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Laboratory Evaluation of Warm Mix Asphalt

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ABSTRACT

Over the last thirty years, road traffic has luxuriate significantly and loading is progressively getting cruddy due to the introduction of newer and ancillary big- wheel trucks with heavier and wider bodies in India. This study emphasizes on the mix design considerations. In this study, bituminous concrete grade-1 (BC-1) and Zycotherm additive on the warm mix asphalt paving mix is used to achieve sufficient stability, durability and to satisfy requirements. It is about the effect of Zycotherm additives on the Marshall Properties, Indirect tensile strength, Tensile strength ratio and retained stability test of warm mix asphalt. The specification such as Bulk density, Volume of air voids, Voids in Mineral Aggregates, Voids Filled with Bitumen, Stability and Flow, Indirect Tensile Strength, Tensile Strength Ratio and Retained Stability are determined. It is taken up with the objectives of to know the effect of Zycotherm on the properties of bituminous mix. The different percentage of Zycotherm additives are added in bitumen and bituminous mix, and tested their viscosity test, penetration values, softening points, ductility test at low temperatures are determined and an attempt is made to compare the Marshall properties of WMA produced with the chemical additive, Zycotherm and HMA for Bituminous Concrete (BC) Grade 1. The results of this study showed that the emissions are significantly reduced during the production and placement of WMA mixtures as compared to the control HMA mixture. The modified bitumen for warm mix asphalt indicated high consistency and lower softening point than ordinary bitumen. Warm mix asphalt mixtures also showed better results in term of strength, stiffness and lower rate of permanent deformation.

Keywords*: *Indirect Tensile Strength, Retained Stability, Warm Mix Asphalt, Zycotherm Warm Mix Additive.

I. INTRODUCTION

1.1 General

The asphalt industry all the time looks for a well-organized way to save energy and reducing the emissions. Rising energy cost and increased environmental awareness due to HMA (Hot Mix Asphalt), Asphalt industry have brought attention to the potential benefits of Warm Mix Asphalt (WMA) binders. WMA is a fast emerging new technology with potential of revolutionizing the production of asphalt mix. WMA technology may permit the mixing, and compaction of asphalt at 30°C to 40°C lower temperatures compared to HMA. WMA is produced by incorporating additives into asphalt mixtures to let the production and placement of the mix at temperatures well below the temperatures of conventional HMA.

1.2 Overview of Warm Mix Asphalt (WMA)

It is the generic term for a variety of technologies that allow producers of Hot Mix Asphalt (HMA) pavement material to lower temperatures at which the material is mixed and placed on the road. It is a proven a technology that can Reduce paving costs , Extend the paving season , Improve asphalt compaction , Allow asphalt mix to be

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hauled longer distances, Improve working conditions by reducing exposure to fuel emissions, fumes, and odors.

As per the guideline given IRC: SP: 101-2014, the basic principle of this technology is that by adding certain additives at the final stages of the mix production, the coating of the aggregates by the binder is greatly enhanced and can be achieved at a considerably less temperature (typically 30°C less) compared to the hot mix process wherein bitumen is heated to a sufficiently high temperature to make it fluid enough to surround the aggregates and coat their surfaces.

1.3 Why to Use WMA

The temperatures in cold republics are very low and it is challenging for them to lay the roads in that temperatures. So they found a new technology for laying the roads at that temperatures. This innovation creates not only the temperature variance but also evenness to the roads. This creates good looking when compared to the normal asphalt roads.

II. OBJECTIVES

- It is aimed to propose the optimum dosage of Zycotherm based on laboratory performance evaluation of bitumen and bituminous mix at different temperature.
- To Compare WMA & HMA with or without adding the addmixture.

