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Preparation of BC Mix using Waste Cooking Oil as Rejuvenator for RAP

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I. INTRODUCTION

A. General

Recycling of bituminous materials has generated considerable discussion and development during the last decades. Although it is not a new idea, recent studies appear to be in response to the need of many countries to reduce their dependency on imported crude oil and the derivative product known as bitumen. Many recent technologies introduce innovative methods for recycling of Reclaimed Asphalt Pavement (RAP). There are many fields of use for RAP from using it as backfill materials to implementation it within pavement superstructure courses. It is important to designate the most valuable field of recycling for RAP. Many studies have addressed many areas of utilization for RAP beside the optimum amount within the mentioned area. Worldwide in addition to science world, within the high petroleum prices period, private sector has developed many methods in order to use RAP with high possible amounts. Although private sector technologies are controlled and confirmed by authorities in accordance with specifications, these technologies are not accessible to the public due to know-how excuses. Bitumen is one of most important material used in highway industry.

It is used extensively in highway industry (110 million tons annually in the world). The ageing of bitumen in storing, transporting mixing and lying as well as in service life is serious problem posed by the use of bitumen in pavements. Main phenomena leading to ageing is the loss of volatiles and oxidation leading to increase in viscosity and stiffness as compared to fresh bitumen. The ageing of bitumen leads to pavement failure in the form of surface raveling and cracking especially reflective cracking these changes can lead to adhesion loss in the presence of moisture, and brittleness (Oxidation products have acidic characteristics and can be hydrolyzed). Ageing of bitumen leads to increased expenses in maintenance of bitumen pavements.

Therefore due to limited nature of bitumen resources, high cost and high demand, different agencies related to highways have introduced use of Recycled Asphalt Pavement (RAP) in Hot Mix Asphalt (HMA) as an environmentally friendly and cost effective measure. The successful application of waste cooking oil as rejuvenator leads to the theory of application waste cooking oil (WCO) as rejuvenator in bitumen. The aim of using Waste Cooking Oil as rejuvenator is to reduce the environmental impact of Waste Cooking Oil and the expense of highway construction by using RAP.

B. Objective and Scope

The objective of the research reported in this paper (a laboratory study) was to investigate the effects of waste cooking oil on the performance of HMA containing RAP. A base asphalt binder, VG-30 was blended with waste cooking oil obtained from a local auto repair shop at 0, 2, and 5% by weight of total asphalt in mix. An RAP aggregate was included into asphalt mixtures at 0, 25, and 40% by weight of aggregate. Both asphalt binder tests and mixture tests were conducted

Bitumen reacts with atmospheric oxygen which stiffens or hardens the bitumen. Atmospheric oxidation is the major factor responsible for the irreversible hardening of asphalts. The change in the amounts of fractional components of asphalt generally seen on oxidative aging is a movement of components from the more nonpolar to the more polar fractions. The saturate sand shows the least change on oxidation. The naphthenic aromatic and aromatic fractions showed slight and no reactivity, respectively. The polar aromatic fraction and the Knotnerus resin with asphaltene fractions, however, were highly reactive with oxygen Corbett's asphaltene fraction showed intermediate reactivity. Direct measurement of the formation of oxygen-containing functional groups by Petersen et al. ranks the relative reactivity with atmospheric oxygen of the saturate, aromatic, polar aromatic and asphaltene fractions as 1 : 7 : 32 : 40, respectively,

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Different colors of fresh and Waste Cooking oil

II. LITERATURE REVIEW

The construction of new highways or the improvement of the existing ones signifies, in most cases, the use of virgin materials (aggregates and bitumen).

This implies an extensive exploitation of quarries, originating a negative environmental impact. This is not the sole environment problem because it is usual to mill-up bitumen layers and place waste material in a landfill.

Recycling Hot Mix Asphalt (HMA) is the process in which reclaimed asphalt pavement (RAP) materials are combined with new materials (the virgin aggregates and asphalt binder) and a rejuvenating agent to produce HMA mixtures. Recycled HMA mixtures, properly designed, must have similar properties to those of conventional HMA, fulfilling the same technical prescriptions that are demanded for conventional ones.

To be able to use reclaimed asphalt successfully, it has to be treated for age hardening caused due to loss of volatiles and oxidation. For making aged bitumen as par with virgin bitumen, rejuvenators are used. Rejuvenators serve the following functions:

A. Restore maltene characterization.
B. Activate aged binder and not just softens or plasticize the binder.
C. Eliminate /reduce cracking and maintain/improve rut resistance.

It has been reported that although the amount of WCO available in the world is approximately 12 million tons per year, only a small amount of the used Engine oil is properly collected and recycled Major quantity of the used Engine oil is illegally dumped into landfills and rivers causing environmental pollution. Supervision of used Engine oil creates a significant challenge because of the dumping problems and possible pollution of the water and land resources. This study investigates the possibility of WCO as a rejuvenator for aged bitumen. The potential uses of waste oil as the rejuvenator were examined using the conventional bitumen test methods including penetration, softening point, Brookfield viscosity and chemical test.

There are many researches done on the subject. Few of them are listed below:

1) *Shen et al. (2007)* evaluated the utilization of rejuvenating agents on Superpave mixtures containing RAP. It is reported that the mechanical properties of mixtures involving RAP and the rejuvenating agent were improved. Additionally, more amount of RAP could be included within the Superpave mixtures by use of oily based rejuvenators.
2) *Asli et al. (2012)* investigated the feasibility of waste cooking oil as a rejuvenator in recycled mixtures. Authors indicated that the use of waste cooking oil rehabilitated the properties of aged bitumen. It is said that the rejuvenated bitumen behaved similar to virgin bitumen in terms of penetration and softening point. The researchers also claimed more amount of RAP within the recycled mixtures could be accessible by implementation of waste cooking oil.
3) *Yu et al. (2014)* implemented waste vegetable oil and an aromatic extract in order to rejuvenate the aged bitumen. The rejuvenator was used to enhance the rheological properties of the aged bitumen. It is reported that the use of these agents could modify the chemical structure of the aged bitumen and thus the mechanical behaviour of the mixtures. The researchers evaluated the samples at both macro- and micro-scales and found out that the characterization of rejuvenating impact on the aged bitumen could gain the advantage of improved recycling for bituminous materials.

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III. MATERIALS AND METHODOLOGY

A. General

To achieve the objectives of this experimental study, an extensive experimental program was planned, which included study of different physical properties of materials used in preparation of BC mix such as aggregates, bitumen, and RAP waste Cooking oil. In this study the requirement of fresh bitumen to be used in preparation of BC mix is found out and also performance tests were conducted to find out the performance of the prepared BC mix. This chapter outlines the experimental program planned in detail. The properties of the materials used for the manufacture of BC mix and tests performed on the prepared samples.

