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Relative Study on Warm and Hot Bituminous Mixes

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ABSTRACT

In this work, comparison made between the Warm mix and bituminous mix technology. Warm Mix Asphalt (WMA) technology is one of the solutions which combine energy savings and environmental benefits. It is a modification of the conventional method of construction of flexible pavements which is surfaced with Hot Mix Asphalt (HMA), which involves high mixing temperatures up to 140oC. A bituminous mix essentially consists of coarse aggregates, fine aggregates, filler and bitumen which bind together all the constituents at high temperature. The optimum dosage of Bitubuild WM was found out to be 2% by weight of bitumen and the optimum binder content for the mix was 5.66% for BC samples and 4.68% in DBM samples. No change in optimum binder content was found by addition of warm mix additive. There was a slight increase in densities of mix with addition of warm mix additive. In BC sample, there was an increase from 2.344 g/cc to 2.370 g/cc and in DBM sample, there was increase from 2.369 g/cc to 2.378 g/cc. There was a slight increase in Marshall Stability value with addition of warm mix additive. In BC sample, there was an increase from 21.15 kN to 25.53 kN and in DBM sample, there was increase from 20.17 kN to 22.14 kN.

KEYWORDS: *Warm Mix Asphalt (WMA), Hot Mix Asphalt (HMA), DBM*

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1. INTRODUCTION

In India consists of transport by roadways, railways, airways and waterways. Out of these, road transport is the most important mode of transportation in India. Indianroads carry 85 per cent of the passengers and 70 per cent of the freight traffic of the country. In a densely populated country like India, where vehicular density has an annual growth of 10.5% the need of improved technologies for road construction methods is being realized lately, which must be efficiently durable as well as cost effective. On the other hand, the modern technologies should also focus on environmental point of view.[1] Construction of roads consumes a lot of energy and resources. With the rise of environmental awareness in recent decades, massive research is taking place for cleaner and greener products and technologies in all fields. In road construction, Warm Mix Asphalt (WMA) technology is one of the solutions which combine energy savings and environmental benefits. It is a modification of the conventional method of construction of flexible pavements which is surfaced with Hot Mix Asphalt (HMA), which involves high mixing temperatures up to 140^{0}C. On the same hand, in the modernization of the technology, there should be no compromise with the strength and other characteristics of the pavement [2].

2. BITUMINOUS MIXES

A bituminous mix essentially consists of coarse aggregates, fine aggregates, filler and bitumen which binds together all the constituents at high temperature. It is used in flexible pavements. The ease of construction, adequate strength, workability, durability and cost- effectiveness of flexible pavement is the reason it is so extensively used in road construction.[3] The design of flexible pavement is two folded, i.e. - calculating thickness required and mix design. The mix design consists of balancing the proportions of various constituents, achieving the desired requirements according to the type of pavement. The performance in service life of the mix is estimated by various laboratory tests. The work of an engineer is to make a precise design which may save considerable investments, give reliable performance and at the same time be environment friendly.

2.1. Types of Bituminous Mixes

The bituminous mix are Dense graded bituminous mix, Semi dense bituminous mix, Open graded bituminous mix, Gap graded bituminous mix.

2.1.1. Dense graded bituminous mix

It is a dense mix which is achieved by well gradation of aggregates. It consists of aggregates of nearly all sizes packed together, resulting in high inter-particle friction and offering good compressive strength.[4] Specifications for dense graded bituminous mixes have been defined in MORTH 5th revision, 2013 in section 500. Dense Bituminous Macadam (section 505) and Bituminous Concrete (section 507) are used as dense mixes in India. They are used as binder course and surface course respectively.

2.1.2. Semi dense bituminous mix

IRC:95-1987 gives specifications for semi dense bituminous mix. There gradation lies in between densely graded and open graded mix. Semi Dense Bituminous Concrete (SDBC) and Mixed Sealed surfacing (MSS) are the two types used in

India. Undesired voids in these types of mix needs to be taken care of as they may allow water seepage to layers below and cause defects like potholes and stripping off of bitumen.[5]

2.1.3. Open graded bituminous mix
They have non uniform grading of aggregates. Filler particles and fine aggregates are minimum in quantity, only crushed stones and small amount of manufactured sands are there.[6] It is designed to be water permeable unlike dense graded mix. It can be used as a base mix (asphalt treated permeable base, bituminous macadam, built-up spray grout) or as surface mix (open graded friction course, premix carpet).

2.1.4. Gap graded bituminous mix
Large course aggregates are absent from the mix. They offer resistance to fatigue and possess good tensile strength. Stone mixed asphalt (SMA) is most commonly used gap graded mix. It comprises of highly durable aggregates, higher binder content and some fibers.[7] It offers a highly stable, tough and rut resistance mix. It is used in high traffic volume roads.

2.2. Layers in Bituminous Roads
A bituminous road is typically formed in a number of layers, each layer having its own functions and accordingly its composition is designed. The load is transferred from top layer to the bottom by grain to grain mechanism and then finally distributed on earth. Each layer demands different properties and hence the type of bituminous mix for that layer is carefully chosen show in fig 1.1.