III. METHODOLOGY

In this study, bituminous concrete mix has been designed for 19 mm nominal size of aggregate. The aggregate used in the study is crusher aggregate and VG30 (60/70) grade of Bitumen to check the suitability of aggregates and bitumen. Firstly, Laboratory testing has been carried out to find the physical properties of aggregates by conducting tests like aggregate impact value test, crushing value test, Los Angeles abrasion 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 Viscosity test at 60^{0}C, Penetration test at 25 °C, Softening Point test, Ductility test at 27 °C etc. to check the suitability as per IS:73-2013 for both virgin bitumen and modified bitumen (Zycotherm additives). Thereafter Marshall Mix design method is adopted for HMA and WMA with different percentage of additives to determine the Optimum bitumen content of bituminous mix at 130^{0}C and 115^{0}C. After determining the OBC, Marshall Samples are prepared at OBC (130^{0}C and 115^{0}C) to check the volumetric properties, Marshall Stability and Flow value as per MORTH 2013 Clause 505.3.1 Specifications. Performance of WMA for BC-1 grade has been evaluated by conducting various tests on Marshall Samples including Indirect Tensile Strength test, Tensile Strength Ratio and Retained Stability test.

IV. LABORATORY EVALUATION

4.1 Aggregate characterization

The aggregates used in this study are crusher aggregates. The sizes of aggregate used are 20 mm, 10mm and Stone Dust (SD) as per recommendation of MORTH Section 509 for nominal size of aggregate 19 mm.

IJARSE
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Table 1: Physical properties of aggregate

Sr. No.	Physical properties of aggregate	Test value
1	Impact Value	19.08%
2	Crushing Value	19.57%
3	Abrasion Value	21.74%
4	Flakiness Index	26.92%
5	Elongation Index	26.92%
6	Water Absorption	0.94%
7	Specific Gravity	2.83

4.2 Methods for Finding Properties of Bitumen

4.2.1. Determination of Penetration Value

It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. BIS had standardized the equipment and test procedure. The penetrometer consists of a needle assembly with a total weight of 100g and a device for releasing and locking in any position. The bitumen is softened to a pouring consistency, stirred thoroughly and poured at a depth at least 15 mm in excess of the expected penetration. The test should be conducted at a specified temperature of 25°C. It may be noted that penetration value is largely influenced by any inaccuracy with regards to pouring temperature, size of the needle, weight placed on the needle and the test temperature.

4.2.2 Ductility test

Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking. Dimension of the briquette thus formed is exactly 1 cm square. The bitumen sample is heated and poured in the mould assembly placed on a plate. These samples with moulds are cooled in the air and then in water bath at 27°C temperature. The excess bitumen is cut and the surface is leveled using a hot knife. Then the mould with assembly containing sample is kept in water bath of the ductility machine for about 90 minutes. The sides of the moulds are removed, the clips are hooked on the machine and the machine is operated. The distance up to the point of breaking of thread is the ductility value which is reported in cm. The ductility value gets affected by factors such as pouring temperature, test temperature, rate of pulling etc.

4.2.3 Softening point test

Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. The test is conducted by using Ring and Ball apparatus. A brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature. A steel ball is placed upon the bitumen sample and the liquid medium is heated at a rate of 5°C per minute. Temperature is noted when the softened bitumen touches the metal plate.

4.2.4 Flash and fire point test

At high temperatures depending upon the grades of bitumen materials leave out volatiles. And these volatiles catch fire which is very hazardous and therefore it is essential to qualify this temperature for each bitumen grade. The flash point as the temperature at which the vapour of bitumen momentarily catches fire in the form of flash under specified test conditions. The fire point is defined as the lowest temperature under specified test conditions at which the bituminous material gets ignited and burns.

IJARSE
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ISSN (P) 2319 - 8346

4.2.5 Mixing of Zycotherm with Bitumen

The adopted mixing temperatures for HMA was 130°C and 115°C and the mixing temperatures for WMA was 130°C and 115°C, with an additive dosage rate of 0.1%, 0.2%, 0.3% by weight of the binder. The optimum binder content was to be found out individually for the mixture for different mixing temperatures and additive dosage rate.

V. TENSILE STRENGTH RATIO (TSR) TEST.

Tensile strength ratio is determined according to AASHTO T283, which is the ratio of wet tensile strength to dry tensile strength of Marshall Specimens. For conditioning of dry samples, Marshall Samples are soaked in water for 30 minutes at 25°C or are put in air chamber for 4 hours at 25°C. For the conditioning of wet samples, the samples are placed in water bath for 24 hours at 60°C and then placed in water bath at 25 °C for 2 hours. Then using Marshall Stability apparatus, Marshall Samples are loaded with compressive load and load at which specimen fails is measured.

