added in the mix. The bulk specific gravity of the mix at 3.5% to 5.5% bitumen is determined, the results shows that the bulk specific gravity value varies from 2.43 to 2.52 gm/cc. Then the VMA varies from 13.09 to 14.18 for bitumen content 3.5% to 5.5%. The air voids keep on decreasing from 6.75% to 2.98% with the increase in bitumen content. Whereas voids filled with bitumen keep on increasing from 48.57% to 78.96%.



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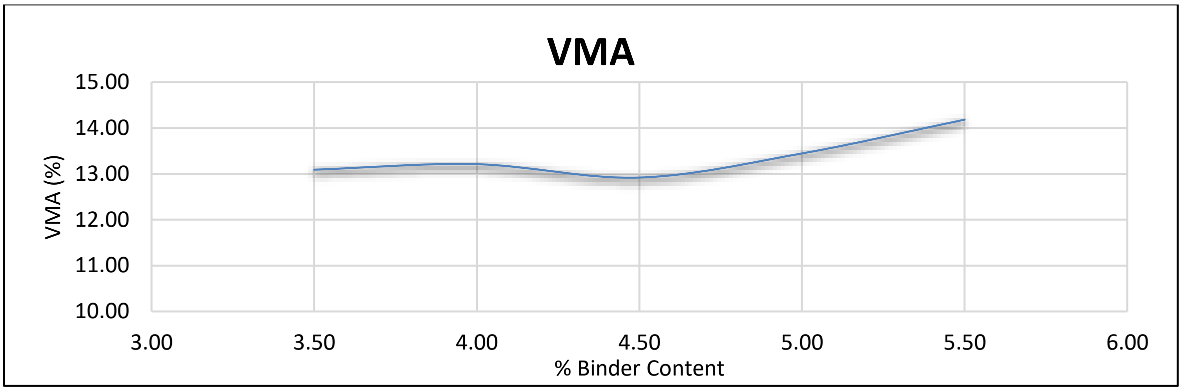

