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Effect of Zycotherem on Mechanical Properties of Warm Mix Asphalt for Different Aggregate Gradations

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Abstract: In general, Roads in India are mainly bitumen-based Roads. Amid 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 1, grade2, Bailey grade2) 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: Bailey method, Bituminous concncrete, Marshall Stability, Optimum Binder Content (OBC), Zycotherm.

I. INTRODUCTION

Due to increasing demand in highway construction,many research works are going constantly trying to improve the performance of bitumen pavement. Asphalt concretes are widely used in pavements. Bitumen is a black or dark brown non crystalline solid or viscous material, composed principally of high molecular weight hydrocarbons. Due to increase in vehicles in recent years the road surfaces have been exposed to high traffic resulting in deformation of pavements due to excessive stress. Permanent deformation happens when pavement does not have sufficient stability, improper compaction and insufficient pavement strength. From practical experiences it is proved that the modification of asphalt binder with chemical additives,offers several benefits.Warm mix asphalt(WMA) is another innovation which was presented as of late. Warm Mix Asphalts (WMA) is produced, laid and compacted in temperature which is lower than conventional mix by mixing chemical additives to the conventional mix to improve the pavement performance.WMA is picking up consideration everywhere throughout the world since it offers a few points of interest over conventional asphalt concrete mixes. The benefits include (1) Reduced energy consumption in the asphalt mixture production process; (2) Reduced emissions, fumes and undesirable odours; (3) More uniform binder coating on aggregate which should reduce mix surface aging; and (4) Extended construction season in temperate climates. WMA requires the use of additives to reduce the temperature of production and compaction of asphalt mixtures.Zycotherm is WMA additive developed by Zydex Industries, Gujarat, India. Mixes that have been modified with Zycotherm can be produced at 120°C - 135°C and compacted at 90°C - 120°C. The Bailey Method, developed in the early 1980's by Robert D. Bailey of the Illinois DOT, this method allows the designer to select an aggregate skeleton that will be more resistant to permanent deformation and to adjust the VMA by changing the packing of the coarse and fine aggregates to ensure that the mix has sufficient asphalt binder. In this study three grades (GradeI, GradeII, Bailey gradeII) with three proportions of Zycotherm (0.075%, 0.1% and 0.125%) at optimum binder content(OBC) is tested by using Marshall Test.

II. LITERATURE REVIEW

Manjunath S Sharanappanavar(2015)[1]conduct Study on Behavior of Warm Mix Asphalt 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.

Vatsal v. Raja, et.al (2015) [3] conducted tests on warm mix asphalt (WMA) with different type of chemicals and they suggested that the dosage of zycotherm at 0.1% with warm mix asphalt (WMA) gives better results in terms of workability &compaction.

Bheemashankar, Amarnath.M.S [4] conducted Studies on effect of Zycotherm additive on bituminous concrete mix with different percentages like 0.075,0.1&0.125 and find out optimum Zycotherm content, at optimum Zycotherm content they observed that the BC mixes with optimumZycotherm content shows higher stability, ITS and TSR values compared to the BC mixes without Zycotherm.

Rohith N. J.Ranjitha (2013) [5] In this study an attempt is made to analyze the Marshall 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 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.

Vavrik, et.al (2002) [6] The Bailey method for gradation selection considers the packing characteristics of aggregates. The parameters in the method are related directly to VMA, air voids, and compaction properties. The principles in Bailey method can be used from the asphalt mix design through the quality control process, but are not a mix design method. The aggregate blends initially selected for this research were based on the upper and lower limits of the three Bailey method criteria. Four sieves are evaluated under the Bailey method: the half sieve, the primary control, the secondary control and tertiary control.

III. MATERIALS & METHODOLOGY

A. Aggregates

In bituminous concrete mix aggregates plays major role interms of strength and durability. Aggregates mainly consists coarse and fine aggregates. Basic engineering tests are conducted on aggregates used in this study to know the physical properties, the test results are shown in Table 1. For present study Aggregates collected from a quary which is located in ponduru mandal,Srikakulam district.

