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EXPERIMENTAL STUDIES ON WARM MIX ASPHALT WITH CHEMICAL ADDITIVE FOR VARIOUS AGGREGATE GRADATIONS

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ABSTRACT

Most of the roads in India is bitumen-based Roads. Development of the bituminous pavement, the temperature of the bituminous mix must be sufficiently high to guarantee the workability of the blend. To check diminished workability of bituminous mix, for the most part the temperature is increased to decrease the thickness of the cover and subsequently to enhance the workability of the bituminous mix. Warm Mix Asphalt (WMA) is an innovation that permits huge bringing down of the generation and significant lowering of Hot Mix Asphalt (HMA). In this investigation an attempt is made to study the impact of zycotherm as an added substance in WMA on gradations (grade I, grade II, Bailey grade II) of bituminous blends. Bitumen VG 30 grade is used as a binder. This exploratory research is carried out by conducting Marshall Stability Test to study Stability, Flow and Optimum Binder Content (OBC) of different aggregate gradations by the addition of zycotherm.

Keywords: Marshall Stability, Bituminous concrete, Optimum Binder Content (OBC), Zycotherm, Bailey method.

INTRODUCTION

India is one of the fastest growing countries in the world. According to Indian road network assessment by National Highway Authority of India, the National highways constitute only about 1.7% of Road network but carry about 40% of the Total road traffic. India has 79,243 Km of National highways connecting all major cities and state capitals and 1, 31,899 Km of State highways connecting National highways and major towns, district Headquarters of states. Traffic on roads is increasing at a rate of 7-10% per annum while the number of vehicles growing at an average rate of 10.16% per annum over the last five years. Bituminous pavements play a vital role in Indian pavements at present. Though life period of concrete pavements has proved to be economical over bituminous pavements they were unable to replace bituminous pavements completely because of Initial cost of construction of rigid pavements is more than 25% of flexible pavements. Flexible pavement allows stage construction and may use a wide range of construction materials, often leading to substantial savings through the use of locally available materials.

Bitumen: Bitumen is a sticky, black or dark brown non crystalline solid or viscous material, dark and exceptionally gooey fluid or semi-strong type of oil, composed principally ofhigh molecular weight hydrocarbons, having adhesive properties, derived from petroleum either by natural or refinery processes and substantially soluble in carbon disulphide. It might be found in regular stores or might be a refined item, Bitumen is athermoplastic material and its firmness is reliant on temperature. The temperature versus firmness relationship of bitumen is reliant on the wellspring of raw petroleum and the technique for refining. It is surveyed that the present world use of bitumen is approximately 102 million-conditions each year. Around 85% of all the bitumen made is used as the cover as a piece of dark best for avenues. It is moreover used as a piece of other cleared areas, for instance, plane terminal runways, auto parks and footways. Customarily, the production of dark best incorporates mixing sand, rock and crushed rock with bitumen, which goes about as the coupling administrators. materials, for instance, polymers, might be added to the bitumen to alter its properties as demonstrated by the application for which the dark best is in the end proposed. Bitumen in pure form is not suitable for modern roads and present traffic, therefore forced engineers to modify bitumen to improve its performance during service life. The modified binder are more stable under heavy loads, braking and accelerating forces and shows increased resistance to permanent deformation in hot weather. It resists fatigue loads and having better adhesion between aggregates and binders.

Warm Mix Asphalt: Basic principle of WMA technology, by adding certain additives at the final stages of the mix production, the coating of the aggregates by the binder is achieved at a considerably less temperature (typically 30^0 C less) compared to the hot mix process wherein bitumen is heated to a sufficiently high temperature (typically 160- 170^0 C) to make it fluid enough to surround the aggregates and coat their Surfaces. Generally the WMA innovation is currently advanced with decreasing the creation or blending temperature of the black-top blend for up to 40º C by adding added substances to the customary black-top clearing blend. This is an innovation which permits the blending, lay down and compaction of black-top blends at lower temperatures contrasted with HMA.

Zycotherm: Zycotherm is WMA additive developed by Zydex Industries, Gujarat, India. This is an odour free, chemical warm mix additive that has been engineered to provide significantly improved benefits over current WMA technologies by offering lower production and compaction temperatures, while simultaneously enhancing the moisture resistance of pavements by serving as an anti-strip. Zycotherm material as an additive allows the mixing laydown, and compaction of asphalt mixes at significantly lower temperatures compared to hot mix asphalt. Mixes that have been modified with Zycotherm can be produced at120°C - 135°C for and compacted at 90°C - 120°C. Overall,

Zycotherm offers temperature reductions depending on the properties of the mix. Zycotherm has built in anti-strip mechanism that allows it to dually function as an anti-strip as well as a warm mix additive.