2.2.1. Surface course
It is the topmost layer of the pavement, which is visible to the traffic. It directly takes up the vehicular load and transfers it to the layers below. It is responsible to provide smooth riding surface to the vehicles.[8] Surface course must be composed of quality materials to resist distortion under traffic load and also ensure that there is no entry of water. Generally, dense graded bituminous concrete is used in this layer.

2.2.2 Binder course
Its main purpose is to distribute load to the base course. It can be treated as a part of surface course only, but with less bitumen content and less quality materials, for a more economical design.

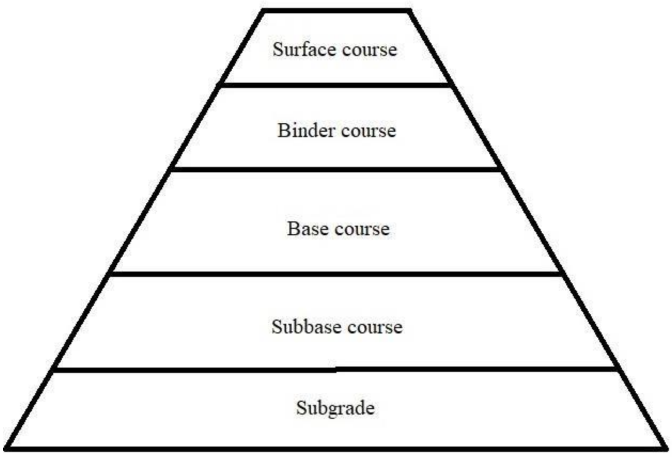

Figure 1.1 Layers of Bituminous Pavement

2.2.2. Base course
It further distributes the load from layer above to the sub base and adds to sub-surface drainage.

2.2.3. Sub-base course
Primary functions are to provide structural support, improve drainage and to reduce the intrusion of fine aggregates from below sub grade.

2.2.4. Subgrade
It is a layer of natural soil, prepared to receive load from above and disperse it safely. Generally, it is made by compaction of naturally occurring soil to desired thickness.

3. WARM MIX ASPHALT
The concept of warm mix was first introduced in Europe in late 1990's with the increase in environmental awareness. The main objective of this technology is to reduce the harmful emissions formed by conventional hot mix. WMA is produced at temperatures 20 to 50^{O}C lower than HMA.[9] Retaining same strength, durability and performance at reduced temperature is achieved by adding certain additives, emulsions or by changing the methodology of production. In future, warm mix technology would effectively replace hot mix technology, due to alarming environmental depletion taking place at present. As the technology is new and developing, continuous research is going on the selection and suitability of the additives used.

3.1. Types Of Warm Mix Asphalt
The warm mix asphalt is Foaming technologies, Organic additives, Chemical additives, Hybrid technologies.

3.1.1. Foaming technology
This method is based on increasing the volume of the bitumen. This is achieved by injecting small amount of water into the bitumen, either directly in hot bitumen or in mixing chamber. When water gets evaporated, it creates foaming action and thus makes the asphalt less viscous at lower temperature. Excess water can cause stripping action, so additional care is required in design[10]. According to the method of addition of water, foaming technology can be of following two types. (i)Water carrying chemical additives: Certain zeolites or mineral additives are added to mix which contains moisture absorbed in them. With rise in mix temperature, water gets released in bitumen in the form of very tiny foam droplets. Hence its volume gets increased and the aim of proper coating of aggregates is achieved. (ii)Wet fine aggregate addition: This is done in two steps.[11] First, the binder is mixed with heated aggregates in the mixer. Fine aggregates containing about 3% moisture content is then added to mix. This water gets evaporated with temperature and causes foaming action.

3.1.2. Organic additives
In this method, an organic compound is added to the mix, which has melting point close to the temperature of mixing. The compound melts and increases the viscosity of bitumen.[12] As the asphalt cools down after placement, the additive solidifies into small dispersed particles, providing stiffness to the binder. Long chain hydrocarbons having large molecular mass can be used as additives. Melting point of the additive should be more than the temperature prevailing at site, as it may melt again and loosen its strength.

3.1.3. Chemical additives
This method is different from the above two methods. The principle behind this method is to decrease the friction between the aggregates and bitumen. This in turn helps in getting desired workability of mix. A mixture of emulsifying agents, surfactants (surface acting agents) and polymers is used in pre- determined proportions. 28-50^{o}C fall of temperature can be noted by using this method.

3.1.4. Hybrid technologies
As the name suggests, it is a combination of two or more technologies. Low energy asphalt (LEA) is an example which makes use of a chemical additive along with injection of water in the mix.

4. METHODOLOGY
To determine optimum binder content Prepare samples of HMA using VG 30 binder for DBM. And Prepare samples of HMA using VG 30 binder for BC. Determine Marshall Stability value, Flow value, density, VMA and VFB of normal HMA mixes. Similar samples of WMA using VG 30 binder and optimum dose of warm mix additive for DBM and BC. The preparation temperature of both HMA and WMA mixes. Determine all the properties of WMA compare it with HMA and also determine the retained stability of HMA and WMA.

