Influence of Zycotherm on Properties of Bituminous Concrete Mix

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Abstract: Bituminous concrete mix is commonly used as a surface course in India. Use of chemical additives in the conventional mix helps to improve the pavement performance. This research paper attempts to compare the use of Nanomaterials in form of Zycotherm and Nano clay as an admixture in bituminous concrete mix against the orthodox design mix. Initially optimum bitumen content was determined by plotting graphs for stability value, flow value, air voids and bulk unit weight with respect to bitumen content percentage by weight. Different samples with quantity of Zycotherm corresponding to 0.1 % 0.2% and 0.5% by the weight of bitumen (Optimum Bitumen Content 5.5%) were made. The laboratory study concludes that the stability value was improved upon the addition of the additive and optimum Zycotherm content was also determined. Nano clay was also added similarly to the conventional mix and was tested for Marshall Stability and Stripping test. The addition of only Nano clay to the bitumen mix indicates a reduced Marshall Stability value while the Stripping resistance was increased considerably.

Index: Nano clay, Nanomaterial, Stripping resistance, Zycotherm

I. Introduction

Bituminous surfacing or simply flexible pavements find their use mostly in the developing parts of the world. These bituminous surfaces do not generally have great life span and maintenance is needed after duration of time. Distress in the pavement is caused due to damage by heavy vehicles and seasonal temperature changes in the pavement. Water also has many adverse effects on pavement performance and leads to loss of strength and durability in the bituminous mix. This parameter thus leads to increase in cost for maintenance. However consequent researches have proved that incorporating some additives in these bituminous mixes can lead to improvement in pavement properties and help in preventing distress symptoms. Adding these admixtures also helps in providing increased durability and cost effectiveness to the entire bituminous mix. The additive used in the current study is Zycotherm an organo silane additive. Zycotherm comes in form of pale yellow liquid which is miscible with water. The chemical is stable under normal temperature and pressure conditions. It works as a bitumen binder and is added to bitumen before it is mixed with aggregates. It helps in resisting moisture by promoting chemical bonding at aggregate interface. The Nano clay exists as minute particles of layered mineral silicates. Clays occur in different forms such as bentonite, kaolinite, montmorillonite etc.

II. Zychotherm as Antistripping Agents

The chemical affinity between bitumen and aggregate can be improved by the addition of very small quantities of chemicals which change the nature of the bitumen or the aggregate to have more affinity for the other. These chemicals are known as "Anti-stripping Agents" or "adhesion promoters". I since the stability of bituminous pavement largely depends on adhesion between bitumen and aggregates, the ionic nature of aggregate is an important factor explaining the problem of stripping that varies for different type of aggregates. This also explains non-formation of stable bond in bituminous pavement construction. The widely used class of Anti-stripping agents belong to Fatty Polyamine group of chemicals where even in a very small dose they serve to provide Active and passive adhesion between Bitumen and the aggregates. A new class of Nano technology- Organo-silicon based anti-stripping additives is now popular which utilizes the chemistry of Silicon-Silicon bonding [which is nature's strongest chemical bond. Being surface active agents Anti-stripping Agents improve bituminous wetting of aggregates, thereby reducing the requirement of Bitumen. They also prolong the pavement life by slowing the ageing process. The main goal of anti-stripping additives, is to increase the strength and durability of the adhesion between aggregate and bituminous binders. Here we use Zychotherm as antistripping agent which is help the Bituminous Concrete from water damage.

Zycotherm: Zycotherm is an organosilane odour free, chemical warm-mix additive. Additives are added to materials to enhance their properties. They are mostly added to improve either workability or durability. However, there are also certain targeted additives that work on improving a particular aspect of a material, like lowering softening point of bitumen. In this study the Nanomaterial used is Zycotherm.

Fig 1: Zychotherm

III. Properties of Bituminous Concrete

A. Stability

Stability of an asphalt pavement is its ability to resist shoving and rutting under loads (traffic). A stable pavement maintains its shape and smoothness under repeated loading; an unstable pavement develops ruts (channels), ripples (wash boarding or corrugation) and other signs of shifting of the mixture.

B. Durability

The durability of an asphalt pavement is its ability to resist factors such as changes in the binder (polymerization and oxidation), disintegration of the aggregate, and stripping of the binder films from the aggregate. These factors can be the result of weather, traffic, or a combination of the two. Generally, durability of a mixture can be enhanced by three methods.

C. Impermeability

Impermeability is the resistance of an asphalt pavement to the passage of air and water into or through it. This characteristic is related to the void content of the compacted mixture, and much of the discussion on voids in the mix design sections relates to impermeability.

D. Workability

Workability describes the ease with which a paving mixture can be placed and compacted. Mixtures with good workability are easy to place and compact; those with poor workability are difficult to place and compact. Workability can be improved by changing mix design parameters, aggregate source, and/or gradation.