Table1: Physical properties of aggregates

Property	Test	Test method	Results obtained	Recommended values
Strength	Crushing value	IS:2386(IV)	25.3%	30% maximum
	Aggregate Impact value	IS:2386(IV)	17.7%	30% maximum
	Los angels Abrasion value	IS:2386(IV)	18%	30% maximum
Specific gravity	Coarse aggregate	IS:2386(III)	2.65%	2.6-2.8
	Fine aggregate		2.63%	
Water absorption	Water absorption test	IS:2386(III)	0.5%	2%maximum
Particle shape	Combined flakiness & Elongation index test	IS:2386(I)	26.7%	30% maximum

B. Bitumen

Bitumen acts as a binding agent to the aggregates, fines and stabilizers in bituminous mixtures. Binder providesdurability to the mix. Binder characteristics affect the bituminous mixture behavior viz., temperature susceptibility,visco-elasticity and aging. In this study VG-30 bitumen is used as binder. To ensure the use of VG-30 grade bitumenbasic engineering tests are conducted as per IS 73:2013, which is significantly more rut resistant than the old 60/70penetration bitumen. The tests results of VG-30 bitumen and VG-30 with Zycotherm are presented in the Table 3.

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C. Additive

The Warm Mix Asphalts (WMA) is modified Hot MixAsphalt(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 shown in fig.2. This is a smell free, warm mix added substance that has been built to give essentially enhanced profits over current WMA advancements by offering lower creation and compaction temperatures. The physical and chemical properties of zycotherm is presented in Table 2.

D. Doping of Zycotherm

For the present study 0.075%, 0.1%, 0.125%was adopted as the additive dosage for preparation of the specimens. Zycotherm was added 0.1% volumetrically or by weight using 3ml plastic syringe and the molten bitumen 155ºC was stirred manually using a glass rod while adding Zycotherm and additional stirring for 10 minutes was done for uniform mixing of the additive with the bitumen.The process of doping of Zycotherm is shown in fig.1.

Fig.1: Doping of Zycotherm

Fig.2: zycotherm bottle

Table2: Properties of zycotherm

Physical properties		Chemical properties	
Colour	Light yellow	Compounds	Percent
State	Liquid	Hydroxyl alkyl Alokoxy-Alkyl silyl compounds	65%-75%
Freezing point	5^0c	Benzyl alcohol	25%-27%
Specific gravity	1.01	Ethylene glycol	3%-5%
Viscosity	1-5 Pascal-second	-	-
Flash point	80^0c	-	-

Source: zydex industries lab manual

Table3: 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^{0}C , mm	63	64	65	66	Min 45
Softening point (Ring & Ball) ,^{0} C	49	49	49	49	Min 47
Flash point ,^{0}C	251	265	270	274	Min 220
Fire point ,^{0}C	271	286	292	298	NA
Ductility @27^{0}C , cm	82	87	98	90	NA
Specific gravity	1.01	1.00	1.00	1.00	NA

E. Gradation of Aggregates

The aggregate gradation used for the work is Bituminous concrete gradeI, gradeIIas per MoRTH specifications (V-Revision) & Bailey grade II.

1) *GradeI:* In grade1 26.5mm is the highest size of aggregate and nominal maximum aggregate size is 19mm for this study mid limit is taken as adopted gradation. Gradation curve for bituminous concrete GradeI is shown in below fig.3.

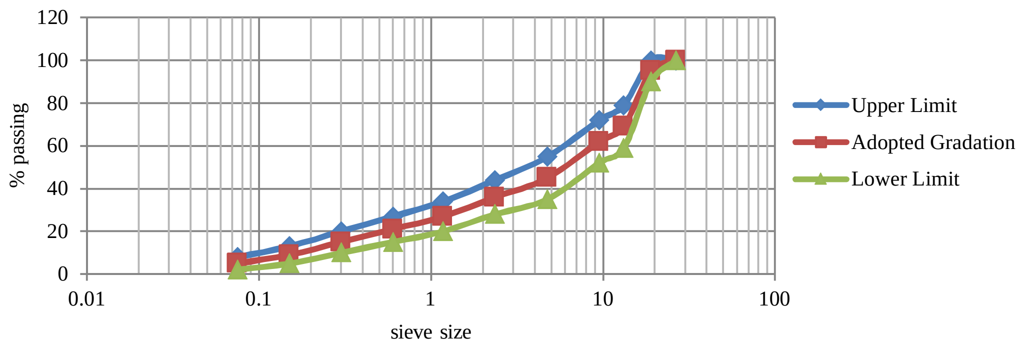

Fig.3: Aggregate gradation curve for BC Grade-1

2) *GradeII:* In grade2 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 GradeII is shown in below fig.4.