The Tensile Strength Ratio (TSR) is calculated as per below equation

TSR = (Stw/Std)*100

Where,

TSR = tensile strength ratio

Stw = average tensile strength of the moisture conditioned subset

Std= average tensile strength of the dry subset

VI. RETAINED MARSHALL STABILITY TEST

This test is conducted as per ASTM D 1075 specifications. Marshall Stability is determined using the standard procedure i.e. after conditioning the one set of specimen at 60^0 C for 30-40 minutes. Another set of specimen is kept for conditioning in water bath maintained at 60°C for 24 hours, and thereafter tested for Marshall Stability value. The results are reported as the percentage ratio of soak stability to standard stability. This test is conducted to know that the mix is susceptible to moisture damage or not. The minimum value of Retained Stability of bituminous mixes is 75% specified by the MORTH section 500 clause 509.

Table 2: Physical properties of Bitumen and Modified Bitumen

Sr. No.	Property	Test Method	Test Results	Requirements as per IS 73:2013 for (Minimum)
1	Absolute viscosity@60°C, Poises	IS 1206 (Part 2)-1978	2569.67	2400
2	Penetration,25°C,100 g,5 s, 0.1mm	IS 1203-1978	52	45
3	Softening point (R&B),°C	IS 1205-1978	50	47
4	Ductility Test, 25°C, cm	IS 1208-1978	100	75
5	Absolute viscosity@60°C, Poises	IS 1206 (Part 2)-1978	2569.67	2400
6	Penetration,25°C,100g, 5 s, 0.1mm	IS 1203-1978	52	45

IJARSE
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Property	Specified Value
Compaction level	75 blows on either side
Stability, (kN) at 60°C	9 minimum
Flow (mm)	2-4
Marshall Quotient (Stability/Flow)	2-5
Air Voids (%)	3-5
Voids in mineral Aggregate (VMA) (%)	12 minimum
Voids Filled with Bitumen (VFB) (%)	65 – 75
Coating of aggregate particle, minimum	95%
Tensile Strength ratio, minimum	80%
Retained Stability	75 minimum

Table 3 Design requirements for Bituminous Mixes as per MORTH(2013)

Bitumen Test Results					
Bitumen Test	Test Results				Requirement as per IS 73-2013 (Minimum)
	VG-30	VG-30+Zycotherm mix			
	0%	0.10%	0.20%	0.30%	
Penetration at 25°C	52	52	53	53	45
Softening point (Ring & Ball), °C	50	49	49	48	47
Absolute viscosity@ 60°C, Poises	2569.67	2540	2533	2521.33	2400
Ductility @25 °C ,cm	100+	100+	100+	100+	75

Table 4 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
9.5	14.0	15.0	16.0
12.5	13.0	14.0	15.0
19.0	12.0	13.0	14.0
25.0	11.0	12.0	13.0
37.5	10.0	11.0	12.0

VII. RESULTS AND DISCUSSION

The volumetric analysis includes calculation of Bulk density (Gm); Percent Air voids (Vv), Percent Voids in Mineral Aggregates (VMA), and Percent Voids Filled with Bitumen (VFB). The Mechanical test includes finding the Marshall Stability and Flow value of Marshall Specimens. This has been carried out for HMA and WMA at 130^{0}C and 115^{0}C for all different additives dosage of Zycotherm and at different binder contents. 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 below. Based on average bulk density, volumetric analysis is carried out. Correction has to be made for non-standard specimen. So volume calculation for the same is calculated and Marshall

Stability, Flow calculations for different additive dosage are calculated. Stability and Flow value are taken as average of three samples to find out Optimum Binder Content (OBC).

The Following figure shows the result of Marshall Stability at 130^{0}C &115^{0}C for HMA (0%) and WMA (0.1%, 0.2%, and 0.3%) with different additives. The test result is increases first up to 5.5% binder content and then decreases. The stability of WMA is much better than the stability of HMA , in that the stability of 0.1% additive is good as compare to other additives.