E. Flexibility

Flexibility is the ability of an asphalt pavement to adjust to gradual settlements and movements in the sub-grade without cracking. Since virtually all sub-grades either settle (under loading) or rise (from soil expansion), flexibility is a desirable characteristic for all asphalt pavements.

F. Fatigue Resistance

Fatigue resistance is the pavement's resistance to repeated bending under wheel loads (traffic). Research shows that air voids (related to binder content) and binder viscosity have a significant effect on fatigue resistance.

G. Skid Resistance

Skid resistance is the ability of an asphalt surface to minimize skidding or slipping of vehicle tires, particularly when wet. For good skid resistance, tire tread must be able to maintain contact with the aggregate particles instead of riding on a film of water on the pavement surface (hydroplaning).

IV. Methods of Zycotherm

(A) Field method

- Start stirrer or circulation system to generate proper shearing in the molten bitumen binder before doping of Zycotherm in molten asphalt at 150 ^{0}C – 170 ^{0}C.
- Dopingofsilaneinhotbitumenbindershouldbecoinjectedinthedischargepumpline or co added while the bitumen is being unloaded in the asphalt tank. Do a recirculation in the asphalt tank for two hours before use.
- Prepare asphalt aggregate mixes using silane modified bitumen binder as per specification. For high quality mixes ensure wet fines are not added to the mix in the monsoon season. In case work is to be done in monsoon season, please keep the fines under cover so as to keep them dry. The old buildup should be cleaned before silane modified bitumen starts getting utilized.
- Maintain all technical parameters viz mix design, aggregate composition, job mix formula, construction operation, opening of traffic etc .as per MORTH specifications.

(B) Doping of Zycotherm in VG Bitumen Binder

- Zycotherm dosage is very low compared to most other additives commonly used with the Bitumen binder for variety of purposes. It works by reacting with the aggregate surfaces when it comes in contact with them in the Hot Mix plant. Hence its distribution within the Bitumen binder is important. The Doping of Zycotherm in hot Bitumen Binder with Co inject Zycotherm at the bitumen terminal while loading to the truck or at the time of unloading to the storage tank. Use an injection system to co inject Zycotherm. Do not add Zycotherm directly into the storage tanker containing bitumen, it will not disperse quickly enough. Alternatively it can be added slowly from top (manhole) of the bitumen storage tank. Start circulation of bitumen in bitumen storage tank and dope ZT, take 20 minutes to add 20 kg Zycotherm while circulating bitumen in storage tank and continue the circulation for overnight.

V. Tests with Addition of Zycotherm

a. Marshall Stability Test

The sample constituents are the same with the exception of the addition of the Nano chemical (Zycotherm) in the bitumen. Since Zycotherm is a hot mix additive, the bitumen is heated to a temperature of about 140°C before the chemicals addition. When the desired fluidity is achieved Zycotherm is added drop wise with the help of a syringe in the desired quantity. In current experiment three dosages corresponding 0.1%,0.2% and 0.3% by weight of bitumen added which corresponds to 5.5% by the weight of the aggregates used. The aggregates are heated at a temperature of 100°C for 24 hours and 150°C for 1 hour before the experiment. Then bitumen modified with Zycotherm is added to the heated aggregates. The quantity of bitumen is 5.5% by weight of aggregates, which corresponds to 63 grams in the current study. The bitumen and the aggregates are then mixed thoroughly. The bituminous concrete mix is transferred to the mold and is tamped 65 times on each side with a standard hammer (4.86kg). The sample is then allowed to cool. Similar procedure is followed for casting the remaining samples with varying concentrations of Zycotherm. After 24 hours of cooling the samples are put in a water bath maintained at a temperature of about 60°C for about 30minutes.The samples are loaded on to the Marshall Stability Testing machine and the results obtained are represented in Graph.

Fig 2: Addition of Zycotherm **Fig 3: Bituminous samples with different Zycotherm concentration**