5. RESULTS AND ANALYSIS
5.1. Materials Used In the Study
For preparing samples of DBM and BC layer, VG-30 grade bitumen was used with aggregates of specified grading. For preparing warm mixes, warm mix additive "Bitubuild WM" was used. The properties of various materials used are discussed are Warm Mix additive: Bitubuild WM in Fig 1.2 was used for preparing warm mix samples. Its main function is to provide necessary workability to the mix so that the mix can be prepared at a lower temperature and provide proper coating of binder on the aggregate surface. Aggregates: For preparing DBM samples, aggregates of nominal maximum size 26.5mm, 19 mm, 13.2 mm and stone dust was used. For preparing BC samples, aggregates of nominal maximum size 19 mm, 13.2 mm and stone dust was used. The tests were performed on aggregates in order to meet the physical requirements as described in MORTH Specifications for Road and Bridge Work (5th revision), in Table 1.1.

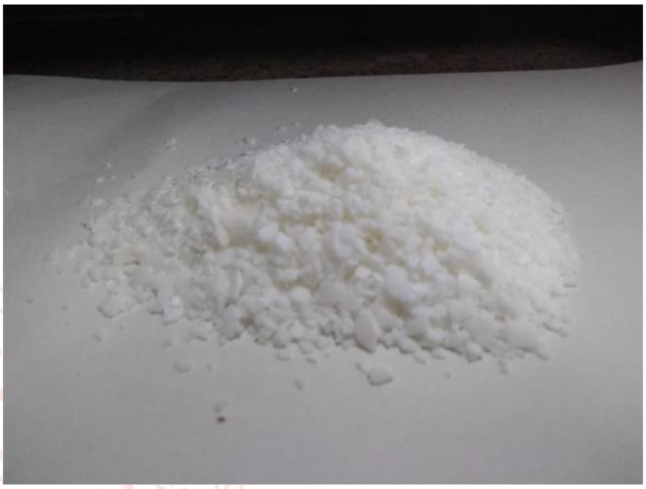

Figure 1.2 Bitubuild WM

Table 1.1 Physical Properties of Aggregates

Physical Properties	Nominal Maximum Aggregate Size			MORTH Specifications
	26.5 mm	19 mm	13.2 mm	
Specific Gravity	2.77	2.62	2.66	2.6-2.8
Elongation Index (%)	12.1	12.3	12.8	Maximum 30% (Combined)
Flakiness Index (%)	9	9.4	8.1	
Impact Value (%)	17.5	18.4	20.3	Max. 24%
Water Absorption (%)	0.39	0.42	0.51	Max. 2%

Cement used for preparation of BC samples was Ordinary Portland Cement. The specific gravity was found out to be 3.15. Binder: VG-30 grade bitumen was used for preparing samples. The tests were performed on bitumen complying with the Indian Standard Specification IS 73:2013 in table 1.2.

Table 1.2 Properties of Bitumen

Properties	VG-30	Required
Penetration	58 mm	50-70 mm
Softening point	49^{o}C	Min. 47^{o}C
SpecificGravity	1.0	0.99-1.1

5.2. Requirements of Bituminous Mixes
The samples prepared for both DBM and BC layer should meet minimum requirements as given in MORTH Specifications for Road and Bridge Work (5th revision), Table 1.3.

Table 1.3 Requirements of Dense Bituminous Mixes

Properties	Required Values
Marshall Stability Value, kN	9
Flow (mm)	2-4
Air Voids (%)	3-5
Minimum Voids in Mineral Aggregates (VMA)%	11-13
Voids filled with bitumen (VFB)%	65-75

5.3. Determination of Job mix formula for BC hot mix by Marshall Method

Sieve analysis was done for aggregates of maximum nominal size 19 mm, 13.2 mm, stone dust and also cement. Grading is shown in table 1.4.

Table 1.4 Sieve analysis of aggregates to be used in BC layer

IS Sieve size	%passing 19mm	%passing 13.2mm	%passing Stone Dust	%passing Cement	Grading of Aggregate blend (%)	%passing required
19mm	89.75	100	100	100	97.74	90-100
13.2mm	12.05	95.00	100	100	78.85	59-79
9.5mm	1.85	78.70	100	100	70.74	52-72
4.75mm	0.05	5.05	96.8	100	42.55	35-55
2.36mm	0	0.05	75.05	100	32.04	28-44
1.18mm	0	0	62.35	100	26.94	20-34
.600mm	0	0	47.95	100	21.18	15-27
.300mm	0	0	34.10	99.20	15.62	10-20
.150mm	0	0	20.05	98.50	9.99	5-13
.075mm	0	0	14.60	98.00	7.80	2-8

Ratio for aggregates of maximum nominal size 19mm, 13.2 mm, stone dust and cement used is 22:36:40:2 respectively. This ratio was calculated by hit and trial method complying with Grading 2 for BC pavement layer given in MORTH Specifications for Road and Bridge Work (5^{th} revision).

5.4. Quantity of Aggregates used

After setting the ratio of aggregate blend, quantity of different aggregates and cement required for the preparation of sample was calculated as shown in table 1.5.