A) Stability at 130^{0}C & 115^{0}C.

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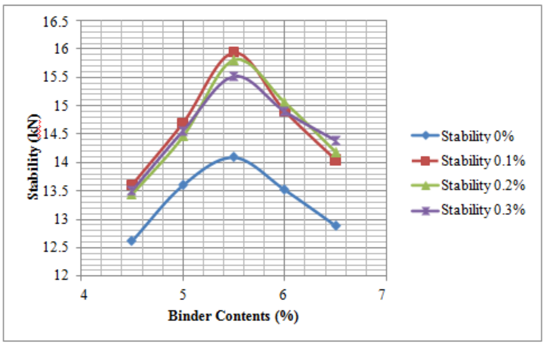

Fig: Stability at 130^{0}C

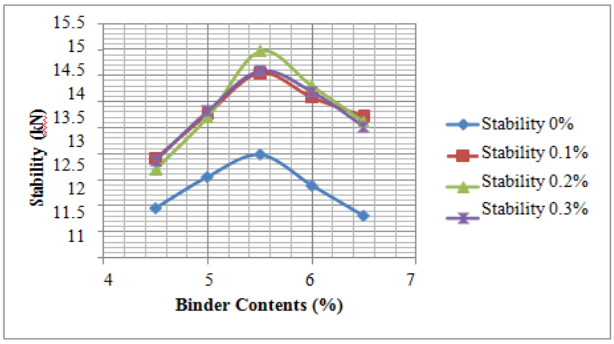

Fig: Stability at 115^{0}C

B) Flow at 130^{0}C & 115^{0}C.

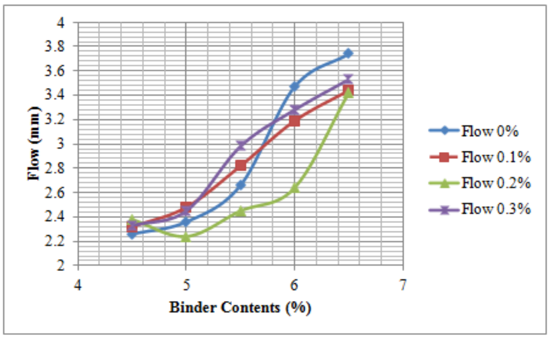

Fig: Flow at 130^{0}C

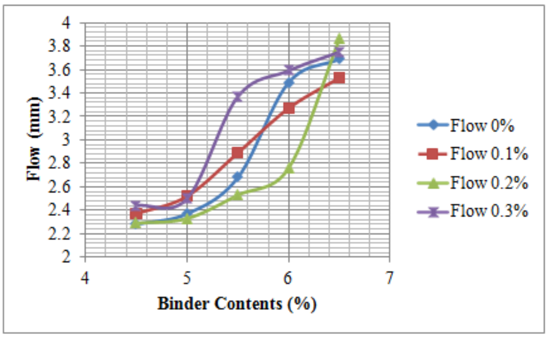

Fig: Flow at 115^{0}C

C) Bulk Density at130^{0}C & 115^{0}C.

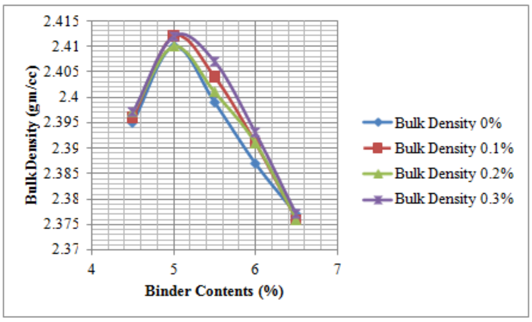

Fig: Bulk Density at 130^{0}C

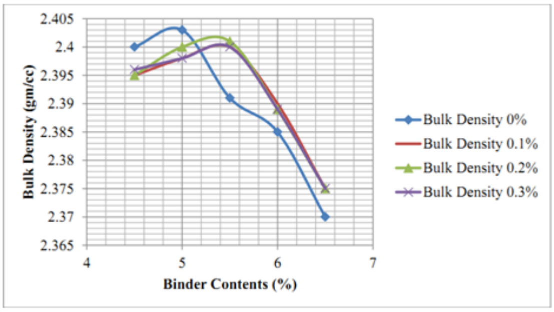

Fig: Bulk Density at 115^{0}C

D) Air Voids at 130^{0}C & 115^{0}C.