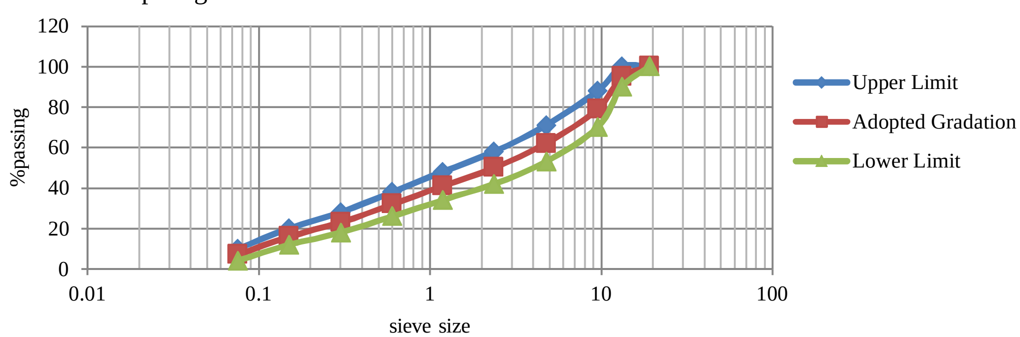

Fig.4: Aggregate gradation curve for BC Grade-2

3) *The Bailey Method:* The Bailey Method is a systematic approach to blending aggregates that provides aggregate interlock as the backbone of the structure and a balanced continuous gradation to complete the mixture. The Bailey Method uses two principles that are the basis of the relationship between aggregate gradation and mixture volumetrics.To determine where to split the fine aggregate, the same 0.22 factor used on the entire gradation is applied to the PCS to determine a secondary control sieve (SCS). The SCS then becomes the break between coarse sand and fine sand. The fine sand is further evaluated by determining the tertiary control sieve(TCS), which is determined by multiplying the SCS by the 0.22 factor. An analysis is done using ratios that evaluate packing within each of the three portions of the combined aggregate gradation. Three ratios are defined: Coarse Aggregate Ratio (CA Ratio),Fine Aggregate Coarse Ratio (FA_c Ratio), and Fine Aggregate Fine Ratio (FA_f Ratio).These ratios characterize packing of the aggregates. By changing gradation within each portion modifications can be made to the volumetric properties.

CA Ratio = (% Passing Half Sieve - % Passing PCS) / (100%-% Passing Half Sieve)

FAc =(% Passing PCS) / (% Passing SCS)

FA_f = (%Passing TCS) / (% Passing SCS)

The gradation curve for bituminous concrete Bailey gradeII is shown infig.5.

Table4: Gradation of Aggregates (Bailey grade2)

Sieve size	20mm	12mm	6mm	Dust	Obtained gradation	Specified limits
Design%	20%	21%	22%	37%	-	-
19	100	100	100	100	100	100
13.2	41.2	99.9	100	100	86.5	79-100
9.5	17.1	92.7	99.8	100	80.03	70-88
4.75	9.5	38.3	67.25	100	60.65	53-71
2.36	0	23.7	7.9	99.4	43.40	42-58
1.18	0	16.1	1.2	95	38.75	34-48
0.600	0	11.3	0.7	81	32.23	26-38
0.300	0	7.8	0.55	63	25.55	18-28
0.150	0	4.25	0.4	45.5	18.32	12-20
0.075	0	1.2	0.25	20	7.16	4-10