Table 1.5 Quantity of Aggregates used in BC samples

Maximum nominal size	Percentage used	Weight of aggregates
19 mm	22%	264 g
13.2 mm	36%	432 g
Stone dust	40%	480 g
Cement	2%	24 g

5.5. Quantity of Bitumen Used

To find out the optimum binder content, samples were prepared at four different binder contents as shown in table 1.6.

Table 1.6 Quantity of Bitumen used in BC samples

Percentage of Bitumen (%)	Weight of Bitumen (g)
5.43	69
5.66	72
5.88	75
6.10	78

5.6. Marshall Stability Test results for BC hot mix

Marshall Stability test was performed on BC samples prepared. Three samples at each binder content were made and their average values are in table 1.7. Also the temperature at the time of mixing was noted.

Table 1.7 Marshall Stability Test for BC hot mix

Bitumen Content (%)	5.43	5.66	5.88	6.10
Specific Gravity of Bitumen	1.0	1.0	1.0	1.0
Density (g/cc)	2.334	2.335	2.338	2.330
Specific Gravity of Aggregate Blend	2.657	2.657	2.657	2.657
Volume of Bitumen, V_b (%)	12.67	13.27	13.75	14.21
Volume of Aggregate, V_a (%)	83.07	83.24	82.82	82.34
Voids in Mineral Aggregate, VMA (%)	16.92	16.75	17.18	17.65
Voids Filled with Bitumen, VFB (%)	74.89	79.19	80.00	80.49
Air Voids (%)	4.25	3.48	3.43	3.44
Stability (kN)	17.58	21.14	19.49	17.49
Flow value (mm)	4.30	4.50	4.65	4.65

5.7. Determination of Optimum Binder Content

Most optimum values of results of Marshal Stability test were found to be at binder content 5.66%. Therefore, the optimum binder content comes out to be 5.66%. The quantity of binder used for making warm mix samples will be 72 gm.

5.8. Quantity of Warm Mix Additive

To find out the optimum dosage of warm mix additive, samples were made at four different additive contents, i.e. – 1%, 2%, 3% and 4% by weight of bitumen show in table 1.8.

Table 1.8 Quantity of Warm Mix Additive used

Additive content by weight of Bitumen (%)	Weight in grams
1	0.72
2	1.44
3	2.16
4	2.88

5.9. Determination Of Optimum Warm Mix Additive Content

Warm mix samples of BC layer were made at optimum binder content (5.66%). Three samples each at four different additive contents i.e. - 1%, 2%, 3% and 4% of binder content were made show in table 1.9. Marshall Stability Test was performed on these samples and results are tabulated below. Also the temperature at time of mixing was noted.

Table 1.9 Marshall Stability Test for BC Warm Mix

Additive Content (%)	1	2	3	4
Specific Gravity of Bitumen	1.0	1.0	1.0	1.0
Density (g/cc)	2.348	2.370	2.350	2.342
Specific Gravity of Aggregate Blend	2.657	2.657	2.657	2.657
Volume of Bitumen, V_b (%)	13.29	13.41	13.30	13.26
Volume of Aggregate, V_a (%)	83.37	84.15	83.44	83.17
Voids in Mineral Aggregate, VMA (%)	16.63	15.85	16.56	16.83
Voids Filled with Bitumen, VFB (%)	79.99	84.62	80.30	78.70
Air Voids (%)	3.34	2.44	3.23	3.57
Stability (kN)	23.80	25.53	24.31	23.71
Flow value (mm)	4.2	4.6	5.0	5.1

From the test results above, most optimum values of results come out to be at 2% additive content. Therefore, optimum dosage of warm mix additive is 2% by weight of bitumen.

5.10. Test for Retained Stability Of BC Samples

To find out the retained stability, samples were made of BC hot mix at optimum binder content and BC warm mix at optimum additive content. Their Marshall stability values after keeping the samples in water bath at 60^{o}C for 24 hours were noted. A comparison is made between the percentage of stability retained after putting the samples in water for 24 hours in hot and warm mix.

5.11. Determination of Job mix formula for DBM hot mix by Marshall Method

Sieve analysis was done for aggregates of maximum nominal size 26.5 mm, 19 mm, 13.2 mm and stone dust. Grading is shown below in table 1.10. Ratio for aggregates of maximum nominal size 26.5 mm, 19mm, 13.2 mm and stone dust used is 16:18:34:32 respectively.

Table 1.10 Sieve analysis for aggregates to be used in DBM layer

IS Sieve Size	%passing 26.5mm	%passing 19mm	%passing 13.2mm	%passing Stone Dust	%passing required	Grading of Aggregate blend (%)
26.5mm	97.7	100	100	100	90-100	99.63
19mm	51.00	91.50	100	100	71-95	90.63
13.2mm	1.20	17.00	99.55	100	56-80	69.10
4.75mm	-	-	25.05	96.80	38-54	39.49
2.36mm	-	-	16.50	75.05	28-42	29.62
.300mm	-	-	-	34.10	7-21	10.91
.075mm	-	-	-	14.60	2-8	4.67

5.12. Quantity of Aggregates used

After setting the ratio of aggregate blend, quantity of different aggregates and cement required for the preparation of sample was calculated as shown in table 1.11.