B. Test Program

Before starting the project following test program was prepared to specify the outline of project:

1) Before starting the preparation of BC mix, the physical properties of aggregates, bitumen and RAP were found out and tested whether these are within range as specified by MORTH.
2) Method of adding the Waste Cooking Oil as rejuvenator to RAP was found out so that it is successfully able to rejuvenate the bitumen of RAP.
3) Proper ratios of different materials were mixed so that the final gradation is within the gradation as specified by MORTH for BC mix.
4) BC mix was prepared using different waste Cooking oils as rejuvenators
5) Different tests were performed on the prepared moulds of BC mix.
6) Analyzing the test results whether Waste Cooking Oil can be used successfully as rejuvenator in preparation of BC mix.

C. Materials

The virgin bitumen with a VG-30 grade obtained from highway Construction site was used in this study. In order to characterize the properties of the virgin bitumen, conventional test such as: penetration test, softening point test, ductility test, etc. were performed. These tests were conducted in conformity with the relevant test methods that are presented in **Table 1**.

Table 1: Properties of Virgin Bitumen

Test	Specification Limits
Penetration (25^{O}c: 0.1mm)	50-70
Softening Point (^{O}c)	46-54
Specific Gravity	0.8-1.2
Ductility	Min. 75cm
Flash Point	230 (min)
RTFO (163^{O}C)	
Retained Penetration after RTFO (%)	50 (min)
Softening Point rise after RTFO (^{O}C)	7 (max)

The BC mixtures were produced using aggregates. Fine and coarse aggregates were procured from Jaipur quarry. In order to determine the properties of aggregate, sieve analysis, specific gravity, Los Angeles abrasion resistance test, fine aggregate angularity test and flat & elongated particles tests were conducted on the aggregates. The results are presented in **Table 2**. Grading of aggregate was chosen in conformity with the Type I Wearing Course of IRC Code Specifications.

Table 2: Properties of Aggregate

Test	Specification Limits
Impact Value	Max. 30%
Abrasion Value	Max. 30%
Specific Gravity	2.5 - 2.9
Flakiness and Elongation Value	Less Than 30%
Water Absorption (%)	0.1 to 2.0 %
Stripping Value	Not Exceeds 2%

Reclaimed type I wearing surface course subjected to traffic loads for a period of 12 to 13 years was used as RAP. 25 x 1000 gr. of batch samples were selected randomly using a random separator. The bitumen content and gradation of RAP materials were determined. The bitumen of the aged asphalt was extracted and distilled using a laboratory type extractor and distillatory. According to the test results, the bitumen content of the RAP was found 3.80%. As a final point, sieve analysis performed on the extracted aggregates. The results are given in Table 3. The conventional bitumen tests were conducted to the extracted bitumen of RAP. The results for the extracted bitumen are presented within Table 3.

Table 3: Sieve Analysis of RAP Aggregate

Sieve Size	Wt. Retained (gm)	Cumulative % Wt. Retained	% Passing
19	49.0	3.46	96.54
13.2	144.5	13.67	86.33
9.5	138.0	23.42	76.58
4.75	581.0	63.07	36.93
2.36	138.0	72.82	27.18
1.18	203.5	87.20	12.80
0.600	53.0	90.95	9.05
0.300	40.0	93.78	6.22
0.150	25.5	95.58	4.42
0.075	33.0	97.91	2.09
Pan	29.0	100	0.00

Table 4: Properties of RAP Bitumen

Test	Results
Penetration (25^{O}C, 0.1 mm)	38
Softening Point (^{O}C)	61
Viscosity (135^{O}C)-Pa.s	0.538

The Waste Cooking Oil that will be used as a rejuvenator was waste vegetable oil obtained from hotels in Sanagner area of Jaipur city.

IV. MATERIALS

Different properties of materials used were tested corresponding to relevant codes of practice. Different materials used in this study are coarse aggregates, fine aggregates, bitumen, RAP and Cooking oil as rejuvenators. Results of the tests conducted to determine physical properties of materials are reported and discussed in this section. The materials in general conformed to the specifications laid down in the MORTH. The materials used have the following characteristics:

A. *Gradation*

Table 5: Gradation of Material used in BC Mix

1) 20 mm 5000gm

Sieve size	Weight retained (gm)
26.5	0
19.0	508.5
13.2	2179
9.5	2005.5
4.75	271.0

2) 10 mm 5000gm

Sieve size	Weight retained (gm)
13.2	381.5
9.5	4020
4.75	431.0
2.36	140.5

3) Stone dust 1000 gm

Sieve size	Weight retained
4.75	18.0
2.36	120.0
1.18	263.0
0.600	112.0
0.300	127.0
0.150	122.5
0.075	103.0
Pan	125.5

4) RAP 1434 GM

Sieve size	Weight retained
26.5	0.0
19	49.0
13.2	144.5
9.5	138.0
4.75	581.0
2.36	138.0
1.18	203.5
0.600	53.0
0.300	40.0
0.15	25.5
0.075	33.0
Pan	29.0

B. Determination of Target Mixtures Contents

As the primary step; the optimum bitumen content of the control mixtures was determined as 3.80%. The Marshall Mix design criteria corresponding to 4% air void was taken into consideration in determination of optimum bitumen content for control mixtures. The amount of virgin bitumen and aggregates in target mixtures which depend on the percentage of RAP supposed to be added to the target mixture was calculated separately for different RAP contents. The amount of virgin bitumen to be added to the target mixture was calculated taking Eq. (1) into account

$$Pr = Pc - (Pa .Pp) \qquad \text{--Eq (1)}$$

where;

P_r: Percent of virgin bitumen to be added in the mix containing RAP

P_a: Percent of RAP bitumen in the mix

P_c: Percent of total bitumen in the mix

P_p: Percentage of RAP in the mix

The target bitumen amounts supposedto be added to the total mixture were calculated using Eq. (1). These values are given in Table 6. Following the calculation of virgin bitumen and aggregates amounts, mixing and compaction temperatures of rejuvenated and control specimens were calculated as per equi-viscous temperature charts. Temperature charts for the virgin and rejuvenated bitumen were plotted on graphs taking the viscosity values at 135 °C and 165 °C into consideration. Viscosity values were measured by means of a Brookfield viscometer.

Table 6: Bitumen Content to be added into the target mixes

RAP Content (%)	Pc (%)	Pa (%)	Pr (%)
10	4.76	4.30	4.33
20			3.9
30			3.47
40			3.04
50			2.61

Determining optimum rejuvenator content and rejuvenation process

Considering the conventional bitumen test results for virgin and RAP bitumen, the objective was defined as to rejuvenate RAP binder in order to obtain a binder similar to virgin binder in terms of specifications. A rejuvenating agent is supposed to enhance and cure the RAP binder in terms of physical and chemical properties. Several studies address the penetration value as an indicator for determining the optimum rejuvenator content.