Bailey Gradation:The Bailey Method provides a set of tools that can be used to analyse aggregate size distribution, using the degree of particles interlock as a design input. The method, developed in the early 1980's by Robert D. Bailey of the Illinois DOT, has been subsequently improved by additional studies and field trials. It can be used to design and evaluate aggregate blends within any mix design method, such as Marshall or Super pave. It provides empirical rules that allow to control mixture volumetric properties, and to achieve compactability and performance in the field. The basic principles of the Bailey Method have been empirically developed, therefore its parameters and rules are strongly based on sieves and aggregate sizes typically adopted in the United States. The focus of the Bailey method is aggregate packing. In order to better understand aggregate packing, we need to determine what particles form the coarse aggregate structure and which ones fit into the voids created within that structure. The packing characteristics are determined by several factors: the shape, strength and texture of the aggregates, the combined blend gradation, and the type and amount of compactive effort. materials, for instance, polymers, might be added to the bitumen to alter its properties as demonstrated by the application for which the dark best is in the end proposed. Bitumen in pure form is not suitable for modern roads and present traffic, therefore forced engineers to modify bitumen to improve its performance during service life. The modified binder are more stable under heavy loads, braking and accelerating forces and shows increased resistance to permanent deformation in hot weather. It resists fatigue loads and having better adhesion between aggregates and binders.

LITERATURE REVIEW

Xijuan Xu, (2011)[18]Warm Mix Asphalt is low-carbon, environmentally friendlyasphalt mixture. This kind mixture not only save resources, reduce harmful gap emissions, but also to maintain the asphalt mixture in a better use of quality. In the article, by adding additives to reduce the viscosity of asphalt, we reach the effect of reducing the temperatures of mixture mixing and compaction. At the same time, we do experiment on study high temperature stability, low temperature crack resistance and water stability, the result show that Warm Asphalt Mix gets excellent performance.

Rohith N. J.Ranjitha (2013)[14]in this study an attempt is made to analyse theMarshall properties of WMA delivered with the synthetic added substance: "ZycoTherm" and HMA for Dense Bituminous Macadam (DBM) Grade 2. They conclude WMA mix produced using ZycoTherm at 130°C with additive dosage rate of 0.1% showed good results when compared with the HMA mix produced at 130°C.The stability and Marshall

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Properties of WMA specimens prepared at 130°C and 115°C were improved by the addition of Zycotherm at an additive dosage rate of 0.1% by weight of the binder.

Manjunath S Sharanappanavar(2015)[10]conduct Study on Behaviour of Warm MixAsphalt Using Zycotherm and he concluded that the Warm Mix Asphalt produced using Zycotherm at 130°C with additive dosage rate of 0.1% showed good results when compared with the Fresh mix.

MATERIALS & METHODOLOGY

Table.1 :Physical properties of aggregates

Property	Test	Test method	Results obtained	Recommended values
Strength	Crushing value	IS:2386(IV)	27.3%	30% maximum
	Aggregate Impact value	IS:2386(IV)	19.2 %	30% maximum
	Los Angeles Abrasion value	IS:2386(IV)	16.5%	30% maximum
Specific gravity	Coarse aggregate	IS:2386(III)	2.53%	2.6-2.8
	Fine aggregate		2.43%	
Water absorption	Water absorption test	IS:2386(III)	0.5%	2%maximum
Particle shape	Combined flakiness & Elongation index test	IS:2386(I)	23.7%	30% maximum

Bitumen:Bitumen acts as a binding agent to the aggregates, fines and stabilizers in bituminous mixtures. Binder provides durability to the mix. Binder characteristics affect the bituminous mixture behaviour viz., temperature susceptibility, visco-elasticity and aging. In this study VG-30 bitumen is used as binder is shown in figure3.3. To ensure the use of VG-30 grade bitumen basic engineering tests are conducted as per IS 73:2013(specifications for paving bitumen), which is significantly more rut resistant than the old 60/70penetration bitumen.