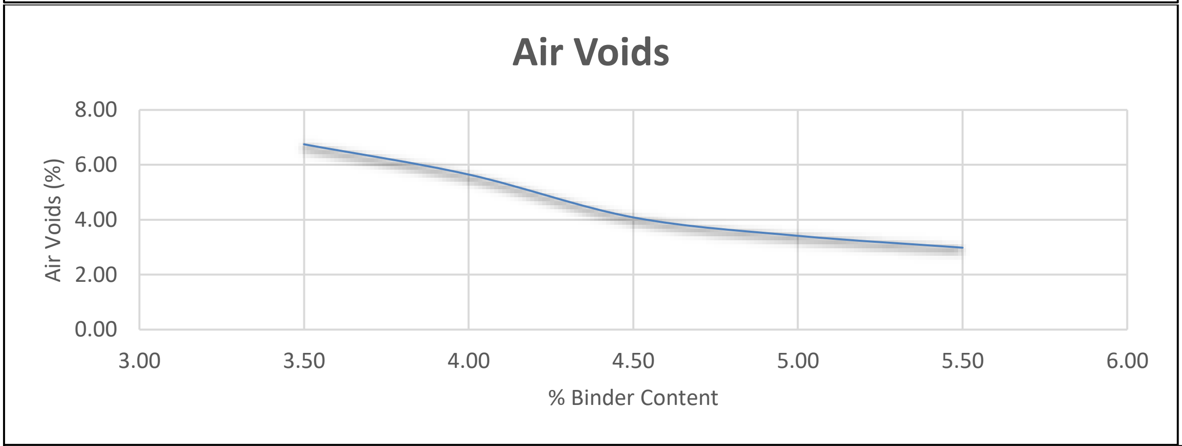

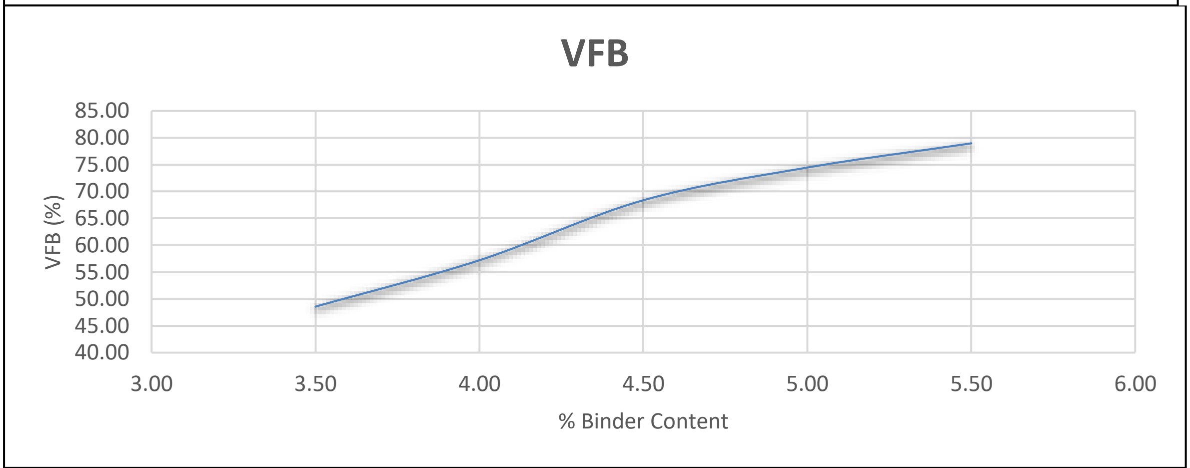

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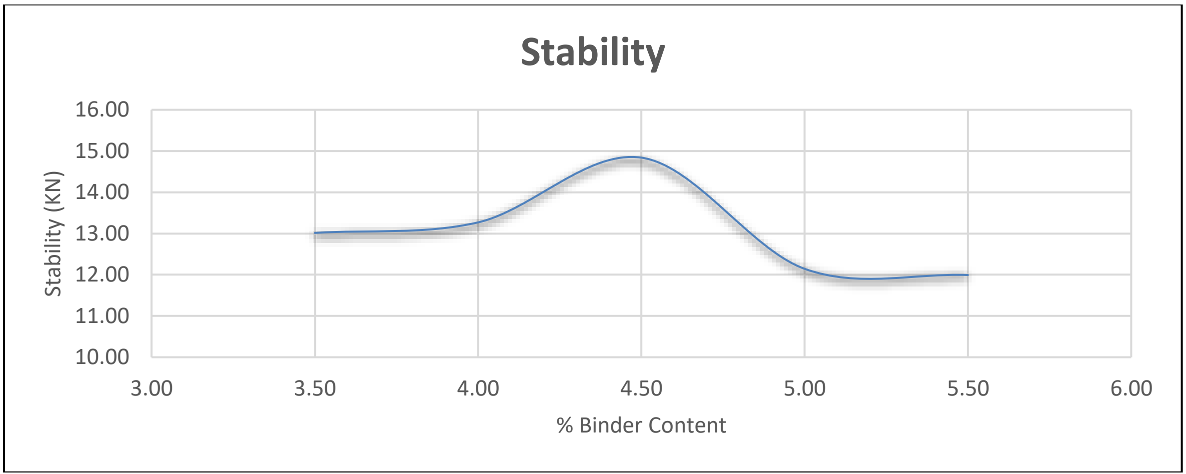

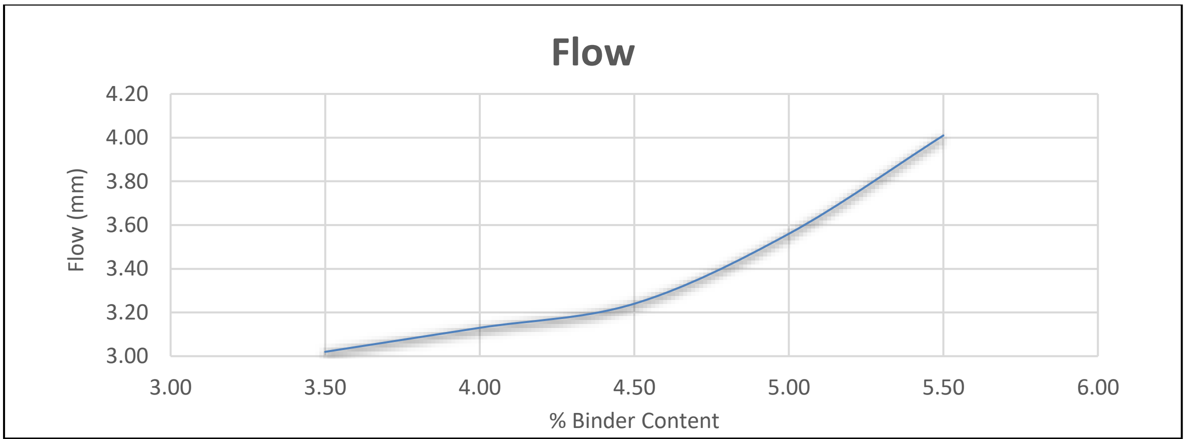

Figure 2 Volumetric and Mechanical Properties Mix with 0% RAP

5 CONCLUSIONS

Based on the detailed study carried out on effect of RAP on performance of bituminous mixes, the following conclusions are drawn:

1. Dense Bituminous Macadam prepared with addition of different percentage of RAP as mentioned in Table 3-9 satisfies the requirements of mix given in Table 3-7. Thus all Mixes with different RAP content are satisfy all necessary requirements as listed in Table 4.4.
2. It is found that Voids in Mineral Aggregates (VMA) and Voids Filled with Bitumen (VFB) increases with increase in RAP content, which further increases the OBC.
3. Looking to the values of retained stability and tensile strength ratio for all different percentage RAP used for present study, it is found that the Mix up to 30% RAP content has good resistance to damaging effect of water submergence conditions, whereas the Mix with 40% RAP content has very low resistance.
4. The results of dynamic creep test performed on mixes indicate that the Mix with 40% RAP content has highest resistance to rutting among all, whereas Mix with 0% RAP content has least resistance to rutting occurrence. The results also conclude that the increase in RAP content in Mix gives increasing resistance to permanent deformations.
5. Looking to the results the study concludes that the Mix up to 30% RAP content can perform well within the limited scope considered in this study.
6. Looking to the results of quantitative analysis it is found that the well performing mix at maximum RAP content (30%) can save 18.06% of virgin bitumen and 30.57% of virgin aggregate.

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