Within the study, the optimum rejuvenator content was determined as the content required to achieve a rejuvenated binder having the same penetration value of the virgin binder. In other words, when the RAP binder is modified with that percentage of rejuvenator, the acquired binder should have the same penetration value of virgin binder. In order to perform this task, RAP binder was modified with various ratios of WCO and WVO. The range was chosen based on literature review and preliminary studies. Modification was processed for 5 minutes at 140°C using a laboratory blender atnormal shear rates (700 rpm) to obtain a homogenous rejuvenated binder. The optimum WCO content was determined as 5.4% by weight of RAP binder corresponding target penetration value of 67 and for WVO is 63, the optimum content was defined to be 5.5%.

Following the determination of optimum WCO and WVO contents; RAP mixtures were rejuvenated and stored. In order to perform the rejuvenation process, 4000 gr batches of RAP were heated to 140°C, the temperature at which the binder blending was processed. The bitumen content of RAP were calculated and taken into account in rejuvenation process. Within the process, the optimum amount of rejuvenating additive was gradually sprayed into the mixture during mixing inside a laboratory mixer for 5 minutes. The obtained rejuvenated RAP had a shining dark brown colour compared to non-rejuvenated RAP.

C. Impact Test

IS: 2386 (Part IV) – 1963

1) To determine the impact value of the road aggregates.

2) To assess their suitability in road construction on the basis of impact value.

Aggregate impact value is used to classify the stones in respect of their toughness property and it is also used to determine the effects of shock and impact on the aggregates.

The property of a material to resist impact is known as toughness. Due to movement of vehicles on the road the aggregates are subjected to impact resulting in their breaking down into smaller pieces.

The aggregates should therefore have sufficient toughness to resist their disintegration due to impact. This characteristic is measured by impact value test.

The aggregate impact value is a measure of resistance to sudden impact or shock, which may differ from its resistance to gradually applied compressive load.

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D. Los Angeles Abrasion Test

IS: 2386 (Part-IV)-1963

1) To determine the Los Angeles abrasion value of aggregates.
2) To find out the suitability of aggregates for its use in road construction.

Los Angeles abrasion test is commonly used to evaluate the hardness of the aggregates. The test has more acceptability because the resistance to abrasion and impact is determined simultaneously.

The Los Angeles test is a measure of degradation of mineral aggregates of standard gradings resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres. The Los Angeles (L.A.) abrasion test is a common test method used to indicate aggregate toughness and abrasion characteristics. Aggregate abrasion characteristics are important because the constituent aggregate in HMA must resist crushing, degradation and disintegration in order to produce a high quality HMA.

E. Flakiness And Elongation Index of Aggregates

IS: 2386 (Part I) – 1963

1) To determine the flakiness index and,
2) To determine the elongation index of given aggregates sample.
3) To assess suitability of aggregates for use in different types of road pavements.

The flakiness index of an aggregates is the percentage by weight of particles whose least dimension (thickness) is less than three-fifths (0.6) of their mean dimension. The test is not applicable to sizes smaller than 6.3 mm.

The elongation index of an aggregate is the percentage by weight of particles whose greatest dimension (Length) is greater than 1.8 times of their mean dimension .The elongation index is not applicable to sizes smaller than 6.3 mm.

F. Tests on RAP

1) *Bitumen Content:* Bitumen content of RAP was found out using benzene. Benzene acts as solvent for petroleum products thus dissolving bitumen coating on RAP. For extracting bitumen , first 500 gm of RAP taken in mould of bitumen extractor then 400 ml of benzene is added RAP and mixed with it properly . After mixing RAP and benzene mould is put in benzene extractor where benzene and bitumen solvent in extracted using centrifugal force by rotation of mould leaving behind aggregates. Earlier step is repeated as long as required thus making aggregates completely void of bitumen coating.

2) *Gradation:* Gradation of aggregates in RAP is done using aggregates left after performing bitumen extraction test using different sieves which are to be used in design mix.

G. Tests on Bitumen

1) Penetration Test of Bitumen(IS: 1203 – 1978)

a) To determine the Penetration value of the Bitumen.

b) To determine the suitability of bitumen for its use under different climatic condition and type of construction

This test determines the hardness or softness of bitumen by measuring the depth in millimeter to which a standard loaded needle will penetrate vertically in 5 seconds while the temperature of the bitumen sample is maintained at 25°C.

2) *Softening Point Test(IS: 1205-1978):* To determine the softening point of bitumen by ring & ball apparatus. Softening point is defined as the temperature at which a substance attains a particular degree of softening under specified conditions of test. Usually softening point for different grades of bitumen used for pavements varies from 35°C to 70°C.

3) Ductility Test(IS: 1208 – 1978)

a) To measure the ductility value of bitumen.

b) To determine the suitability of bitumen for its use in road construction.

Ductility is a measure of elasticity of adhesiveness of bitumen. It is expressed as the distance in centimeters to which a standard briquette of bitumen can be stretched before the thread breaks.

H. Testing of Prepared Sample

1) *Marshall Test*(IRC: 111-2009)

a) To determine the strength (Marshall Stability Value) and flexibility (flow value) for the given bitumen mixture.

b) To determine the density-voids analysis for the given bituminous mixture;

c) To determine the suitability of bituminous mixture to meet the specified criteria for the surface course.

Strength is measured in terms of the "Marshall's Stability" of the mix which is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60^0C.

The flexibility is measured in terms of the "Flow Value" which is measured by the change in diameter of the sample in the direction of load application between the start of loading and the time of maximum load. In this test an attempt is made to obtain optimum binder content for the aggregate mix type and traffic intensity.

Voids Filled with Bitumen

It is the percentage of VMA that is occupied by the effective bitumen.

$$VFB = \frac{Vb}{VMA} \times 100$$

V_b= Volume of bitumen

VMA= Voids in mineral aggregate

V. TEST RESULTS AND DISCUSSION

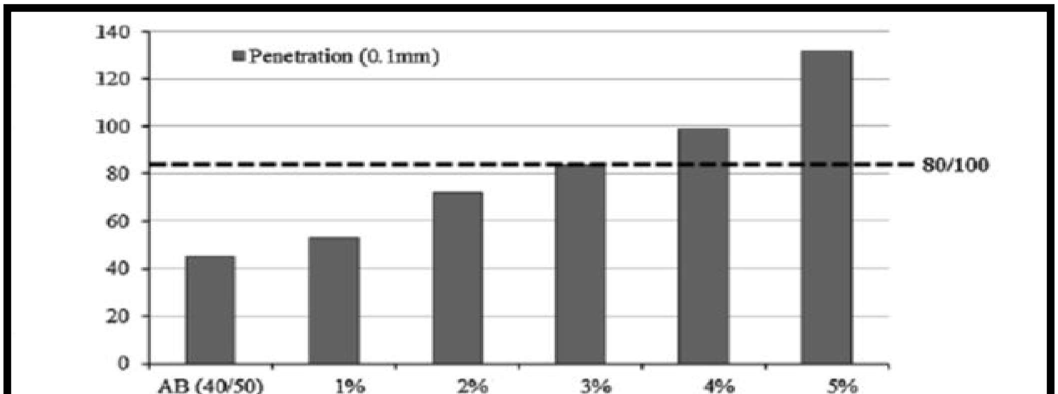
Table 7:- Physical properties of stone aggregates