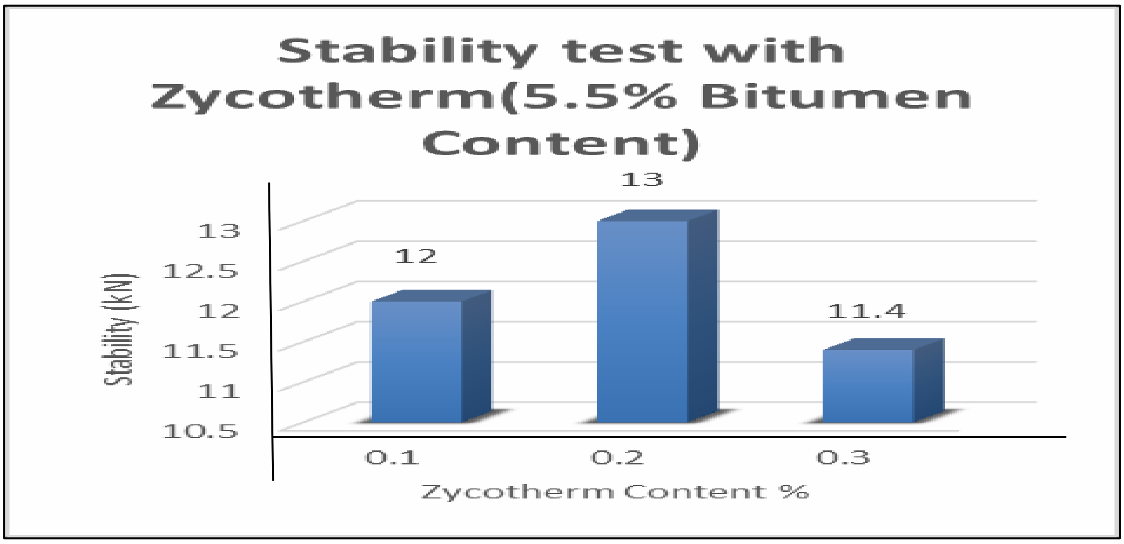
Fig 4: Mixing of bituminous concrete

b. Stripping Test

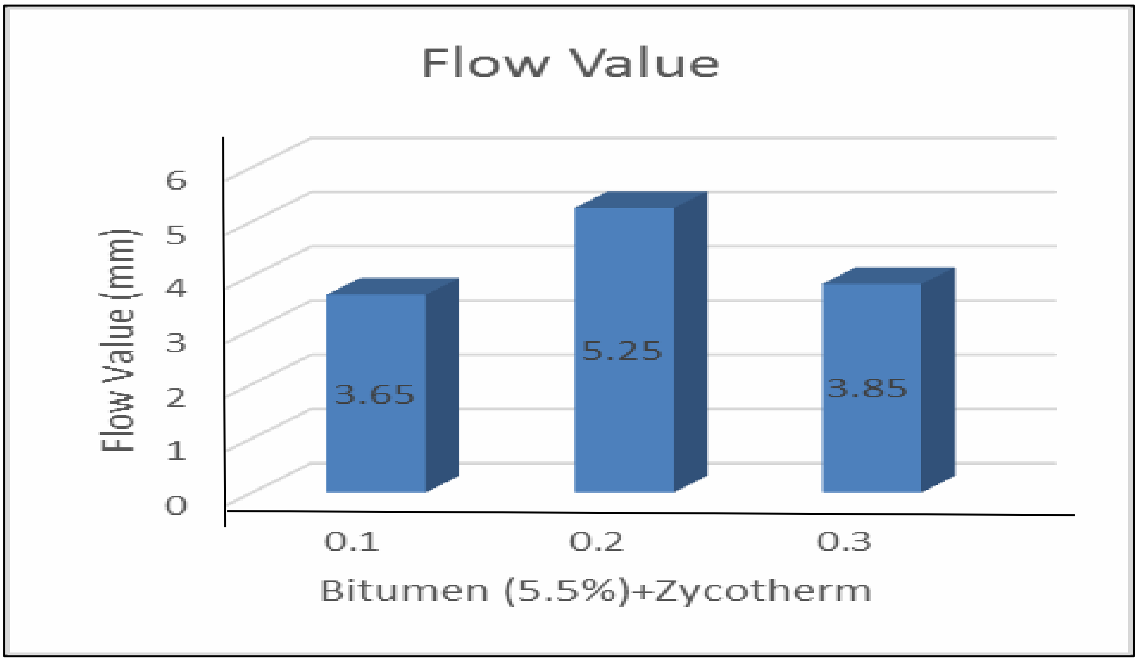
The sample constituents same as taken before except the addition of the additive Zycotherm. The chemical is added with the help of a syringe in desired concentration in bitumen after it is heated to temperature of140^{o}C. The stripping value after the addition of the Nano clay chemical < 2%

Fig 5: Aggregates after Stripping Test

Graph 1: Values of Marshall Stability test with different Zycotherm concentration



Graph 2: Comparison of Flow Value with different Zycotherm concentration



VI. Result and Discussion

A. Aggregate Test Results

Table 1: Physical Properties of Aggregates

Sl. No.	Property	Results	Specifications for BC	Test Method
1	Specific gravity (%)	2.85	2.5-3	IS 2386 PART-3
2	Abrasion Value (%)	14.10%	Max 30%	IS 2386 PART-4
3	Impact Value (%)	9.20%	Max 24%	IS 2386 PART-4
4	Crushing Value (%)	12.80%	Max 30%	IS 2386 PART-4
5	Water Absorption (%)	0.54%	Max 2.0%	IS 2386 PART-3
6	Combined Elongation & Flakiness Indices (%)	29.0%	Max 35%	IS 2386 PART-1

B. Bitumen Test Result

The bitumen for HMA of bituminous concrete shall be of plain bitumen of grade (VG-40) is used for preparation of specimens and for WMA of bituminous concrete specimens were prepared by modified the plain bitumen of VG grade with adding the warm mix asphalt additives.