Table.2. Physical properties of bitumen

Bitumen test	VG-30	VG-30+ Zycotherm (0.075%)	VG-30+ Zycotherm (0.1%)	VG-30+ Zycotherm (0.125%)	Requirements as per IS 73-2013
Penetration at 25°C , mm	61	63	65	67	Min 45
Softening point (Ring & Ball) , °C	52	51	52	52	Min 47
Flash point °C	240	252	265	268	Min 220
Fire point ,°C	258	276	282	288	NA
Ductility @27°C , cm	72	77	86	88	NA
Specific gravity	1.01	1.00	1.00	1.00	NA

Additive: The Warm Mix Asphalts (WMA) is modified Hot Mix Asphalt (HMA) which is produced, laid and compacted in temperature which is lower than conventional HMA. The WMA is produced by mixing chemical additives to the conventional mix to improve the pavement performance. Zycotherm is an advance generation Silane additive with multiple benefits. It is WMA added substance grew by Zydex Businesses, Gujarat, India

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Table.3Properties of Zycotherm

Physical properties		Chemical properties	
Colour	Light yellow	Compounds	Percent
State	Liquid	Hydroxyl alkyl Alokoxy-Alkyl silyl compounds	65%-75%
Freezing point	5°c	Benzyl alcohol	25%-27%
Specific gravity	1.01	Ethylene glycol	3%-5%
Viscosity	1-5 Pascal-second	-	-
Flash point	80°c	-	-

Gradation of Aggregates:The properties of the bituminous mix including the density and stability are very much dependent on the aggregates and their grain size distribution. Gradation has a profound effect on mix performance. It might be reasonable to believe that the best gradation is one that produces maximum density. This would involve a particle arrangement where smaller particles are packed between larger particles, thus reducing the void space between particles. This creates more particle-to-particle contact, which in bituminous pavements would increase stability and reduce water infiltrationA dense mixture may be obtained when this particle size distribution follows Fuller law which is expressed as:p = 100 *(d/ D) n

Where, p is the percent by weight of the total mixture passing any given sieve sized, D is the size of the largest particle in that mixture, and n is the parameter depending on the shape of the aggregate (0.5 for perfectly rounded particles).

Grade I (26.5mm is the highest aggregate size)

Table.4 :Gradation of Aggregates (Grade I)

S.NO	IS sieve size (mm)	Cumulative % by wt. of total Agr. Passing	Mid-range for percentage of passing	% Of Retained 100-P	W=(R/100)*1200 Wt. of Agr. In grams
1	26.5	100	100	0	0
2	19	90-100	99	1	12
3	13.2	59-79	74	25	300
4	9.5	52-72	66	8	96
5	4.75	35-55	49	17	204
6	2.36	28-44	39	10	120
7	1.18	20-34	28	11	132
8	0.6	15-27	25	3	36
9	0.3	10-20	18	7	84
10	0.15	5-13	11	6	72
11	0.075	2-8	5	6	72
12	<0.075	-	0	5	60
					Total=1200 g

Grade II (19mm is the highest aggregate size): In Grade II maximum aggregate size is 19mm and 13.2 mm is the nominal maximum aggregate size. For this study mid limit is taken as adopted gradation. Gradation curve for bituminous concrete Grade II is shown in below.

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Table.5 :Gradation of Aggregates (Grade II)

S.NO	IS sieve size (mm)	Cumulative % by wt. of total Agg. Passing	Mid-range for percentage of passing	%Of Retained 100-P	W=(R/100)*1200 Wt. of Agg. In grams
1	19	100	100	0	0
2	13.2	90-100	94	6	72
3	9.5	70-88	78	16	192
4	4.75	53-71	58	20	240
5	2.36	42-58	48	10	120
6	1.18	34-42	42	6	72
7	0.6	26-38	31	10	120
8	0.3	18-28	21	9	108
9	0.15	12-20	13	8	96
10	0.075	4-10	5	8	96
11	<0.075	2-8	0	5	60
					Total=1200 g

The Bailey Method: Coarse and fine aggregate particles are commonly separated using a conventional sieve dimension, customarily placed between 4.75 mm and 2 mm. In the Bailey Method a different definition of "coarse" and "fine" is adopted, with reference to their volumetric function inside an aggregate blend. Specifically, when packed together in an aggregate blend, coarse particles create the voids, whereas fine particles fill the voids. This definition is therefore related to the overall grading of the mixture, and particularly to its Nominal Maximum Aggregate Size (NMAS). The break sieve between coarse and fine, named Primary Control Sieve (PCS), is defined as:

PCS = NMAS *0.22

In this relationship, NMAS is used to represent the size of the coarse particles, whereas PCS represents the size of the inter-granular voids, that is proportional to that of the coarse particles. Equation was found to represent average conditions of AC mixtures which are composed by particles having different shape, texture and strength. Single aggregate sizes are classified as "coarse" or "fine" whether their PCS passing is below or above 50%, respectively