Test description	Coarse aggregates	Fine aggregates	Standard values AS Per MoRTH
Impact value	16.54	-	<18
Water absorption	0.1		1.3
Aggregate crushing value (%)	17.53	-	<30
Combined Elongation index Flakiness index (%)	26.6	-	<30
Specific gravity	2.81	2.41	2.6-2.9
Los Angeles abrasion value (%)	21.8	-	<25

Table 8:- Properties of VG 30 bitumen

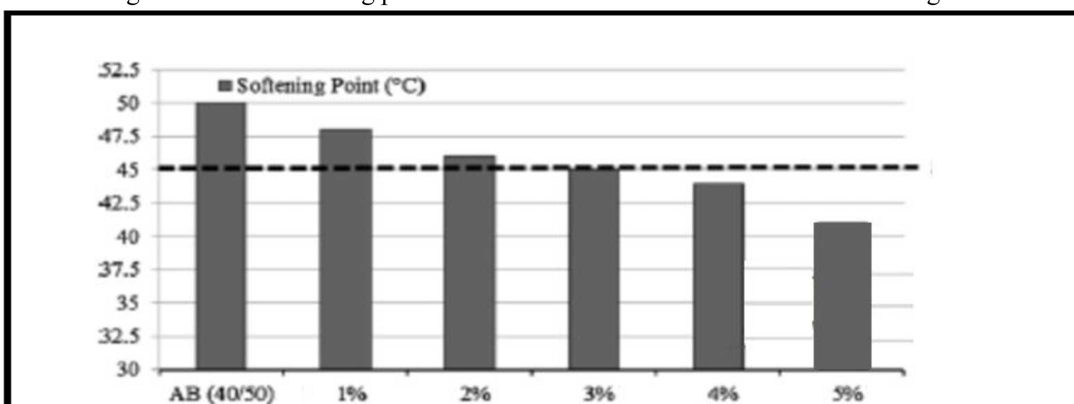
Test description	Standard values	Results
Ductility (cm)	>40	85
Penetration at 25 °C(1/10mm)	>45	65
Specific gravity	-	1.01
Softening point °C	47 °C	45

Aged Bitumen Penetration value Graphs with Different Values of Waste Cooking Oil



Penetration Value versus different Rejuvenated WEO Bitumen's (AB: Aged Bitumen).

Aged Bitumen Softening point value with Different Values of Waste Cooking Oil



Softening Point Value Versus different Rejuvenated WEO Bitumen's (AB: Aged Bitumen)

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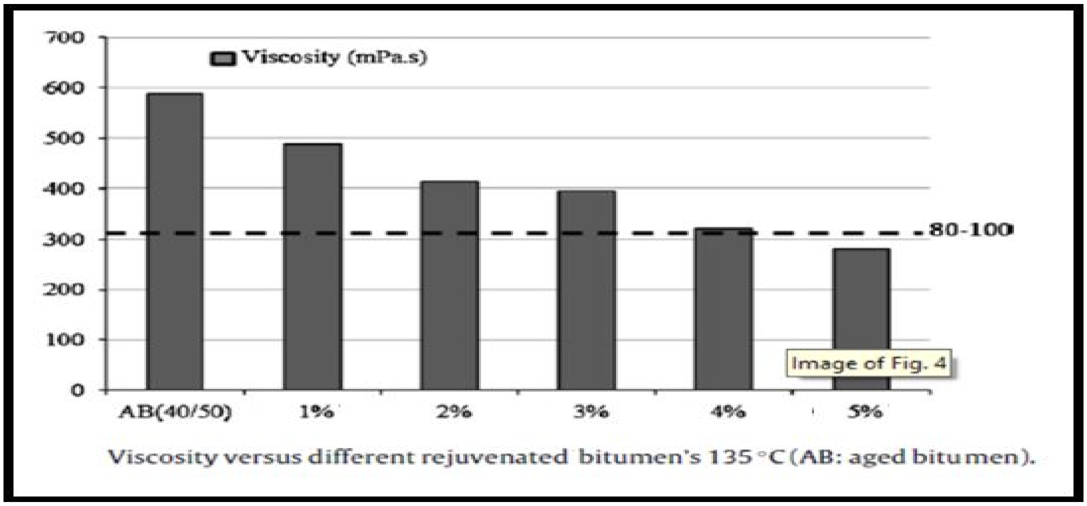
VISCOSITY value with Different Values of Waste Cooking Oil mix in Aged Bitumen



From These graphs we got optimum 3% Waste Cooking Oil used in Marshall Mix

Table 9: TEST RESULTS OF AGGREGATES ARE

Property tested	Test result	Max. permissible limit
Impact value	18.00%	27%
Los Angels abrasion value	21.52%	35%
Combined flakiness and elongation index	22.53%	35%

A. Bitumen Test Results

1) *Binder Test Results:* Results for rejuvenated binder with optimum WCO content are presented in Table 11. The test results represented that the oily based additives are capable of increasing penetration values of aged bitumen. Then again, by using these rejuvenators the softening point values can be lowered to the specification limits. Fig 3 represents the penetration values for various contents of WCO and WVO rejuvenators. The optimum additive content was derived from the chart choosing the content corresponding the same penetration value of the virgin binder. As seen on the Fig. 3, the penetration values track an increasing polynomial trend-line as rejuvenator content increases. It is possible to gain a desired penetration by adding adequate content of WCO and/or WVO to RAP binder. The results for WCO and WVO were similar to each other in terms of penetration. WVO represented slightly higher values than WCO in terms of penetration. This can be attributed to the viscosity values of two oily based rejuvenators. After modifying aged bitumen by rejuvenators, the softening point must be controlled as per specification limits. Volatilization of oily based rejuvenators during production phase is a concerned issue in using of rejuvenators. Both WCO and WVO have acceptable temperature resistance to volatilization. Some Past studyindicatedthat the heavy fuel oils are sensitive to volatilization and at high recycling temperature (over 180°C) disappear from the mixture and accordingly this causes to less RAP materials in total mixture. They suggested that vegetable oils are rich in unsaturated fatty acids and are similar to light oils resist better against volatilization. Although the results after RTFOT were with the specification limits, the results proved that the rejuvenated binders are more sensitive to short term aging than virgin binder. Furthermore, the viscosity values showed that the workability of rejuvenated RAP mixtures improved significantly. Mixing and compaction of rejuvenated mixtures were made with a regular effort. Softening point values of rejuvenated samples were more than softening point of virgin binder. Although these values are around the borderline value in terms of specifications, it can be concluded that the rejuvenated bitumen can endure higher temperatures during hot seasons. The rejuvenated binders behave similar to air-blown asphalts in this case.