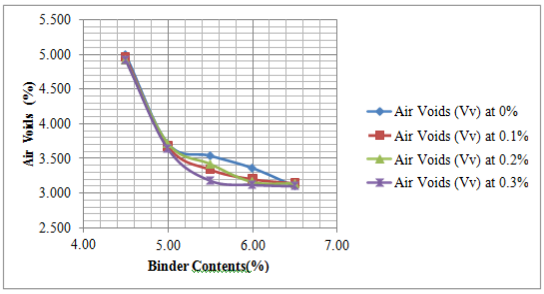

Fig: Air Voids at 130^{0}C

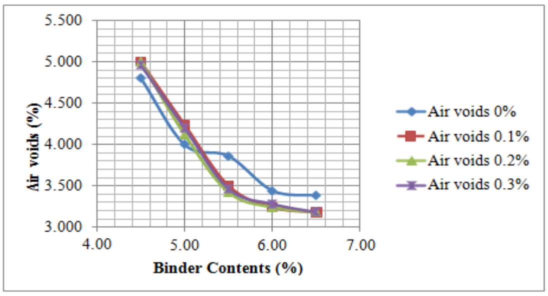

Fig: Air Voids at 115^{0}C

IJARSE
ISSN (O) 2319 - 8354
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E) Voids in mineral aggregates at 130^{0}C & 115^{0}C.

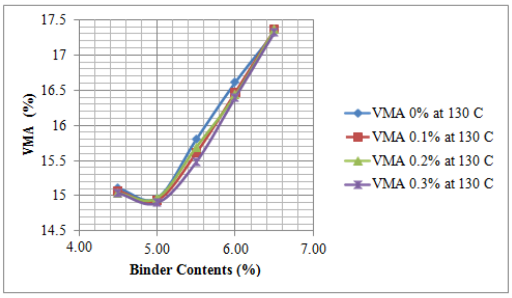

Fig: Voids in mineral aggregates at 130^{0}C

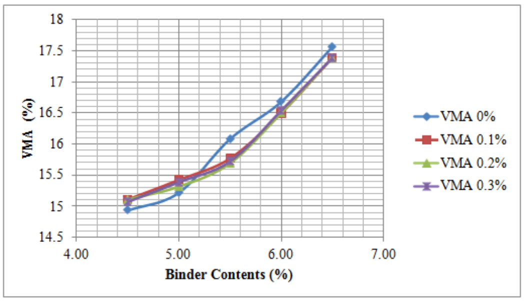

Fig: Voids in mineral aggregates at 115^{0}C

F) Voids filled with bitumen at 130^{0}C & 115^{0}C.

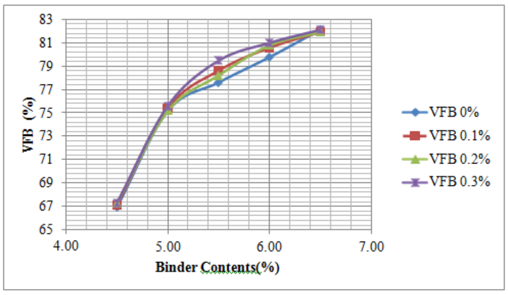

Fig: Voids filled with bitumen at 130^{0}C

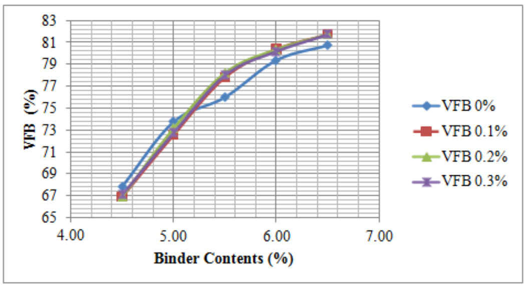

Fig: Voids filled with bitumen at 115^{0}C

VIII.DETERMINATION OF OPTIMUM BINDER CONTENT (OBC)