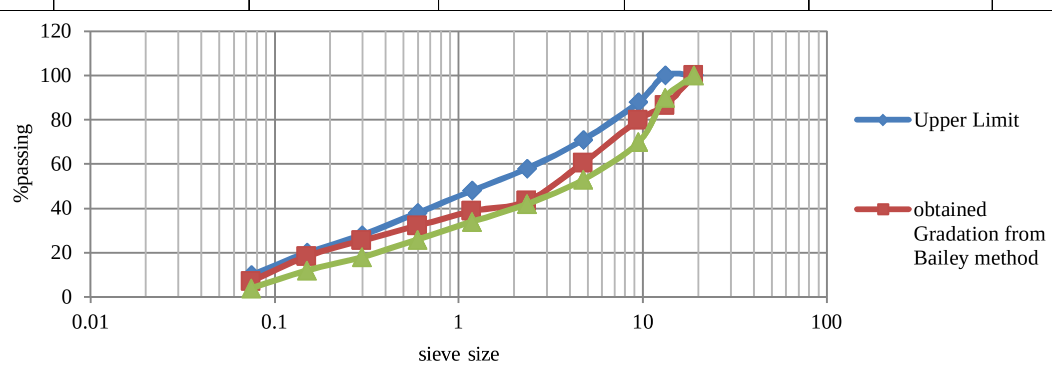

Fig.5: Aggregate gradation curve for Bailey Grade-2

IV. ANALYSIS AND RESULTS

A. *Marshall Test*

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 GradeI, GradeII & Bailey GradeII at mixing temperatures of 130^0c 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 table5.The graphs were plotted for bitumen content and Marshall Stability, Flow, Air voids, Bulk density, Voids filled with bitumen.

Table 5: Marshall mix design values with varying bitumen content

Bitumen content (%)	Marshall stability (KN)	Flow (mm)	Air voids (%)	Voids in mineral aggregate (VMA) (%)	Voids filled with bitumen (VFB) (%)	Bulk density (g/cc)
Grade1						
4	10.10	1.50	5.68	13.70	58.80	2.34
4.5	11.20	2.45	4.80	13.45	68.90	2.35
5.0	11.52	2.90	4.15	13.30	75.48	2.37
5.5	12.05	3.50	4.05	14.30	81.56	2.38
6.0	13.01	3.80	3.80	14.90	84.13	2.37
6.5	12.67	3.97	3.65	15.01	85.73	2.36
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
Bailey grade2						
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