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Table 10: Properties of Rejuvenated RAP binder modified with optimum WCO Content

Test	Results	
	WCO	**WVO**
Penetration (25°: 0.1mm)	68	70
Softening Point (°c)	56	58
Viscosity (135°c)	0.412	0.400

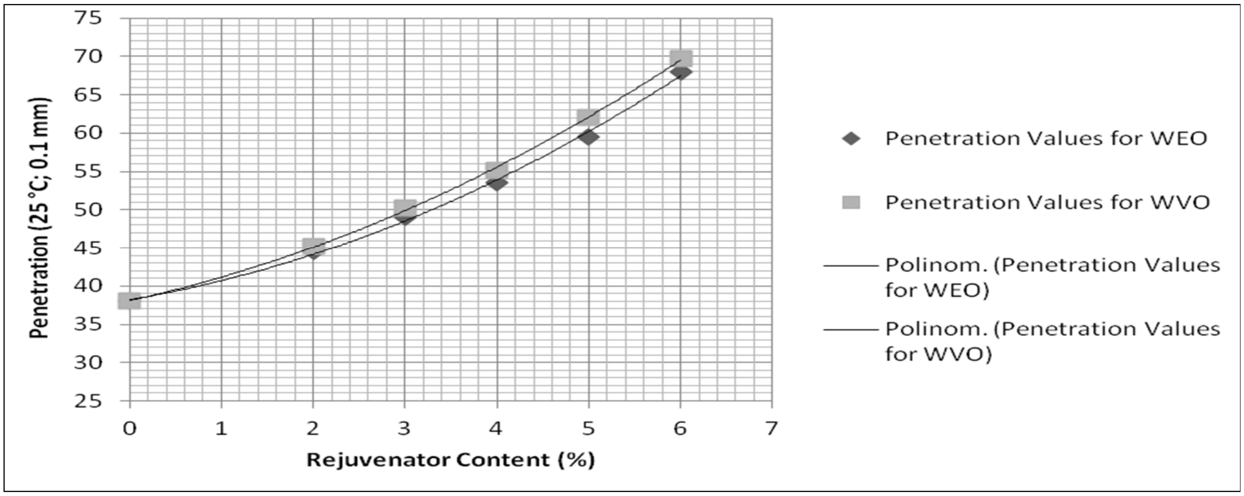

Fig. 1: Penetration values corresponding various contents of WCO and WVO

2) *Fresh Bitumen Test Result:*

PROPERTIES	RESULT	Method of testing
Penetration test	67	IS 1203-1978
Softening point	58	IS 1205-1978

B. RAP Test Results

S.no	Type of Material tested	Wt. before extraction (gms) (A)	Wt. After Extraction (B)	Difference (A-B)	% of Bitumen in Mix
1	RAP	500	480.5	19.5	3.9
2	RAP	500	481	19	3.8
3	RAP	500	480	20	4
4	RAP	500	482	18	3.6
5	RAP	500	481.5	18.5	3.7

Bitumen content in RAP = 3.80 %

C. *Design Gradation*

Sieve size in mm	19 mm		10 mm		RAP		6mm		Stone dust		filler	Comb. Grading	Mid-Range	MORTH specifications
	% pass	Trial	% pass	Trial	% pass	Trial	% pass	Trial	% pass	Trial				
		30%		0%		48%		0%		20%	2%	100%		
19	92.41	27.72	100	0	96.54	46.34	100	0	100	20	2	96	95	90-100
13.2	49.39	14.82	99.83	0.00	86.33	41.44	100	0	100	20	2	78	69	59-79
9.5	9.55	2.86	89.39	0.00	76.58	36.76	99.25	0.00	100	20	2	62	62	52-72

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Sieve size in mm	19 mm		10 mm		RAP		6mm		Stone dust		filler	Comb. Grading	Mid-Range	MORTH specifications
	% pass	Trial	% pass	Trial	% pass	Trial	% pass	Trial	% pass	Trial				
4.75	0.00	0	8.26	0.00	36.93	17.73	62.34	0.00	98.18	19.64	2	39	45	35-55
2.36	0	0	0.00	0	27.18	13.05	36.57	0.00	86.08	17.22	2	32	36	28-44
1.18	0	0	0	0	12.8	6.14	3.33	0.00	59.54	11.91	2	20	27	20-34
0.600	0	0	0	0	9.05	4.34	0.90	0.00	48.24	9.65	2	16	21	15-27
0.300	0	0	0	0	6.22	2.99	0.60	0.00	35.42	7.08	2	12	15	10-20
0.150	0	0	0	0	4.42	2.12	0.00	0	23.06	4.61	2	9	9	5-13
0.075	0	0	0	0	2.09	1.00	0	0	12.66	2.53	2	6	5	2-8

D. Marshall Test Results

As mentioned before, the highest RAP contents were determined for mixture containing non-rejuvenated and rejuvenated RAP in order to compare the highest potential of RAP to be employed within a type I wearing course.

Marshall Stability and flow results

Volumetric analysis together with Marshall Stability and flow values were base criteria in selection of maximum possible RAP content for both mixtures involving non-rejuvenated and rejuvenated RAP. Results for air void contents, stabilities and flow rates are respectively presented in Fig. 4 to Fig. 6 for WCO and WVO rejuvenated specimens as well as control specimens.

As can be seen in the Fig. 4, all mixtures containing rejuvenated RAP could meet volumetric criteria in terms of air voids since mixtures containing non-rejuvenated RAP fail to satisfy desired air voids content for mixtures containing more than 40% of non-rejuvenated RAP. The reason that volumetric characteristic of rejuvenated RAP containing mixtures remained within the desired contents is attributed to lower viscosity values of rejuvenated RAP binder and hence improved workability. At standard mixing and compaction temperatures, it is more convenient to process WCO and WVO rejuvenated RAP mixtures than non-rejuvenated RAP mixtures. Vegetable based oil performed better than cooking oil in terms of softening the stiff RAP materials. This is in parallel with the result of penetration test. This can be attributed to higher resistance of vegetable based oils to volatilization during production (mixing & compaction) phase at high temperatures.

When Fig. 5 is analyzed, it is seen that all stability values are over specification limit. This result is expected since the bitumen within RAP is considered as an aged binder and thus the mixtures containing RAP are stiffer than virgin bituminous mixtures hence these mixtures recorded high stabilities. In fact, the most concerned issue for RAP recycling technologies is considered as durability rather than stability. Therefore, volumetric characteristics and flow rates (somehow, as an indicator of flexibility) are more determinative for maximum possible RAP content than stability values.

When evaluating flow rates, it is understood that this criteria is determinative for both non-rejuvenated and rejuvenated RAP involving mixtures. It is seen that, mixtures containing over 20% of RAP almost fail to meet the flow rate criteria since Waste Oil rejuvenated mixtures performed better in terms of flow. Flow rates however, has been decisive in determination of maximum possible amount of rejuvenated RAP within type I wearing course as per IRC Code specifications. In this sense, 50% of rejuvenated (WCO modified) RAP can be employed within type I wearing course can be implemented. It is obvious that the amount of maximum RAP which can be implemented without failing to meet all IRC criteria increases substantially by rejuvenation process with these rejuvenating oils.