Table 1.11 Quantity of aggregates used in DBM samples

Maximum nominal size	Percentage used	Weight of aggregates
26.5 mm	16%	192 g
19 mm	18%	216 g
13.2	34%	408 g
Stone Dust	32%	384 g

5.13. Quantity of Bitumen used
To find out the optimum binder content, samples were prepared at four different binder contents as shown in table 1.12.

Table 1.12 Quantity of bitumen used in DBM samples

Percentage of Bitumen (%)	Weight of Bitumen (g)
4.53	57
4.68	59
4.83	61
4.99	63

5.14. Marshall Stability Test Results For DBM Hot Mix
Marshall Stability test was performed on DBM samples prepared. Three samples at each binder content were made and their average values are table 1.13. Also the temperature at the time of mixing was noted.

Table 1.13 Marshall Stability Test for DBM hot mix

Bitumen Content (%)	4.53	4.68	4.83	4.99
Specific Gravity of Bitumen	1.0	1.0	1.0	1.0
Density (g/cc)	2.346	2.369	2.355	2.345
Specific Gravity of Aggregate Blend	2.667	2.667	2.667	2.667
Volume of Bitumen, V_b (%)	10.63	11.09	11.37	11.70
Volume of Aggregate, V_a (%)	83.98	84.71	84.03	83.54
Voids in Mineral Aggregate, VMA (%)	16.02	15.29	15.97	16.46
Voids Filled with Bitumen, VFB (%)	66.43	72.53	71.20	71.00
Air Voids (%)	5.37	4.20	4.60	4.76
Stability (kN)	18.55	20.17	18.21	15.79
Flow value (mm)	3.1	3.3	3.4	4.1

5.15. Determination Of Optimum Binder Content
Most optimum values of results of Marshal Stability test were found to be at binder content 4.68%. Therefore, the optimum binder content comes out to be 4.68%. The quantity of binder used for making warm mix samples will be 59 gm.

5.16. Quantity Of Warm Mix Additive
To find out the optimum dosage of warm mix additive, samples show in table 1.14 were made at four different additive contents, i.e. 1%, 2%, 3% and 4% by weight of bitumen.

Table 1.14 Quantity of Warm Mix Additive used

Additive content by weight of Bitumen (%)	Weight in grams
1	0.72
2	1.44
3	2.16
4	2.88

5.17. Determination of Optimum Warm Mix Additive Content For DBM Layer
Warm mix samples of DBM layer were made at optimum binder content (4.68%). Three samples each at four different additive contents i.e. - 1%, 2%, 3% and 4% of binder content were made. Marshall Stability Test was performed on theses samples and results are table 1.15. Also the temperature at time of mixing was noted.

Table 1.15 Marshall Stability Test for DBM warm mix

Additive Content (%)	1	2	3	4
Specific Gravity of Bitumen	1.0	1.0	1.0	1.0
Density (g/cc)	2.370	2.378	2.372	2.361
Specific Gravity of Aggregate Blend	2.667	2.667	2.667	2.667
Volume of Bitumen, V_b (%)	11.09	11.13	11.10	11.05
Volume of Aggregate, V_a (%)	84.70	85.00	84.77	84.38
Voids in Mineral Aggregate, VMA (%)	15.30	15.00	15.23	15.62
Voids Filled with Bitumen, VFB (%)	72.48	74.20	72.90	70.70
Air Voids (%)	4.21	3.87	4.13	4.57
Stability (kN)	20.89	22.14	21.42	18.39
Flow value (mm)	3.45	4.15	5.00	5.50

From the test results above, most optimum values of results come out to be at 2% additive content. Therefore, optimum dosage of warm mix additive is 2% by weight of bitumen.

5.18. Test For Retained Stability Of DBM Samples
To find out the retained stability, samples were made of DBM hot mix at optimum binder content and DBM warm mix at optimum additive content. Their Marshall stability values after keeping the samples in water bath at $60^{O}C$ for 24 hours were noted. A comparison is made between the percentage of stability retained after putting the samples in water for 24 hours in hot and warm mix.

5.19. Test For Stripping Action Of Bitumen
Stripping test is performed by immersing the aggregates fully coated with bitumen in water for 24 hours at $40^{O}C$. Aggregates were mixed with bitumen at optimum binder content (5.66% for BC layer and 4.68% for DBM layer) and tested for stripping action. Similar samples but with addition of 2% warm mix additive were prepared and test was performed.

6. RESULTS
6.1. Comparison of Different Parameters In Hot V/S Warm Mixes For BC Layer
Observing various parameters, now we can compare values of those parameters between hot mix prepared at optimum binder content (5.66%) and warm mix prepared at optimum additive dosage (2%) show in fig 1.3. It is observed that there is an increase in Marshall Stability value from 21.15 kN to 25.53 kN by adding 2% warm mix additive show in fig 1.4.