Table.6: Gradation of Aggregates

Sieve size	20mm	12mm	6mm	Dust	Obtained gradation	Specified limits
Design%	20%	21%	22%	37%	-	-
19	100	100	100	100	100	100
13.2	38.5	99.4	99.9	100	84	79-100
9.5	19.3	96.5	99.8	100	79.8	70-88
4.75	8.7	36.5	65.2	100	64.5	53-71
2.36	3.2	24.2	6.9	99.4	46	42-58
1.18	0	15.2	1.7	95	42	34-48
0.600	0	10.3	0.9	81	34	26-38
0.300	0	8.3	0.53	63	22	18-28
0.150	0	5.3	0.42	45.5	15	12-20
0.075	0	1.8	0.27	23	6	4-10

RESULTS AND DISCUSSIONS

Marshall Test results for conventional mix of all Grades The Marshall test was carried out on warm mix asphalt (WMA) mixes by varying bitumen contents of 4%, 4.5%, 5.0%, 5.5%, 6.0%, 6.5% for Grade I, Grade II & Bailey Grade II at mixing temperatures of 1300c to find the optimum binder content for conventional mix. The specimens were compacted manually (75 blows per side) using Marshall Compaction hammer. The Optimum Binder Content (OBC) of the mixes is determined by using on maximum stability, maximum bulk density and 4% Air voids is considered. The test is carried out according to IRC: 111 standards. The test results are presented in tables 4.1, 4.2 & 4.3. The graphs were plotted for bitumen content and Marshall Stability, Flow, Air voids, Bulk density, Voids filled with bitumen.

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Table.7: Marshall Mix design values with varying bitumen content for bituminous concrete mix Grade I

Bitumen content (%)	Marshall stability (KN)	Flow (mm)	Air voids (%)	Voids in mineral aggregate (VMA) (%)	Voids filled with bitumen (VFB) (%)	Bulk density (g/cc)
Gradel						
4	10.15	1.6	5.7	13.73	57.54	2.34
4.5	11.18	2.42	4.78	13.43	64.31	2.35
5.0	11.51	2.88	4.25	13.32	68.79	2.37
5.5	12.04	3.52	4.35	14.26	71.67	2.38
6.0	13.11	3.81	3.83	14.85	74.49	2.37
6.5	12.61	3.94	3.62	15.00	75.68	2.36

Table.8:Marshall Mix design values with varying bitumen content for bituminous concrete mix Grade II

Bitumen content (%)	Marshall stability (KN)	Flow (mm)	Air voids (%)	Voids in mineral aggregate (VMA) (%)	Voids filled with bitumen (VFB) (%)	Bulk density (g/cc)
Grade2						
4	11.50	1.50	5.50	13.50	59.25	2.43
4.5	11.96	2.15	5.10	13.95	63.44	2.45
5.0	12.15	2.55	4.95	14.10	64.89	2.44
5.5	12.44	3.10	4.70	14.45	67.47	2.46
6.0	11.82	3.60	4.10	14.70	78.91	2.45
6.5	11.66	3.95	3.80	15.10	74.83	2.44

Table.9: Marshall Mix design values with varying bitumen content for bituminous concrete mix Bailey Grade II

Bitumen content (%)	Marshall stability (KN)	Flow (mm)	Air voids (%)	Voids in mineral aggregate (VMA) (%)	Voids filled with bitumen (VFB) (%)	Bulk density (g/cc)
Bailey Grade II						
4	11.43	1.42	5.42	13.50	59.85	2.43
4.5	11.85	2.07	5.01	13.89	63.93	2.45
5.0	12.07	2.49	4.85	14.01	65.38	2.44
5.5	12.39	3.03	4.63	14.36	67.75	2.46
6.0	11.75	3.56	4.00	14.62	72.64	2.45
6.5	11.51	3.87	3.72	15.03	75.24	2.44

Marshall test results at OBC without Zycotherm

The Marshall test results of warm mix asphalt (WMA) without additive for BC mix at 1300c at optimum bitumen content (OBC) is presented in table 4.4 Graphs were plotted for varying Zycotherm content and Marshall Stability, Flow, Air voids, Voids filled with bitumen, Bulk Density & voids in mineral aggregate.