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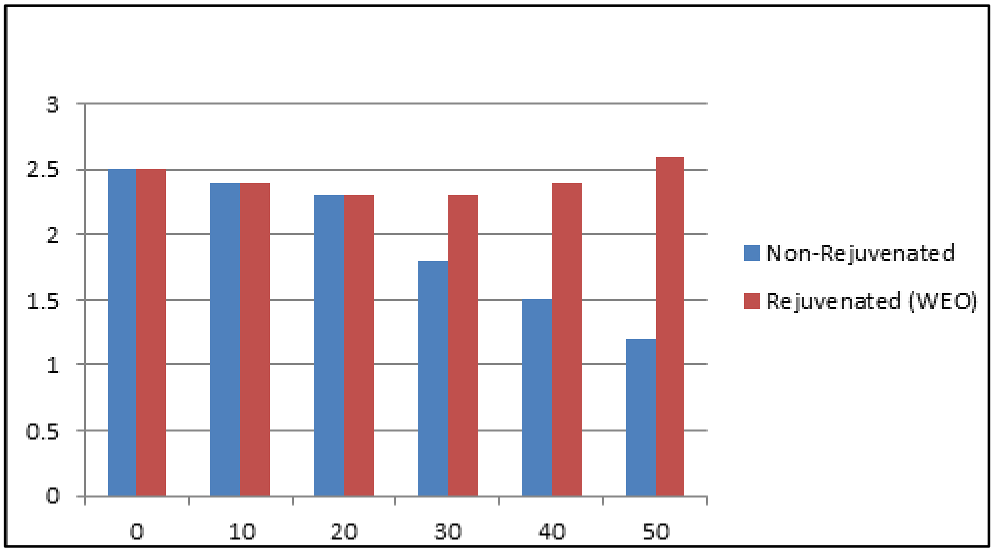

For Cooking Oil (Marshal Values):

S. No.	Binder Content	Weights (grams)			Volume, cc	G_{mb}	Gmm	% air voids	% VMA	% VFB	Stability	Flow Value, mm	Stability			Vb	VMA	VFB
		In Air	In Water	SSD in Air									Observed stability	Volume Correction factor	corrected Stability in kg			
1	**4.5**	1095.0	649.5	0.0	445.50	2.458	2.547	3.496	14.45	75.80	5.300	2.0	1462.8	1.32	1930.90	10.95	14.45	75.80
2	**4.5**	1103.5	651.5	0.0	452.00	2.441	2.547	4.145	15.02	72.41	5.600	2.6	1545.6	1.19	1839.26	10.88	15.02	72.41
3	**5.0**	1121.0	659.0	0.0	462.00	2.426	2.529	4.042	16.05	74.82	7.200	4.1	1987.2	1.25	2484.00	12.01	16.05	74.82
4	**5.0**	1127.0	663.5	0.0	463.50	2.431	2.529	3.841	15.88	75.81	7.800	4.5	2152.8	1.25	2691.00	12.04	15.88	75.81
5	**5.5**	1145.0	668.0	0.0	477.00	2.400	2.511	4.394	17.47	74.84	4.600	4.7	1269.6	1.25	1587.00	13.07	17.47	74.84
6	**5.5**	1155.0	675.5	0.0	479.50	2.409	2.511	4.061	17.18	76.36	5.500	4.3	1518.0	1.32	2003.76	13.12	17.18	76.36
7	**6.0**	1120.0	655.0	0.0	465.00	2.409	2.493	3.395	17.70	80.82	3.400	5.0	938.4	1.25	1173.00	14.31	17.70	80.82
8	**6.0**	1148.5	673.0	0.0	475.50	2.415	2.493	3.124	17.47	82.12	3.700	4.0	1021.2	1.14	1164.17	14.35	17.47	82.12
9	**6.5**	1157.0	672.0	0.0	485.00	2.386	2.476	3.659	19.01	80.75	3.000	4.5	828.0	1.14	943.92	15.35	19.01	80.75
10	**6.5**	1124.0	655.0	0.0	469.00	2.397	2.476	3.214	18.64	82.75	3.200	5.5	883.2	1.19	1051.01	15.42	18.64	82.75

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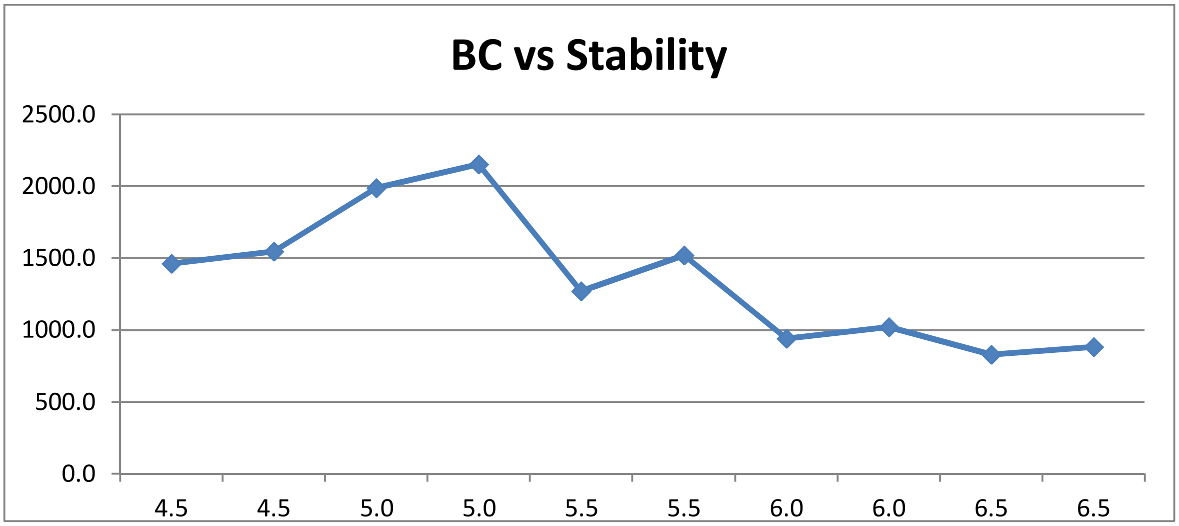
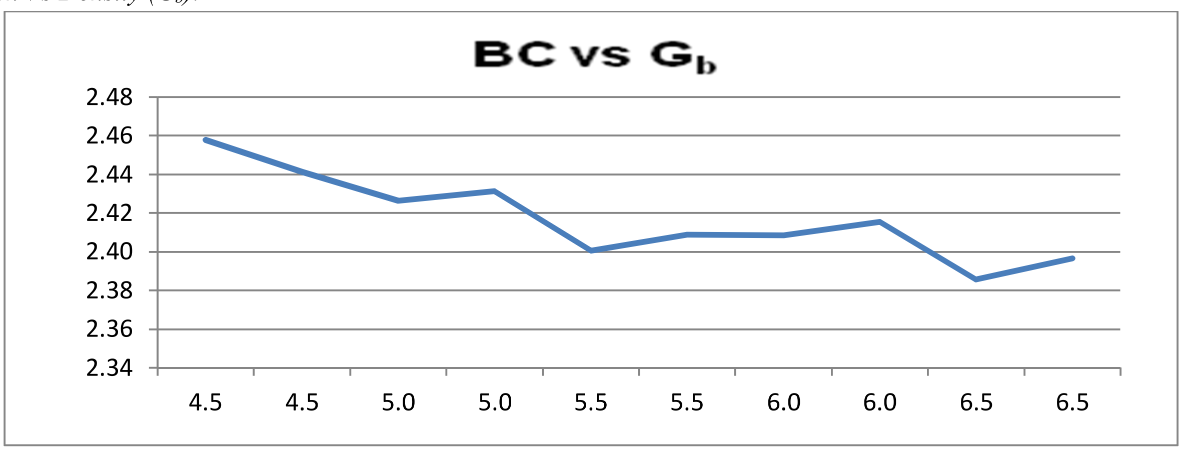
E. Graphs