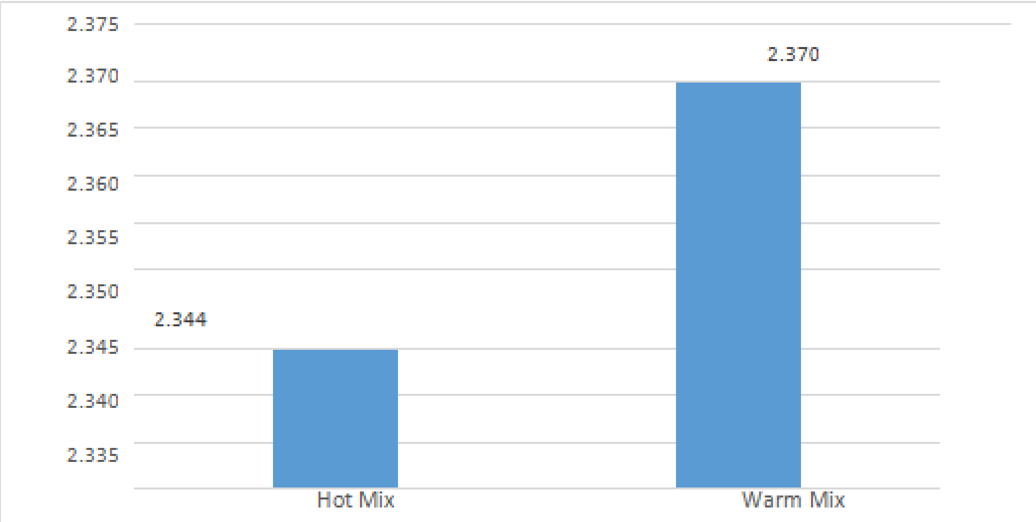

Fig 1.3 Comparison of Density in hot mix and warm mix (BC samples)

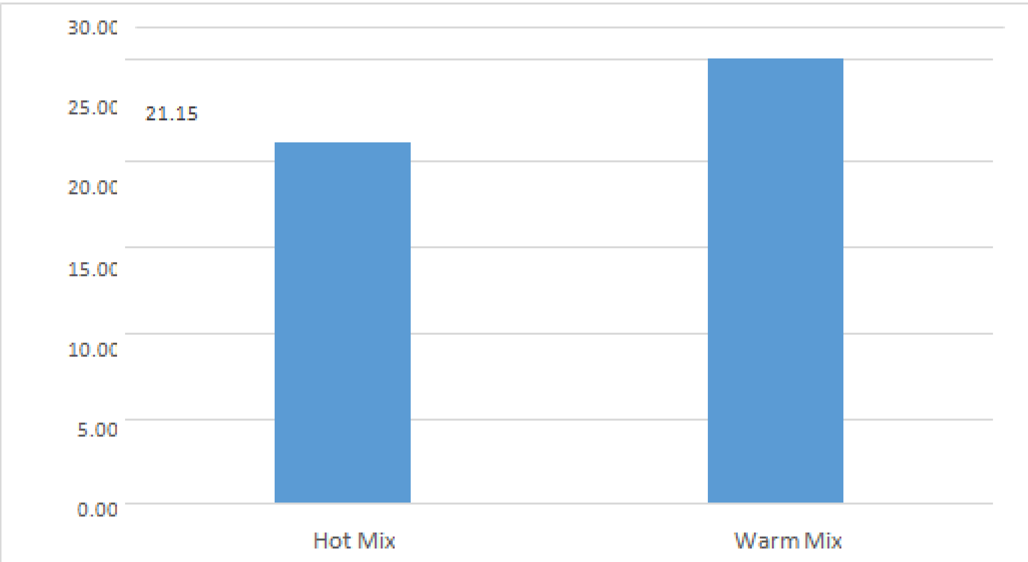

Fig 1.4 Comparison of Marshall Stability value in hot mix and warm mix (BC samples)

6.2. Comparison Of Different Parameters In Hot V/S Warm Mixes For DBM Layer
Observing various parameters from above graphs, now we can compare values of those parameters between hot mix prepared at optimum binder content (4.68%) and warm mix prepared at optimum additive dosage (2%) show in fig 1.5. It is observed that there is an increase in density from 2.369 g/cc to 2.378 g/cc by adding 2% warm mix additive. It is observed that there is an increase in Marshall Stability value from 20.17 kN to 22.14 kN by adding 2% warm mix additive show in fig 1.6.