Table.10: Marshall Mix design values at OBC without Zycotherm

	Without zycotherm		
	Grade 1	Grade 2	Bailey grade 2
Optimum binder content (%)	5.70	5.72	5.67
Stability (KN)	12.33	12.06	12.07
Flow (mm)	3.6	3.32	3.18
Air voids (%)	3.91	4.33	4.22
Voids in mineral aggregate (%)	14.44	14.55	14.44
Voids filled with bitumen (%)	72.63	69.21	70.18
Bulk density (g/cc)	2.34	2.44	2.46

Marshall test results at OBC with 0.075% Zycotherm

The Marshall test results of warm mix asphalt (WMA) with an additive dosage rate of 0.075% by weight of binder for BC mix at 1300c at optimum bitumen content (OBC) is presented in table 4.5 Graphs were plotted for varying Zycotherm content and Marshall Stability, Flow, Air voids, Voids filled with bitumen, Bulk Density & voids in mineral aggregate.

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Table11 : Marshall Mix design values at OBC with 0.075% Zycotherm

	0.075%zycotherm		
	Gradel	Grade2	Bailey grade2
Optimum binder content (%)	5.70	5.72	5.67
Stability (KN)	15.28	14.95	14.36
Flow (mm)	3.12	3.32	3.3
Air voids (%)	4.85	4.84	4.42
Voids in mineral aggregate (%)	16.09	17.64	17.81
Voids filled with bitumen (%)	68.84	72.73	74.90
Bulk density (g/cc)	2.38	2.46	2.47

Marshall test results at OBC with 0.10% Zycotherm The Marshall Test results of warm mix asphalt (WMA) with an additive dosage rate of 0.1% by weight of binder for BC mix at 1300c at optimum bitumen content (OBC) is presented in tables 4.6. Graphs were plotted for varying Zycotherm content and Marshall Stability, Flow, Air voids, Voids filled with bitumen, Bulk Density & voids in mineral aggregate

Table.12: Marshall Mix design values at OBC with 0.1% Zycotherm'

	0.1%zycotherm		
	Gradel	Grade2	Bailey grade2
Optimum binder content (%)	5.70	5.72	5.67
Stability (KN)	16.03	15.72	15.63
Flow (mm)	3.58	3.8	3.40
Air voids (%)	4.50	4.63	4.39
Voids in mineral aggregate (%)	17.02	17.01	16.96
Voids filled with bitumen (%)	73.56	72.78	74.11
Bulk density (g/cc)	2.36	2.46	2.46

Marshall test results at OBC with 0.125% Zycotherm

The Marshall test results of warm mix asphalt (WMA) with an additive dosage rate of 0.125% by weight of binder for BC mix at 1300c at optimum bitumen content (OBC) is presented in tables 4.7 Graphs were plotted for varying Zycotherm content and Marshall Stability, Flow, Air voids, Voids filled with bitumen, Bulk Density & voids in mineral aggregate.

Table.13: Marshall Mix design values at OBC with 0.125% Zycotherm

	0.125%zycotherm		
	Gradel	Grade2	Bailey grade2
Optimum binder content (%)	5.70	5.72	5.67
Stability (KN)	15.8	15.5	15.39
Flow (mm)	3.43	3.61	3.32
Air voids (%)	4.35	4.56	4.23
Voids in mineral aggregate (%)	16.54	16.15	15.97
Voids filled with bitumen (%)	73.70	71.76	73.51
Bulk density (g/cc)	2.37	2.44	2.44

CONCLUSIONS

1.Addition of Zycotherm to Warm mix asphalt effectively improves the stability of the mix.

2.For conventional mix the maximum stability was found to be 12.3kN for grade I at an OBC of 5.7%.

3.By the addition of Zycotherm to bituminous concrete mix, maximum stability was found to be 16.03kN at 5.7% optimum binder content for grade I at a dosage rate of 0.1%.

4.Stability is increased by 30.24% when zycotherm is added to the conventional mix for grade I at a dosage rate of 0.1% which is 29.27% for grade II, 28.51% for Bailey grade II.

5.Flow value is Minimum for Grade I at a dosage rate of 0.075%zycotherm which is 3.02mm.

6.By adding 0.125% of zycotherm to bituminous concrete mix all grades gives minimum Air voids than other two dosage rates (0.075% and 0.1%)

7.Voids filled with bitumen are more for Bailey Grade II at an additive dosage rate of 0.1%zycotherm to the bituminous concrete mix.

8.Voids in mineral aggregate are less for Grade I at an additive dosage rate of 0.075%zycotherm to the bituminous concrete mix.

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