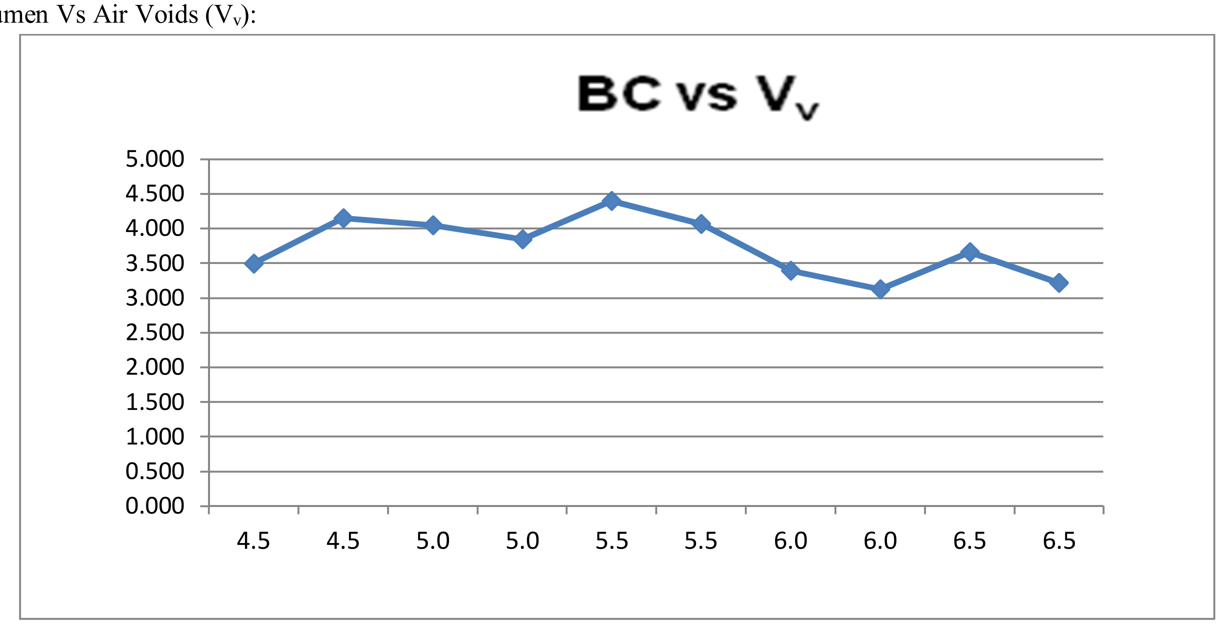
1) Bitumen Vs Stability:



2) Bitumen Vs Density (G_b):



3) Bitumen Vs Air Voids (V_v):



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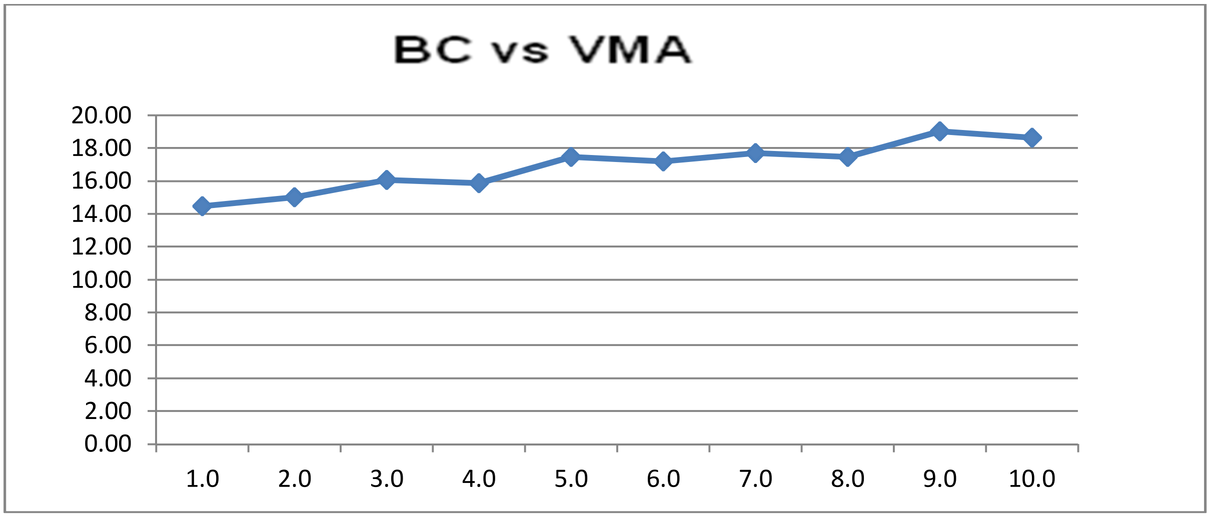
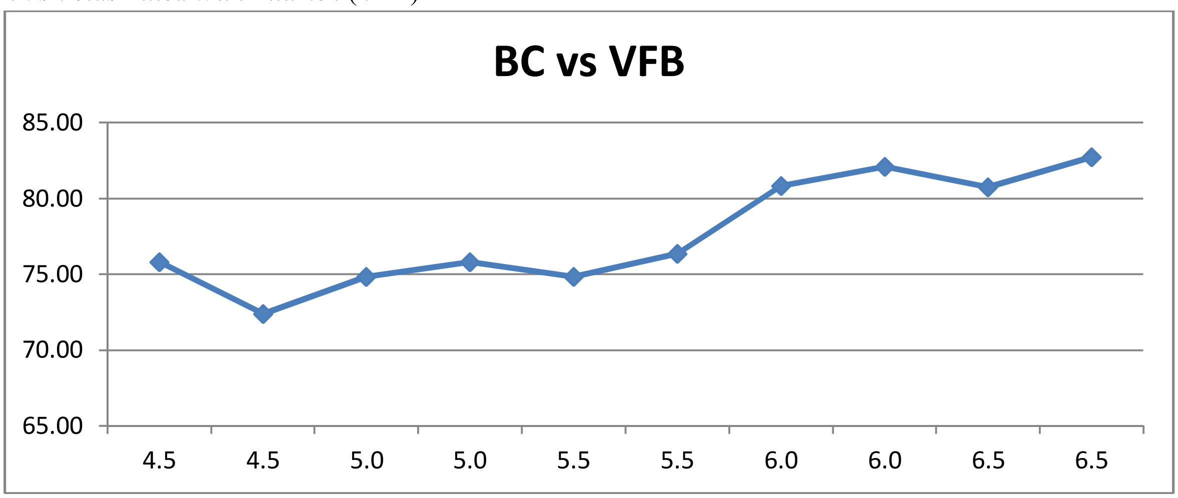
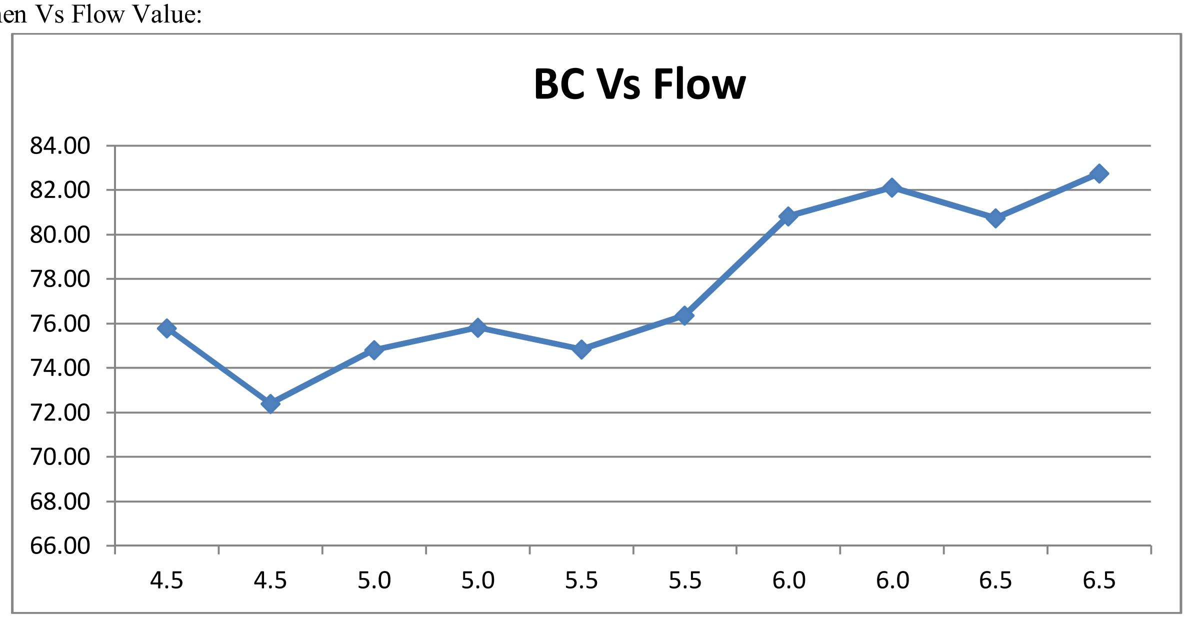
4) Bitumen Vs Voids In Mineral Aggregate (VMA):