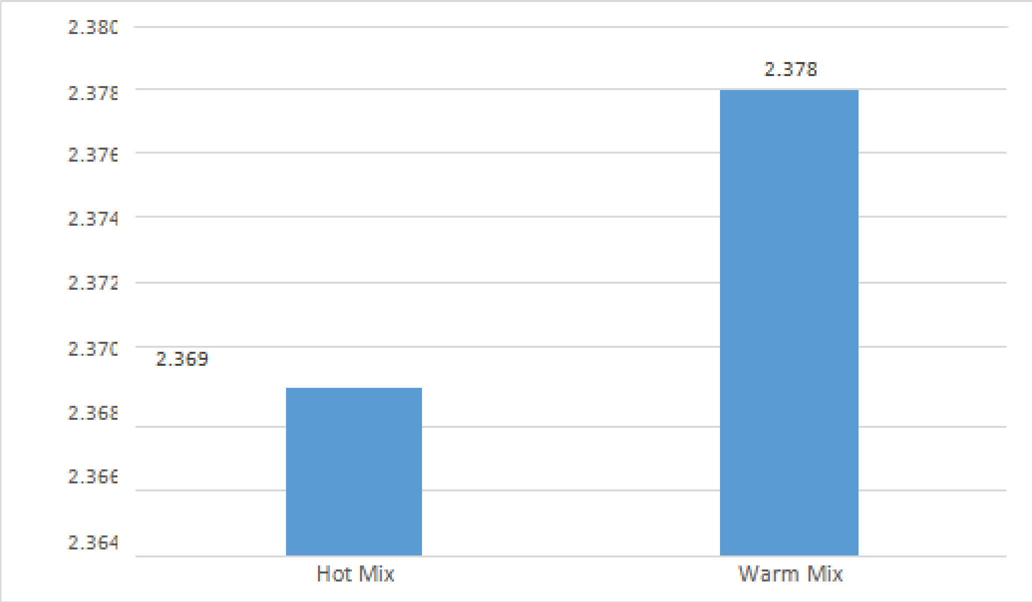

Fig 1.5 Comparison of density in hot mix and warm mix (DBM samples)

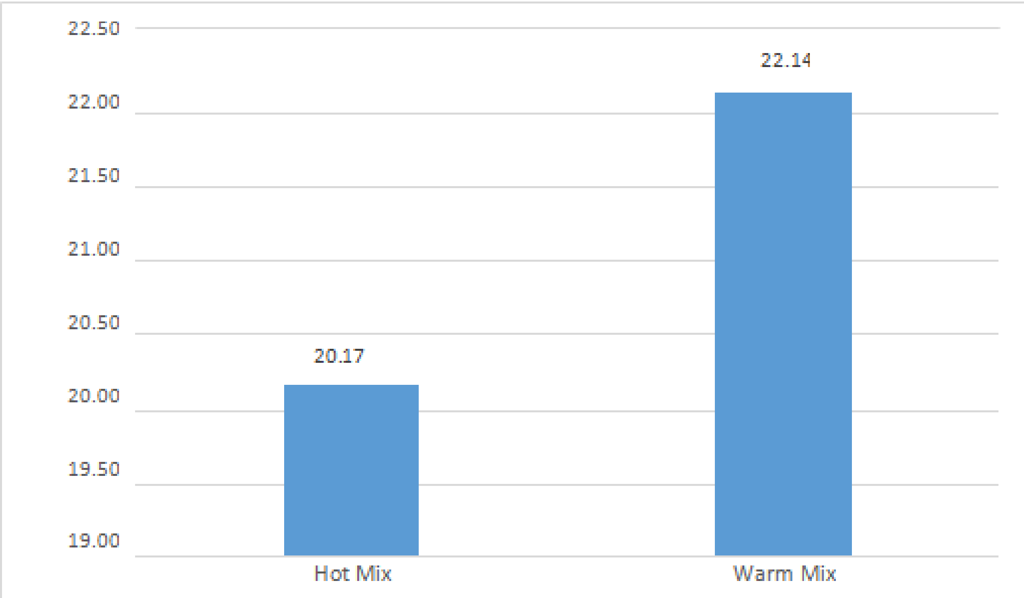

Fig 1.6 Comparison of Marshall Stability in hot mix and warm mix (DBM samples)

6.3. Retained Stability Of DBM Hot Mix And Warm Mix

To compare the retained stability of hot mix and warm mix, charts have been made for stability values before and after putting the samples in water for 24 hours at $60^{O}C$ show in fig 1.7. It is observed that there is a decrease in retained stability in warm mixes. The percentage retained stability in hot mix is 95.93% whereas in warm mix, it is 90.56%. The minimum value of percentage retained stability as prescribed in MORTH Specifications for Road and Bridge Work (5^{th} revision) is 80% in fig 1.8.

7. OBSERVATIONS FOR STRIPPING TEST

It was observed that mix without warm mix additive showed 2% stripping value. The mix prepared with addition of 2% warm mix additive also showed 2% stripping value. Note that the observations are made at optimum binder content and at optimum dosage of warm mix additive for our mix show in fig 1.9. Warm mixes are prepared at much lower temperature than hot mix, making it susceptible to water. Presence of moisture in the mix may lead to stripping off of bitumen from the aggregates. To avoid this, some anti-stripping additives can be used.