Table 5: OBC values for different Zycotherm content

At 130^0 C		At 115^0 C	
Zycotherm contents (%)	OBC (%)	Zycotherm contents (%)	OBC (%)
0	5.35	0	5.18
0.1	5.27	0.1	5.25
0.2	5.22	0.2	5.32
0.3	5.2	0.3	5.2

The Optimum Bitumen Content (OBC) for HMA (0% additive) is 5.35% and 5.18% at 130^{o}C and 115^{o}C respectively by weight of mix. The volumetric parameters i.e. Bulk Density, Air Voids, Voids Filled with Bitumen, Voids in Mineral Aggregates and Marshall Stability and Flow value at Optimum Binder Content (OBC) are given in Table 6 and Table 7 at 130^{o}C and 115^{o}C respectively. All parameters satisfies the MORTH 2013 Specifications

Table 6 : Volumetric Properties at OBC at 130^{0}C

Property	Zycotherm content (%)				Specified Values as per MORTH, 2013
	0%	0.10%	0.20%	0.30%	
Stability (kN)	14.24	15.35	14.01	12.61	> 9
Avg. Flow, (mm)	3.24	3.24	2.84	2.65	2-4
Marshall Quotient	4.05	4.73	4.93	4.77	2-5
Air Voids, %	4.123	4.168	4.208	4.978	3-5
Voids in Mineral Aggregate, %	16.47	16.08	15.83	16.14	12 inimum
Voids Filled with Bitumen, %	74.97	74.075	73.412	69.138	65-75

IJARSE
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Table 7: Volumetric Properties at OBC at 115°C

Property	Zycotherm content (%)				Specified Values as per MORTH, 2013
	0%	0.10%	0.20%	0.30%	
Stability (KN)	12.01	14.35	13.24	13.02	> 9
Avg. Flow, (mm)	2.5	3.12	3.38	2.79	2-4
Marshall Quotient	4.84	4.83	4.17	4.87	2-5
Air Voids, %	4.924	4.729	4.655	4.766	3-5
Voids in Mineral Aggregate, %	16.35	16.39	16.48	16.23	12 minimum
Voids Filled with Bitumen, %	69.891	71.143	71.763	70.629	65-75

IX. SUMMARY OF TEST RESULT

The Table No. 8 and Table No. 9 include the summary of test result at OBC with different additive content at 130°C and 115°C.

Table 8: Summary of test result at 130°C

Additive Contents (%)	OBC	At OBC (130°C)								
		Gt	Gm	Vv	Vb	VMA	VFB	Bulk Density	Stability	Flow
0	5.35	2.498	2.395	4.123	12.35	16.473	74.970	2.395	14.24	3.51
0.1	5.27	2.495	2.391	4.168	11.91	16.078	74.075	2.391	15.35	3.24
0.2	5.22	2.495	2.39	4.208	11.62	15.828	73.412	2.39	14.01	2.84
0.3	5.20	2.491	2.367	4.978	11.16	16.138	69.154	2.367	12.61	2.65

Table 9: Summary of test result at 115°

Additive Contents (%)	OBC	At OBC (115°C)								
		Gt	Gm	Vv	Vb	VMA	VFB	Bulk Density	Stability	Flow
0	5.18	2.498	2.375	4.924	11.43	16.354	69.891	2.375	12.1	2.5
0.1	5.25	2.495	2.377	4.729	11.66	16.389	71.143	2.377	14.35	3.12
0.2	5.32	2.492	2.376	4.655	11.83	16.485	71.763	2.376	13.24	3.38
0.3	5.20	2.497	2.378	4.766	11.46	16.226	70.629	2.378	13.02	2.79

X. PERFORMANCE EVALUATION OF BITUMINOUS MIXES

Table 10: Retained Stability at 130°C

At 130° C (OBC)					
Additives (%)	Binder Contents (%)	Normal Stability @60° C for 30 minute	Soaked Stability @60° C for 24 hr.	Retained Stability (%)	MORTH Specification 2013
0	5.35	12.61	11.04	87.55	**75 % Minimum**
0.1	5.27	14.01	13.02	92.93	
0.2	5.22	15.35	14.35	93.49	
0.3	5.2	14.35	13.24	92.26	