Table 2: Physical Properties of VG-40Bitumen

Sl. No	Tests	Results	Specifications	Test Method
1	Penetration Test (mm)	88	80-100	IS 1203 – 1978
2	Ductility Test (cm)	102	Min. 75	IS 1208 – 1978
3	Softening point (°C)	48	45-52	IS 1203 – 1978
4	Flash point (°C)	235	Min. 175	IS 1209 – 1978
5	Fire point (°C)	240	Min. 220	IS 1209 – 1978
6	Specific Gravity	1.02	0.97-1.02	IS 1203 – 1978

Table 3: Physical Properties of VG-30 Bitumen

Sl. No	Tests	Results	Specifications	Test Method
1	Penetration Test (mm)	66	50-70	IS 1203 – 1978
2	Ductility Test (cm)	53	Min. 40	IS 1208 – 1978
3	Softening point (°C)	48	45-52	IS 1203 – 1978
4	Flash point (°C)	240	Min. 220	IS 1209 – 1978
5	Fire point (°C)	255	Min. 220	IS 1209 – 1978
6	Specific Gravity	1.02	0.97-1.02	IS 1203 – 1978

C. Specific Gravity Test Result

Table 4: Specific gravity of Materials

Type of material	Specific Gravity Values	Standard Value	Percentage by wt.
Coarse Aggregate (Granite)	2.817	2.5-3	66%

Fine Aggregate (Sand)	2.869	2.4-3	24%
Filler (Stone dust)	2.644	2.02-2.8	4% to 10%
Binder (Bitumen-VG40)	1.02	0.97-1.02	4.5% to 6.5%
Binder (Bitumen-VG30)	1.02	0.97-1.02	4.5% to 6.5%
Additive (Zycotherm)	1.01	-	0.1%

D. Results of WMA at 120°C with Zycotherm

Table 5: Marshall Parameters of WMA at 120ºC with Zycotherm

Bitumen content (%)	Bulk density G_m (g/cm^3)	Percent air voids V_a(%)	Voids in mineral aggregate VMA(%)	Voids filled with bitumen VFB (%)	Stability (KN)	Flow (mm)	(Stability/ Flow)
4.5	1.75	4.93	12.65	61.03	12.45	2.52	4.94
5.2	2.514	4.01	14.96	73.05	13.96	3.59	4.97
5.5	2.37	4.71	17.48	73.05	14.93	3.12	4.79
6	2.18	3.83	16.65	77.00	12.34	3.21	3.84
6.5	2.08	3.53	16.78	78.96	10.39	3.84	2.71

E. Results of Wma Mix At 125°C With Zycotherm

Table 6: Marshall Parameters of WMA at 125ºC with Zycotherm

Bitumen content (%)	Bulk density G_m(kg/m^3)	Percent air voids V_a(%)	Voids in mineral aggregate VMA (%)	Voids filled with bitumen VFB (%)	Stability (KN)	Flow (mm)	(Stability/ Flow)
4.5	1.89	4.87	13.20	63.11	14.95	3.02	4.95
5	2.16	4.48	15.06	70.25	15.71	3.25	4.85
5.5	2.45	4.22	17.43	75.79	17.12	3.43	4.99
6	2.3	3.35	16.87	80.14	14.14	3.67	3.85
6.5	2.16	2.95	16.71	82.35	12.35	4.89	3.17

F. Results of Wma at 130°C With Zycotherm

Table 7: Marshall Parameters of WMA at 130ºC with Zycotherm

Bitumen content (%)	Bulk density G_m (g/cm^3)	Percent air voids V_a (%)	Voids in mineral Aggregate VMA (%)	Voids filled with Bitumen VFB (%)	Stability (KN)	Flow (mm)	(Stability/ Flow)
4.5	1.71	5.12	12.66	59.56	12.13	2.71	4.48
5	1.96	4.85	14.45	66.44	13.24	2.89	4.58
5.5	2.31	4.78	17.23	72.26	13.97	3.23	4.33

6	2.16	4.23	16.93	75.01	11.96	3.25	3.68
6.5	2.02	3.95	16.82	76.52	10.24	3.96	2.59

G. Optimum Bitumen Content Result

Table 8: Average Volumetric properties of mix for finding OBC

PARAMETER	HMA @ 160ºC		WMA @ 120 ºC		WMA @ 125 ºC		WMA @ 130 ºC	
	Max. Value	B.C (%)	Max. Value	B.C (%)	Max. Value	B.C (%)	Max. Value	B.C (%)
Stability(KN)	14.93	5.5	14.93	5.5	17.12	5.5	13.97	5.5
Bulk density(g/cm^3)	2.42	5.5	2.42	5.5	2.45	5.5	2.31	5.5
Air voids (%)	4	5.81	4	5.9	4	5.62	4	6.41
O.B.C (%)	**(5.5+5.5+5.81)/3 =5.6**		**(5.5+5.5+5.9)/3 =5.63**		**(5.5+5.5+5.62)/3 =5.54**		**(5.5+5.5+6.41)/3 =5.80**	

The result obtained in the WMA specimens with varying bitumen content from 4.5% to 6.5% at 125°C temperature, of which the optimum bitumen content was found to be 5.54% which is lower compared to HMA at 160ºC and also WMA at other temperatures.