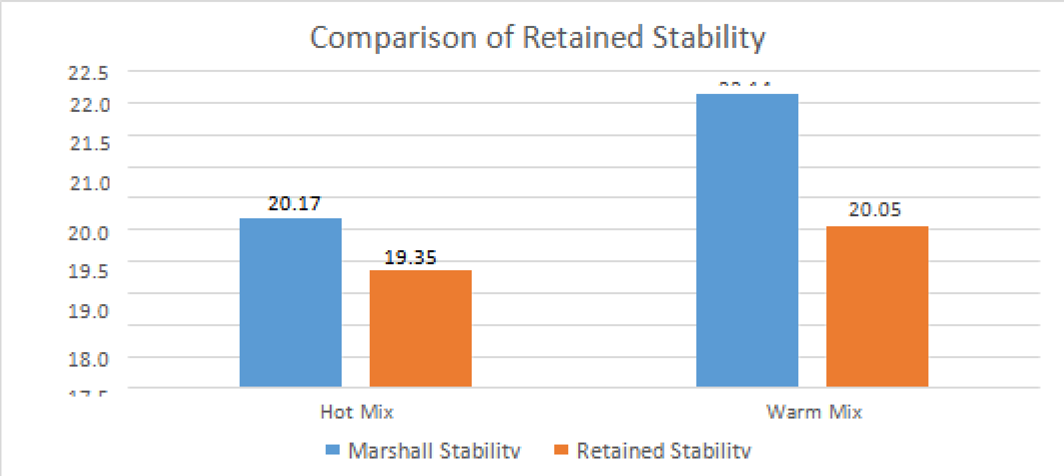

Fig 1.7 Comparison of Retained Stability (DBM samples)

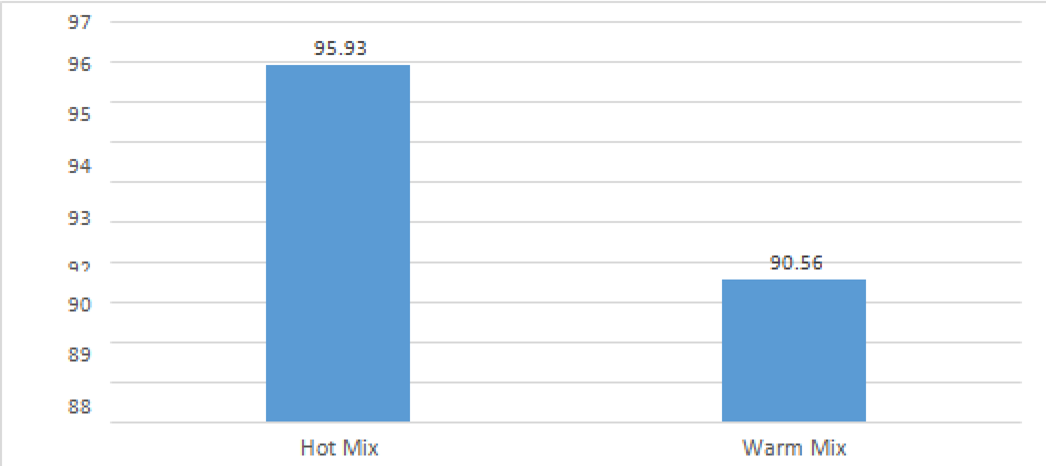

Fig 1.8 Marshall Stability (%) retained in hot mix and warm mix (DBM samples)

Fig 1.9 DBM Samples prepared at different Binder Content

8. CONCLUSION

Warm mixes prepared by addition of warm mix additive Bitubild WM is quiet suitablefor utilization in construction of bituminous pavements as they show good results in Marshall Stability test. The optimum dosage of Bitubuild WM was found out to be 2% by weight of bitumen and the optimum binder content for the mix was 5.66% for BC samples and 4.68% in DBM samples. No change in optimum binder content was found by addition of warm mix additive. There was a slight increase in densities of mix with addition of warm mix additive. In BC sample, there was an increase from 2.344 g/cc to 2.370 g/cc and in DBM sample, there was increase from 2.369 g/cc to 2.378 g/cc. There was a slight increase in Marshall Stability value with addition of warm mix additive. In BC sample, there was an increase from 21.15 kN to 25.53 kN and in DBM sample, there was increase from 20.17 kN to 22.14 kN. There was a reduction in air voids with addition of warm mix additive. In BC sample, there was a decrease from 3.433% to 2.436% and in DBM sample, there was a decrease from 4.20% to 3.87%. The mixing temperature required for warm mixes was noted to be 30-40^{O}C less than that required in hot mixes. To prepare hot mix, mixing temperature was noted to be 150-170^{O}C, whereas to prepare warm mix, mixing temperature required was about 120-130^{O}C. Hence warm mixes save fuel consumption and cost. There was a major difference noted in mixing efforts for warm mix and hot mix. Warm mixes were able to mix well with significantly less efforts and time. This further saves fuel and cost in practical purposes. The retained stability for warm mixes after putting samples in water for 24 hours were observed to be less than that of hot mixes. Percentage stability retained in warm mixes were 89.15% in BC samples and 90.56% in DBM samples as compared to 95.32% in BC samples and 95.93% in DBM samples. Nonetheless, it is more than 80% which is minimum value as prescribed in MORTH Specifications for Road and Bridge Work (5th revision). Bitubuild WM may be susceptible to water causing reduction in retained stability inwarm mixes. Therefore, use of warm mixes in bituminous pavements in places where there is prominent rainfall for longer durations may be avoided or other bitumen modifiers may be used like anti-stripping agents. Use of warm mixes as compared with hot mix in bituminous pavements reduces fuel consumption significantly for practical purposes. It also reduces harmful emissions which affects the environment notably.

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