Fig.6: Marshall Stability Test Equippment

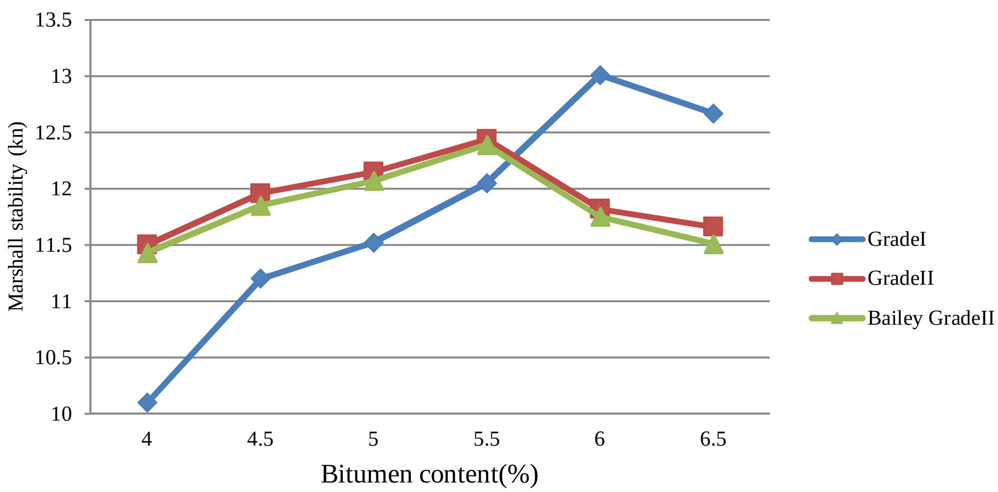

Fig.7 : Marshall stability v/s Bitumen Content

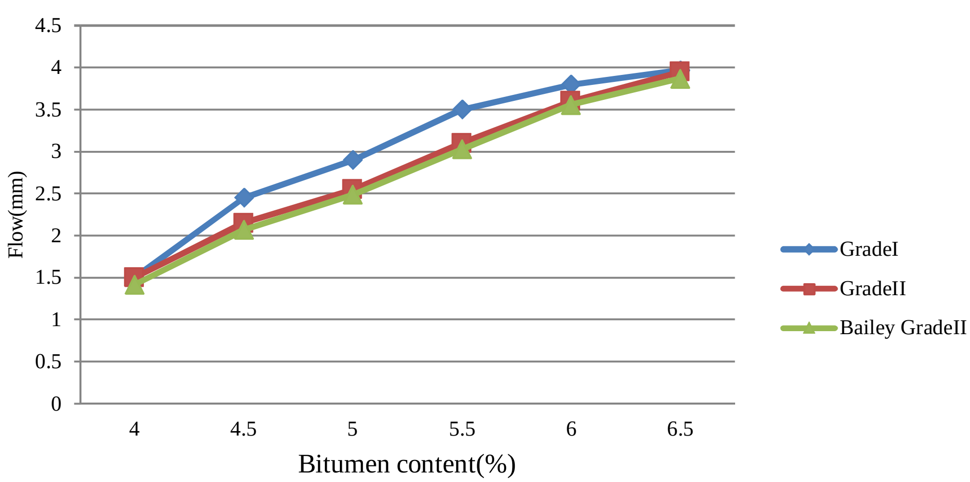

Fig.8 : Flow v/s Bitumen Content

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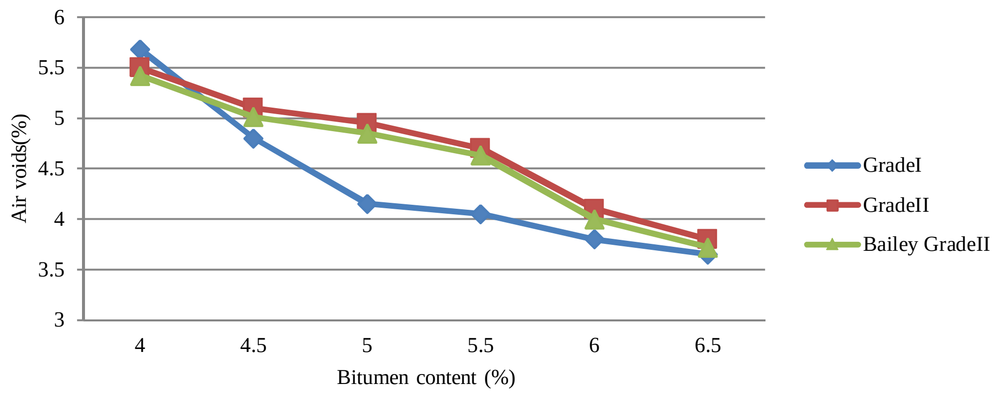