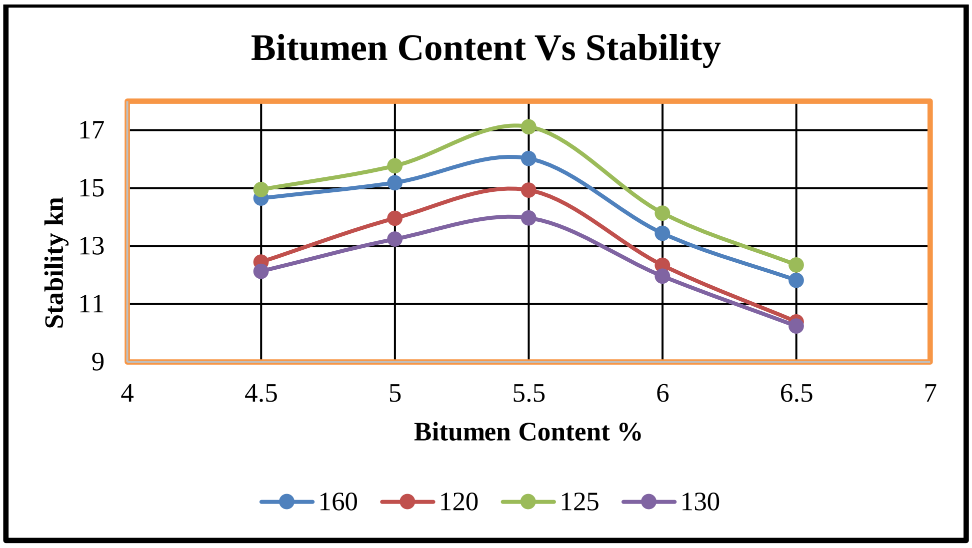
H. Comparision Between Hma And Wma

After getting the laboratory test results compared them through graphical representation as shown below.

Table 9: Comparison of Stability values for HMA and WMA at different temperatures

Stability (KN)				
Bitumen Content (%)	**HMA at160°C (plainbitumen)**	**WMA at 120°C (Zycotherm)**	**WMA at 125°C (Zycotherm)**	**WMA at 130°C (Zycotherm)**
4.5	14.65	12.45	14.95	12.13
5	15.19	13.96	15.77	13.24
5.5	16.02	14.93	17.12	13.97
6	13.44	12.34	14.14	11.96
6.5	11.82	10.39	12.35	10.24

Graph3 : Comparison of Stability values for WMA at 120°C, 125°C, 130°C & HMA at 160°C



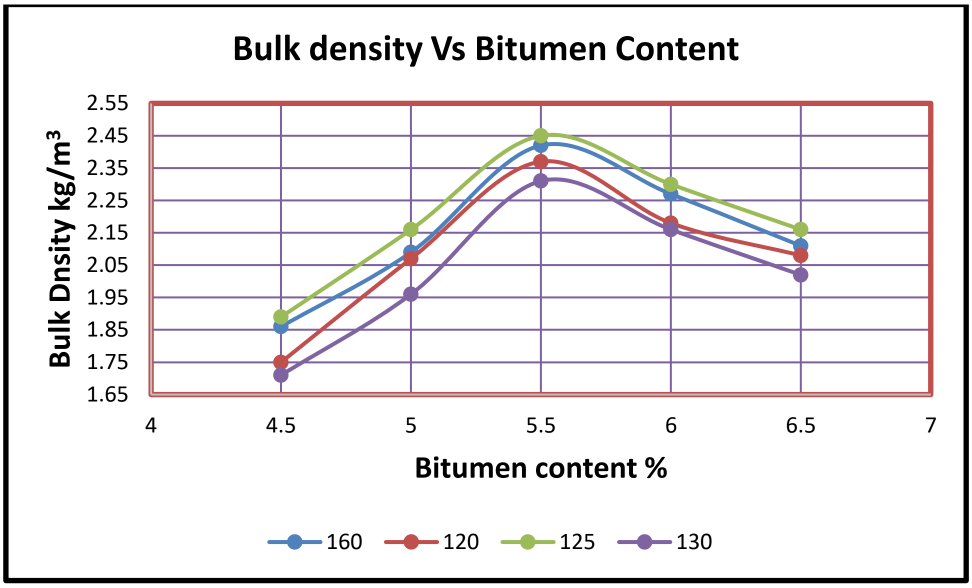
The stability value for the HMA mix at 160°C is 16.02 KN at 125°C and stability of WMA mix is 17.28 KN due to the addition of Zycotherm at a dosage rate of 0.1%. Which shows the stability values of the mix was improved at 125°C with the addition of the Zycotherm.