5) Bitumen Vs Voids Filled With Bitumen (VFA)



6) Bitumen Vs Flow Value:



Optimum binder content = 5.5%
Virgin bitumen to be added = 5.5-1.82 = 3.68%

VI. FUTURE SCOPE

A. Physical properties of BC can be tested with respect to following tests :
Resilient modulus
Dynamic Creep
Rutting characteristics
Wheel tracking tests

B. Different types of mixes can be prepared instead of BC and suitability of Waste Cooking Oil as rejuvenator can be found out for different mixes.

VII. SUMMARY AND CONCLUSIONS

A laboratory study has been conducted in which the effects of waste automobile cooking oil on performance of asphalt mixtures containing reclaimed asphalt pavement (RAP) were investigated.VG-30 was employed as virgin binder and waste cooking oilwas collected from auto repair shop. The rheological and fatigue properties of asphalt binder blended with extracted RAP binder were characterized by E* master curve as well as linear amplitude sweep test. The asphalt mixture properties investigated included Volumetric parameters, resilient modulus, indirect tensile strength,dissipated creep strain energy at failure, fatigue life, and rut resistance. Based on the results from the research reported in this paper,the following conclusions can be summarized:

A. The performance of HMA with RAP is partially improved by the incorporation of Waste Cooking Oil in that the stiff component in aged asphalt in RAP could be offset by the oil. However, the amount of waste oil should be limited due to potential negativeeffects.
B. The inconsistency of binder tests and mixture tests may be the evidence of incomplete blending between RAP binder and virgin binder. The Waste Cooking Oil seems to improve the blending efficiency.
C. The volumetric analysis of asphalt mixture indicated that the incorporation of waste oil would result in an increase in VMA and a decrease in VFA. This means the inclusion of waste oil will result in lower optimum asphalt content and improve the workability of asphalt mixture.
D. The inclusion of waste oil softened the aged binder in RAP,which resulted in a decrease in IDT strength, increase in failure strain, and a decrease in resilient modulus of asphalt mixtures.The inclusion of waste oil did not increase $DCSE_f$ (dissipated creep strain energy). It is unlikely that adding waste oil would improve the crack initiation resistance of HMA with RAP.
E. Beam fatigue test indicated the inclusion of waste oil made limited improvements on fatigue resistance of HMA with RAP.
F. The increase of rutting resistance gained from the incorporation of RAP will eventually be compromised if enough waste oil were included.

VIII. RECOMMENDATIONS

This paper provides the preliminary results of the influence of Waste Cooking Oil on HMA containing RAP. Implementing WCO as a rejuvenator makes it possible to involve high amounts of RAP within HMA wearing courses. By rejuvenation technology up to 70% of RAP can be utilized without undesirable effects within surface courses. Rejuvenated mixtures are convenient to process in terms of mixing and compaction. WCO helps compaction fully done at standard HMA application temperature ranges. Investigations present that rejuvenated RAP mixtures are less brittle and more durable than non-rejuvenated RAP mixtures. Aging index of rejuvenated mixes are improved compared to non-rejuvenated mixes. It is recommended to evaluate mechanical properties of rejuvenated RAP mixtures in accordance with Super-pave criteria. Mixtures should be prepared by means of a gyratory compactor and evaluated for volumetric analysis.
Supplementary performance based experiments should be conducted. For RAP mixture tests, rutting and fatigue performance evaluation are recommended. It is also recommended that the comparative evaluation of HMA with RAP in the presence of rejuvenating agent and Waste Cooking Oil be studied. The results of a comparative study may provide information on whether Waste Cooking Oil functions similar to rejuvenating agent, which will be a supportive conclusion when one determines whether the Waste Cooking Oil can partially replace the rejuvenating agent in mix design.