Table 11: Retained Stability at 115°C

At 130° C (OBC)					
Additives (%)	**Binder Contents (%)**	**Normal Stability @60° C for 30 minute**	**Soaked Stability @60° C for 24 hr.**	**Retained Stability (%)**	**MORTH Specification 2013**
0	5.18	12.1	10.5	86.78	**75 % Minimum**
0.1	5.25	13.57	12.47	91.89	
0.2	5.32	15.06	13.93	92.50	
0.3	5.2	14.11	12.87	91.21	

IJARSE
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The figure I shows the actual representation of how of retained stability are changes as the additives changes from 0% to 0.3%. The retained stability is increases first and then decreases from 0% to 0.3%. Retained stability at 115°C and 130°C having optimum additive content 0.16% and 0.15% respectively.

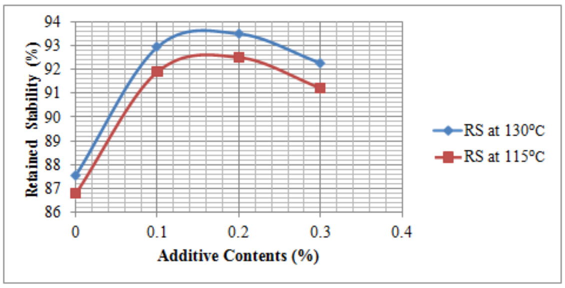

Fig I: Retained Stability at 130°C and 115°C

XI. INDIRECT TENSILE STRENGTH TEST

The Dry and Wet Indirect Tensile Strength of Marshall Specimens for HMA and WMA at 130°C and 115°C, while Figure II shows the Tensile Strength Ratio (TSR) for the same HMA and WMA at 130°C and 115°C. The mixes with 130°C showed better TSR than mixes with 115°C. This is also understandable as the water susceptibility of a mix depends the dense mix provides better moisture resistance, as the samples prepared at 130°C are more dense than samples at 115°C. As per Indian specifications in force, the minimum requirement of TSR for a bituminous mix is 80 percent and here all mixes pass the test.

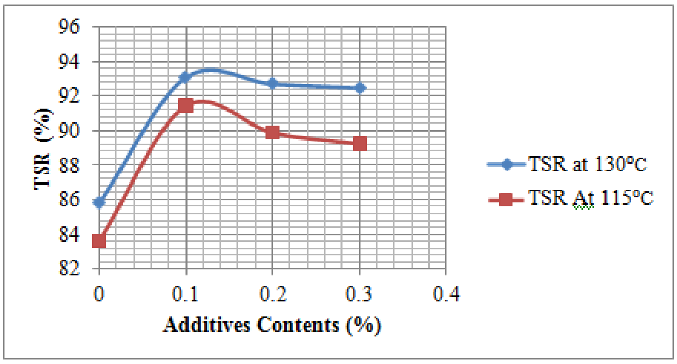

Fig II: Tensile Strength Ratio at 130°C and 115°C

XII. CONCLUSIONS

Based on the detailed study carried out on effect of Zycotherm content for WMA on performance of bitumen and bituminous mixes, the following conclusions are drawn:

- The properties of modified bitumen shown in Table No. 2, satisfies the requirement of Viscosity value, Penetration value, Softening point value and Ductility value as per the Requirement of IS 73-2013.
- Bituminous mixes of HMA and WMA prepared by adopting different additive dosage of Zycotherm warm mix additive as mentioned in Table No. 6 and Table No.7 satisfies the requirements of mix given in Table 3.
- The values of retained stability and tensile strength ratio of HMA and WMA for given additive contents at 130°C and 115°C adopted for present study. From Figure: I, it is found that the retained stability at 115°C and 130°C having optimum additive content 0.16% and 0.15% respectively. And from Figure: II, tensile strength ratio at 115°C and 130°C having optimum additive content 0.12% and 0.13% respectively.

IJARSE
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