H. Comparison of Bulk Density for Hma And Wma

Table 10: Bulk density values for HMA and WMA at different temperatures

Bulk Density (g/cm^3)				
Bitumen Content (%)	HMA at160°C (plainbitumen)	WMA at 120°C (Zycotherm)	WMA at 125°C (Zycotherm)	WMA at 130°C (Zycotherm)
4.5	1.86	1.75	1.89	1.71
5	2.09	2.07	2.16	1.96
5.5	2.42	2.37	2.45	2.31
6	2.27	2.18	2.3	2.16
6.5	2.11	2.08	2.16	2.02

Graph 4: Comparison of Bulk Density for WMA at Different Temperature



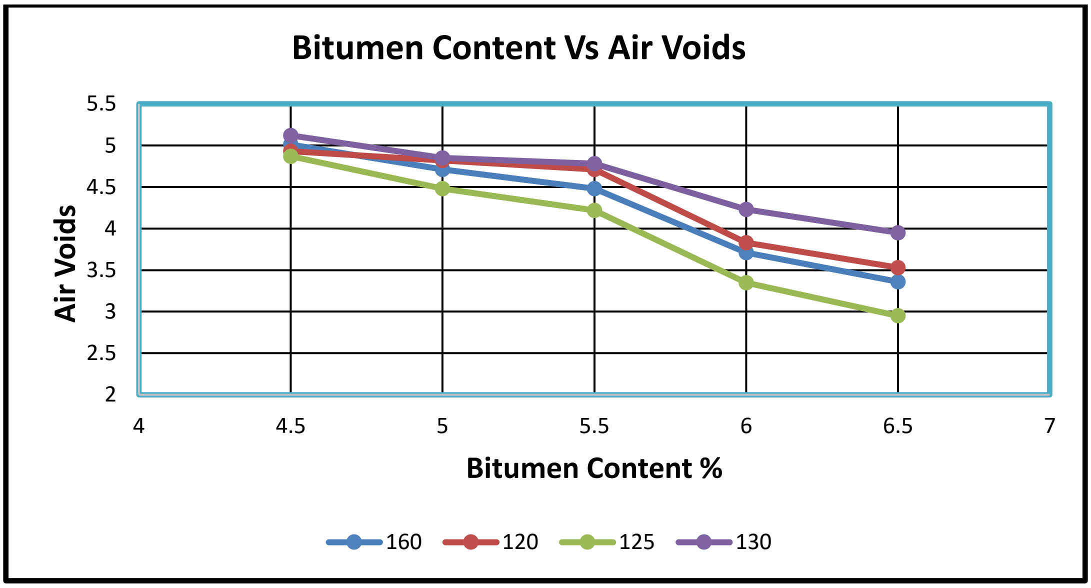
Initially the increase in the binder content increased the bulk density but further increase in bitumen content decreases the bulk density for both HMA and WMA mix at three temperatures. The Bulk density for the HMA mix at 160°C was 2420 kg/m³, at 125°C the WMA mix had a Bulk density of 2450 kg/m³ with the addition of Zycotherm at a dosage rate of 0.1%. It showed that the bulk density of the WMA mix at 125ºC is greater than the HMA mix.

I. Comparison of air voids for HMA and WMA

Table 11: Comparison of Air voids for WMA with additive and HMA without additive

Air Voids (%)				
Bitumen Content (%)	**HMA at160°C (plain bitumen)**	**WMA at 120°C (Zycotherm)**	**WMA at 125°C (Zycotherm)**	**WMA at 130°C (Zycotherm)**
4.5	5.01	4.93	4.87	5.12
5	4.71	4.82	4.48	4.85
5.5	4.48	4.71	4.22	4.78
6	3.71	3.83	3.35	4.23
6.5	3.36	3.53	2.95	3.95