Fig.9 : Air Voids v/s Bitumen Content

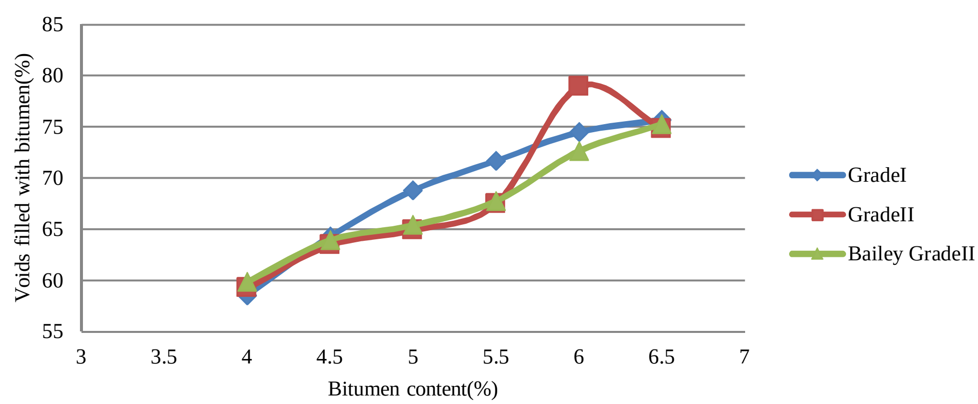

Fig.10 : Voids filled with bitumen v/s Bitumen Content

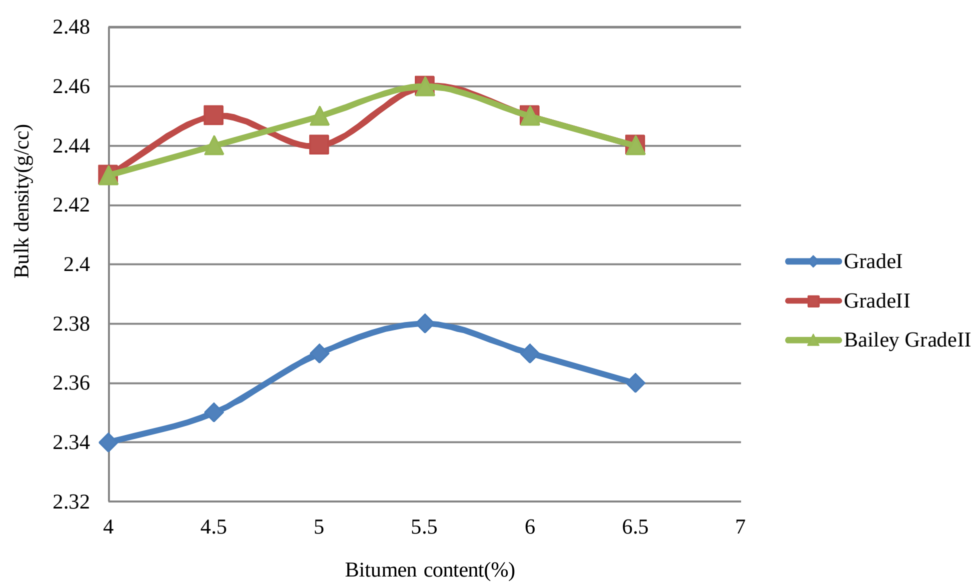

Fig.11 : Bulk Density v/s Bitumen Content

The Marshall test results of warm mix asphalt (WMA) without &with an additive dosage rate of 0.075%,0.1%&0.0125% by weight of binder for BC mix at 130^{0}c at optimum bitumen content (OBC) is presented in table6. Graphs were plotted for varying Zycotherm content and Marshall stability,flow,air voids,voids filled with bitumen,bulk density & voids in mineral aggregate.

Table 6: Marshall mix design values at OBC

	Without zycotherm			0.075%zycotherm			0.1% zycotherm			0.125% zycotherm		
	Grade 1	Grade 2	Bailey grade2	Grade1	Grade 2	Bailey grade 2	Grade 1	Grade 2	Bailey grade 2	Grade 1	Grade 2	Bailey grade 2
Optimum binder content (%)	5.70	5.72	5.67	5.70	5.72	5.67	5.70	5.72	5.67	5.70	5.72	5.67
Stability (KN)	12.43	12.16	12.17	15.20	14.96	14.06	16.19	15.72	15.63	15.8	15.5	15.39
Flow (mm)	3.62	3.30	3.21	3.02	3.42	3.35	3.58	3.8	3.40	3.43	3.61	3.32
Air voids (%)	3.95	4.43	4.32	4.95	4.81	4.47	4.50	4.63	4.39	4.35	4.56	4.23
Voids in mineral aggregate (%)	14.54	14.50	14.44	15.89	17.64	17.81	17.02	17.01	16.96	16.54	16.15	15.97
Voids filled with bitumen (%)	72.83	69.11	70.08	68.84	72.73	74.90	73.56	72.78	74.11	73.70	71.76	73.51
Bulk density (g/cc)	2.34	2.44	2.46	2.37	2.45	2.45	2.36	2.46	2.46	2.37	2.45	2.44

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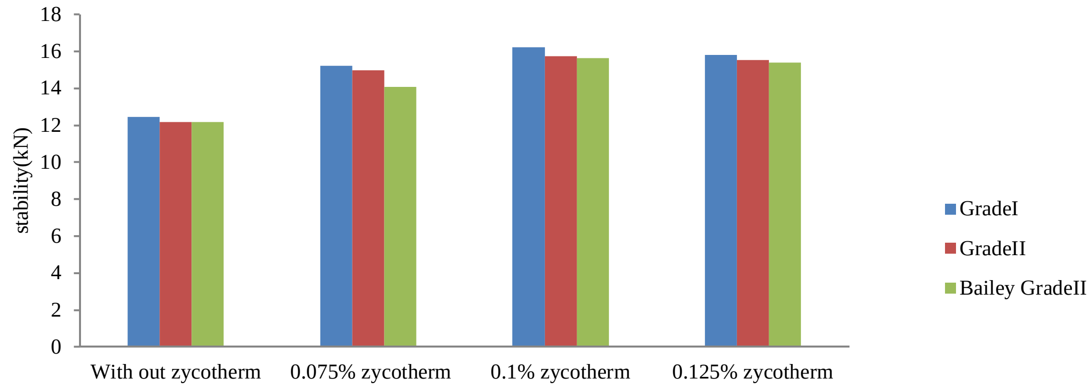