Graph 5: Comparison of Air voids for WMA at Different Temperature



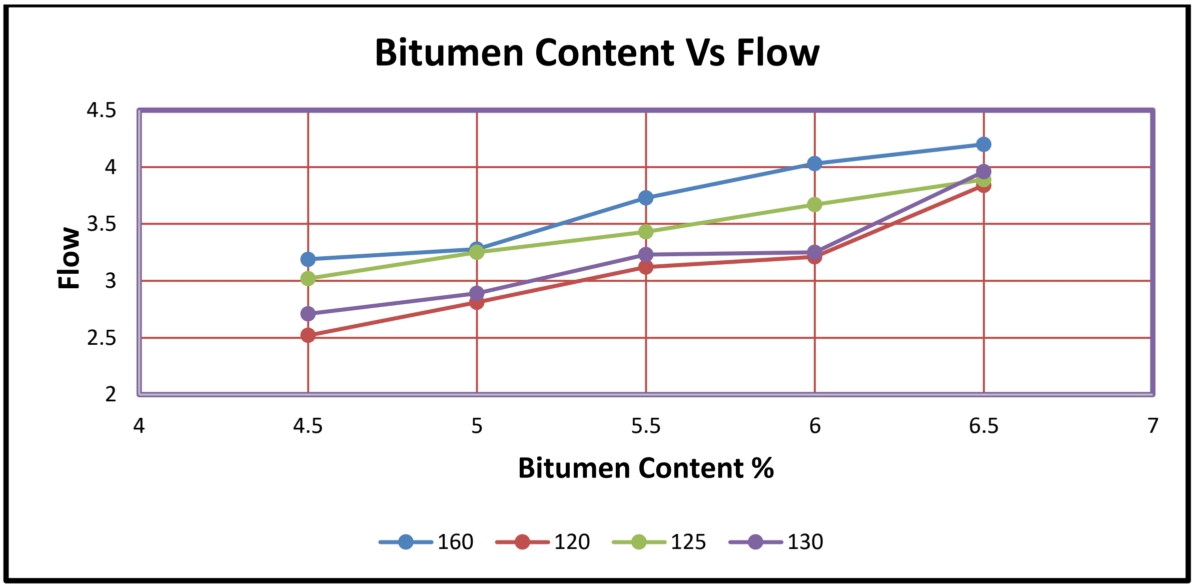
As shown in above graph, the percentage air voids in the mix were found to decrease with the increase in the binder content for different temperature. These values were compared with HMA specimens at 160°C temperature, of which WMA specimens at 125°C meets the design requirement due to addition of chemical additive.

J. Comparison of Flow Value For Hma And Wma

Table 12: Comparison of flow value for HMA without additive and WMA with additive

Flow(mm)				
Bitumen Content (%)	**HMA at160°C (plainbitumen)**	**WMA at 120°C (Exothermic)**	**WMA at 125°C (Exothermic)**	**WMA at 130°C (Exothermic)**
4.5	3.19	2.52	3.02	2.71
5	3.28	2.81	3.25	2.89
5.5	3.73	3.12	3.43	3.23
6	4.03	3.21	3.67	3.25
6.5	4.2	3.84	3.89	3.96

Graph 6: Comparison of Flow value for WMA at 120°C, 125°C, 130°C & HMA at 160°C



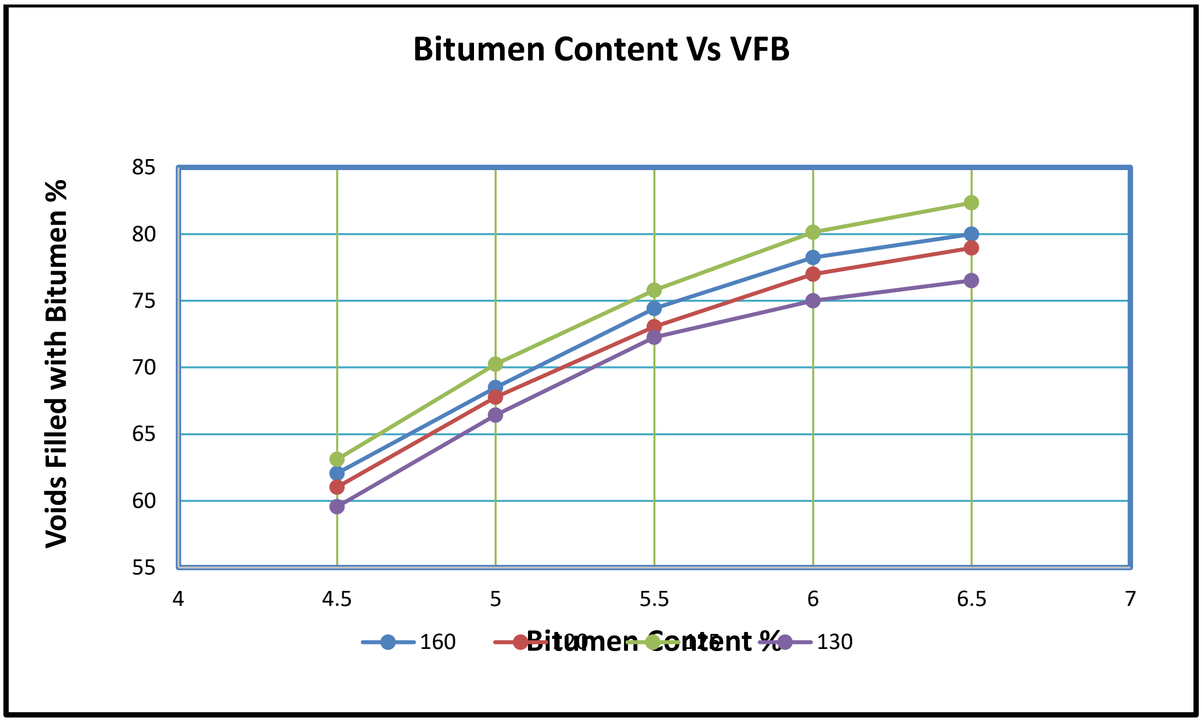
As shown in above graph, the flow values were found to increase with the increase in binder content for each temperature. The WMA values at 120°C, 125°C, 130°C were compared with HMA specimen at 160°C temperature, of which WMA specimen values at are lower and meets the requirement of HMA.

K . Comparison Vfb Values For Hma And Wma

Table 13: Comparison of VFB values for HMA without additive and WMA with additive

VFB (%)				
Bitumen Content (%)	**HMA at160°C (plainbitumen)**	**WMA at 120°C (Exothermic)**	**WMA at 125°C (Exothermic)**	**WMA at 130°C (Exothermic)**
4.5	62.07	61.03	63.11	59.56
5	68.49	67.78	70.25	66.44
5.5	74.43	73.05	75.79	72.26
6	78.25	77	80.14	75.01
6.5	80.00	78.96	82.35	76.52

Graph 7: Comparison of VFB values for WMA at 120°C, 125°C, 130°C &HMA at 160°C



As shown in above graph the flow values were found to increase with the increase in the bitumen content for each temperature. The WMA values at 120°C, 125°C, 130°C were compared with HMA specimens at 160°C temperature, of which WMA specimen at 125°C temperature showed the better result.

Improved Marshall StabilityValue

The Marshall Stability Value at 5.5% bitumen content was 11.7 kN whereas when Zycotherm at 0.2% (by weight of bitumen) was used which was calculated as the optimum dosage for the Nano chemical the Marshall Stability Value was considerably higher at 13 kN.

Improved Workability

At optimum dosage 0.2% (by weight of bitumen) the workability of the mix was greatly improved. The mixing force required for the manual mixing of the bituminous concrete was enough to support the claim.

Improved Compaction

The heights of the two Marshall Stability samples in the two cases with and without Zycotherm were different. The sample with Zycotherm showed improved compaction and therefore was lesser in height when compared to sample without Zycotherm. Sample Height (Without Zycotherm) = 64 mm. Sample Height (With Zycotherm) = 59 mm.

Reduced StrippingValue

Though Zycotherm is not advertised as an anti-strip its use still improved the stripping resistance of the bituminous concrete mix. Stripping Value without Zycotherm= 20%. Stripping Value with Zycotherm= 5%.

Insignificant change in stabilityvalue

Marshall Stability value without Nano clay =11.7 KNMarshall stability value with Nano clay (10%) =10.9 KN

The Marshall stability value got slightly reduced.

Highly improved Stripping Resistance

Stripping Value without Nano Chemicals= 20%. Stripping Value with Nano Clay<2%. The stripping value when Nano Clay was used was almost negligible.

Improved Structure

NanoClay within the bitumen leads to improved structure and reduction in air voids. This makes the resulting mix less susceptible to moisture damage. This is also the reason for the improved stripping resistance.

Conclusion

Nanotechnology offer the possibility of great advances and incremental improvements in construction materials. Nano particle additives have high potential for application in bituminous concrete mixes. Addition of Zycotherm as an additive improves the durability of the pavement and hence helps in decreasing the maintenance cost. Hence it is evident that Nano Chemicals such as Zycotherm have many benefits and have favorable results for flexible pavements. It helps in stiffening of the binder material and also increases its stripping resistance. The only problem with utilization of Nano materials is its cost effectiveness. As the cost of these Nano materials are very high the application of these materials is therefore limited. Adequate research still needs to be carried out as well as implemented if the sector has to progress. Just like the Nano Chemicals used in this study there are numerous others available commercially manufactured chemicals which have not been tested for the flexible pavements and can have other advantages.

The benefits of Zycotherm mentioned above tests to this statement.

Future scope

Pavement structures consisting of several hot mix bituminous layers require a certain degree of bonding with layer interfaces. A tack coat is applied at the interface between the two bituminous layers which acts as an adhesive so that combined pavement layers perform as a monolithic structure. Hot bituminous binder such as VG-10, cutback bitumen or bitumen emulsion are commonly used as a tack coat materials according to IRC: 16.The use of bitumen emulsion as a tack coat material is escalating instead of cutback bitumen or hot bituminous binder because of their lower application temperature and environmental concerns. Tack coat is a light application of low viscosity liquid bituminous material like emulsion, hot melted bitumen and cutback bitumen to an existing surface (bituminous/cement concrete/primed granular surface) to facilitate a bond between the surface being paved and the overlaying course. The tack coat is recommended for all types of overlays. The only possible exclusion might be when an overlay is to be placed within 48 hours on a freshly laid bituminous surface that has not been subjected to any traffic or contaminated by dust. Bitumen emulsion commonly used for tack coat are RS-1, SS-1, CSS-1 and CSS-1. Some of the drawbacks in use not bitumen emulsions as tack coat are i) Tire pick up ii) Long curing time iii)Clogging of spray nozzles due coarser emulsion particles. Zydex Industries developed an additive known as NANOTAC, which is used as an additive in diluted cationic bitumen emulsion for tack coat applications for ensuring chemical bonding i.e trackless tack coat.

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