Fig.12: Stability v/s Varying Zycotherm Content

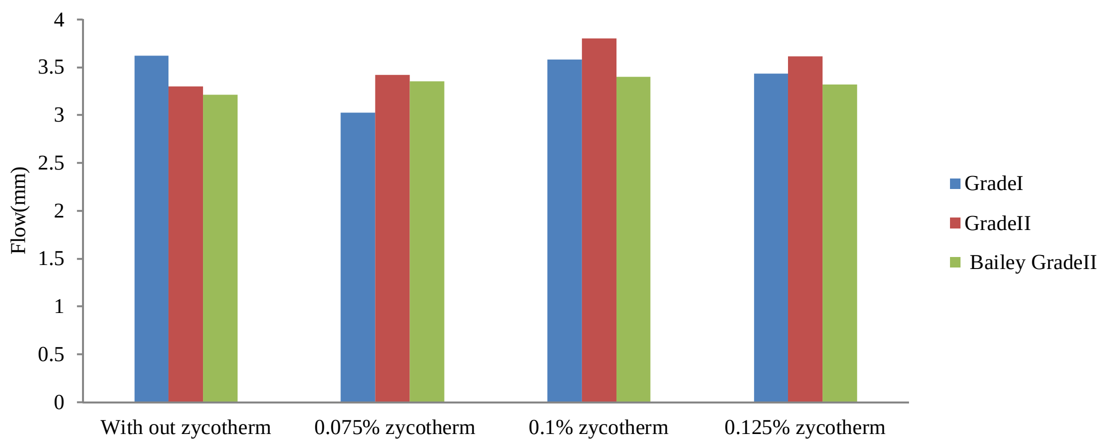

Fig13 : Flow v/s Varying Zycotherm Content

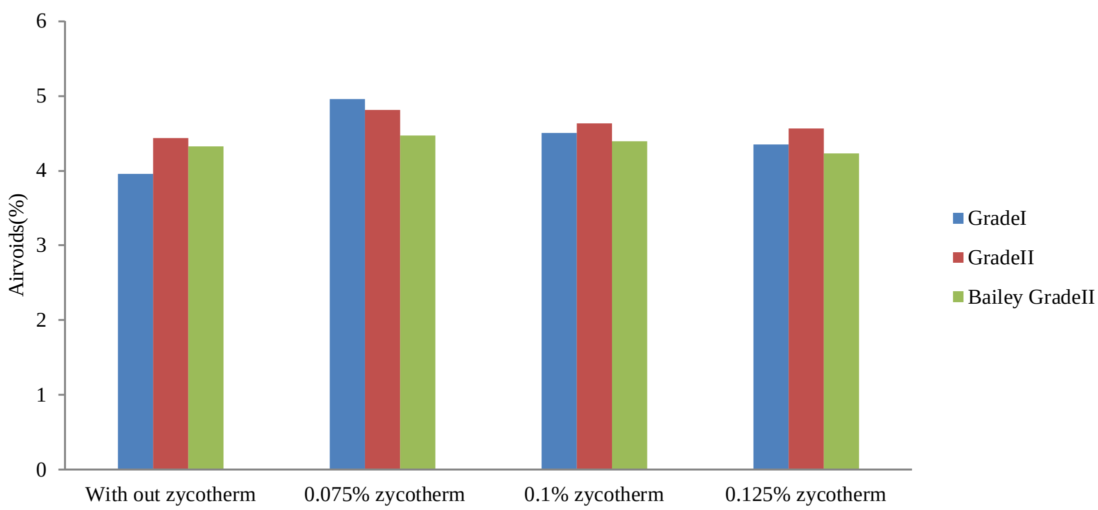

Fig.14 : Air voids v/s Varying Zycotherm Content

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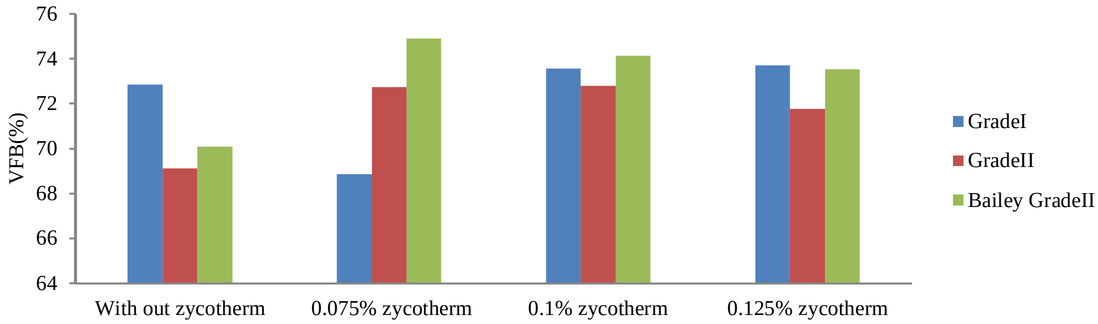

Fig.15 : VFB v/s Varying Zycotherm Content

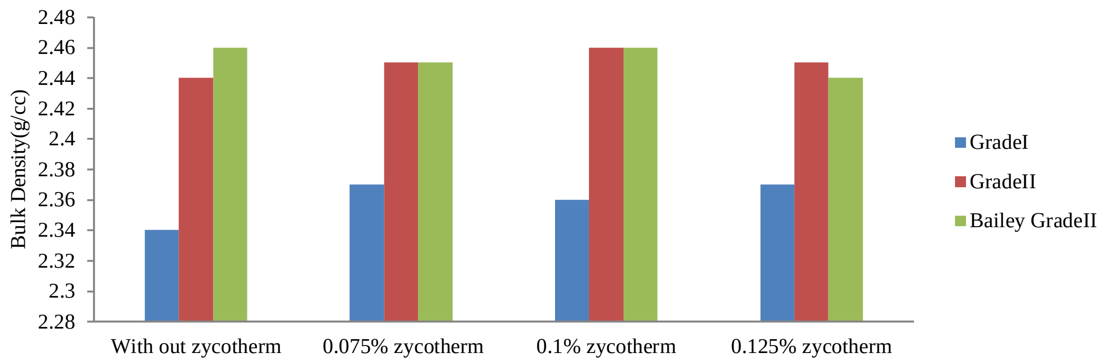

Fig.16 : Bulk Density v/s Varying Zycotherm Content

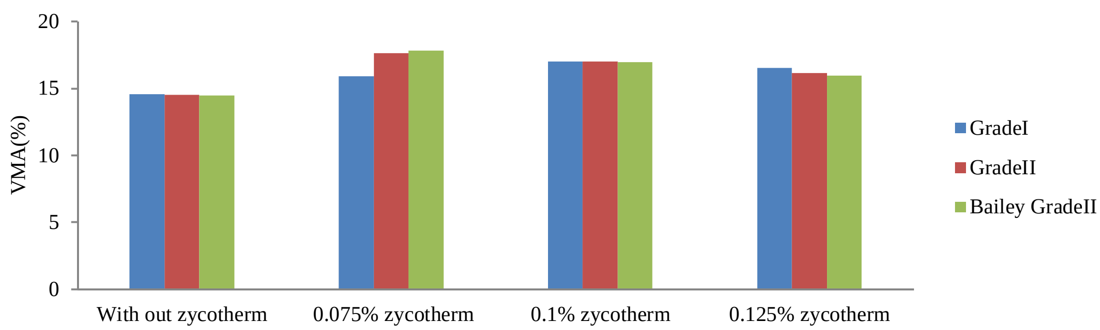

Fig.17: VMA v/s Varying Zycotherm Content

V. CONCLUSION

A. Addition of Zycotherm to Warm mix asphalt effectivey improves the stability of the mix.
B. For conventional mix the maximum stability was found to be 12.43kN for gradeI at an OBC of 5.7%.
C. By the addition of Zycotherm to bituminous concrete mix, maximum stability was found to be 16.19kN at 5.7% optimum binder content for gradeI at a dosage rate of 0.1%.
D. 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 gradeII,28.51% for Bailey gradeII.
E. Flow value is minimum for Grade I at a dosage rate of 0.075%zycotherm which is 3.02mm.
F. 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%)

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

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

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