Performance evaluation of Warm Mix Additives-Rediset LQ-1102 & Nanobond

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Abstract : Warm mix asphalt (WMA) is an innovative technology which is similar to Hot Mix Asphalt in every sense, though it uses warm mix additive to lower the temperature for mixing, laying and compaction than hot mix asphalt (HMA) leading to a better environment and conservation of fuel resources. This study has been undertaken to investigate the properties of Crumb rubber modified bitumen 60 (CRMB 60) binder with and without warm mix additive. Also, according to the provisions of codal practice Marshall Mix design is done on CRMB 60 for Bituminous Macadam (BM) Grade II layer with and without the use of warm mix additives. The additives used are Rediset LQ-1102 and Nanobond which are used in reasonable measurements of 0.5%, 0.6%, 0.7% and 0.5%, 0.6%, 0.7% respectively at lower temperatures. Basic bitumen tests were conducted on CRMB 60 blended with additives of varying percentage to find the optimum dosage for each additive. Optimum dosage of additives been set, optimum temperature for both additives are determined by Marshall test. Marshall specimens are prepared at 110ºC, 120ºC and 130ºC with the optimum dosage of additives and these moulds are subjected to Marshall test. Laboratory tests were conducted to evaluate the performance of asphalt mixtures with respect to moisture damage, fatigue and stability. Based on laboratory test results, optimum dosage for Rediset LQ-1102 pans out to be 0.7% and for Nanobond is 0.5%, optimum temperature for Rediset LQ-1102 is 120ºC and for Nanobond is 130ºC. Retained stability results are 89.1% for Rediset Lq-1102 and 89.4% for Nanobond, Tensile strength ratio for Rediset LQ-1102 is 50% and for Nanobond is 37%. The conclusion of the test proposes that Rediset LQ-1102 performed better than Nanobond in all aspects i.e., stability, moisture damage, temperature reduction, indirect tensile strength etc. Also it can be concluded that there is immense implication of warm mix additive, so that the temperature is significantly cut down compared to hot mix asphalt without much compromise in quality.

***Index Terms* – WMA (warm mix asphalt), BM (bituminous macadam), Retained stability, Indirect tensile strength.**

I. INTRODUCTION

Warm mix asphalt facilitates the laying of pavement at much lower temperature compared to hot mix asphalt. Temperature reduction up to 20º to 30º C are achieved which leads to various benefits with respect to fuel consumption in producing these asphalts and simultaneously cutting down the assembly of greenhouse gases. Additionally, the other important advantages of warm mix asphalt include improved workability, ease of compaction, long haul distances ranging from 1-3 hours with formation of lumps, cold weather paving etc.

II. LITERATURE REVIEW

Km. Monu studied about the suitability and advantages of Warm Mix Asphalt technology as compared to Hot Mix Asphalt and concluded that WMA technology enables us to prepare a bituminous mix at lower temperature by adding particular external agents compared to HMA. This helps in the reduction of greenhouse gases by 20-30%. Also, WMA has significant effect on bituminous mix characteristics in terms of stability, density, ITS, TSR etc.

Brian D. Prowell study investigates the potential use of Evotherm as a warm mix additive for bituminous concrete. The addition of Evotherm® does not statistically affect the resilient modulus of an asphalt mix nor does it increase the rutting potential of an asphalt mix as measured by the Asphalt Pavement Analyzer. The rutting potential did increase with decreasing mixing and compaction temperatures, which may be related to the decreased aging of the binder resulting from the lower mixing and compaction temperatures. Warm mix asphalt containing Evotherm can be opened to traffic quickly, as there is no difference in indirect tensile strength gain with time for Evotherm mix as compared to control mix.

Martins ZAUMANIS evaluate the use of two different WMA technologies – Sasobit and Rediset WMX. First, the properties of bitumen were evaluated after modification with both of the additives. The test results shows that the binder is affected differently by the use of these additives, both of this additive have different effect on the viscosity of the binder. It was observed that the addition of Sasobit reduced the viscosity of the binder at high temperatures and lowered it at intermediate temperatures, whereas the addition of Rediset WMX changed the bitumen properties only slightly.

Graham C. Hurley study about the capability of Sasobit, an organic additive for warm mix technology. This study concluded that compatibility of mixtures is improved in both SGC and vibratory compactor. Addition of Sasobit lowers the measured air voids in gyratory compactor upto 0.87%. Also compaction temperature as low as 88 ºC is attained for Sasobit and 110 ºC for Sasoflex. Addition of Sasobit decreased the rutting potential of asphalt mixes.

Shaleha I. Vahora studied the use of Evotherm and Rediset LQ as a potential warm mix additive and also studied the improvements in designing properties of VG30 with and without this warm mix additive. Marshall Mix design is adopted for DBM Grade II layer and various tests were done to evaluate and compare the performance of these chemical additive. The conclusion of this study proposes the use of warm mix additives, so that the temperature is cut down to 120 ºC.

Yi Wang studied effect of gradation on the high temperature performance and water stability of asphalt rubber mixture that contains Evotherm. Marshall test, rutting test and freeze-thaw split test were conducted to investigate the volumetric properties and performance analysis of asphalt rubber mixture with warm mix additive. The results indicated that the asphalt aggregate ratio played a critical role in determination of the feasibility of warm-mix process.

Jingwen Zhu evaluated the possibility of using bitumen emulsion as an additive applied to WMA samples of Stone Matrix Asphalt (SMA) and Dense Bituminois Macadam (DBM) mix as per MORTH specification and concluded that Cationic Medium Setting emulsion when used improved the properties of mix. Also, with increase in bitumen content the flow value of SMA and DBM samples grafually increases.

III. MATERIALS AND METHODOLOGY

3.1Crumb rubber modified bitumen 60 (CRMB 60)

Crumb Rubber Modified Bitumen (CRMB) is hydrocarbon binder obtained through physical and chemical interaction of crumb rubber (produced by recycling of used tyres) with bitumen and some specific additives. The Flextal range of CRMB offers binders which are stable and easy to handle with enhanced performances.

Table 3.1: CRMB variation and area of usage

Product	Description
CRMB 60	**Crumb Rubber Modified Bitumen For Hot Climate Areas**
CRMB 55	**Crumb Rubber Modified Bitumen For Moderate Climate Areas**
CRMB 50	**Crumb Rubber Modified Bitumen For Cold Climate Areas**

3.2 Warm Mix Additive

- **Rediset LQ-1102:** Rediset LQ is a chemical warm mix additive that is in liquid form. The workability of the mix is increased as the surfactants in Rediset LQ reduce the surface tension of asphalt binder, enabling coating of asphalt binder on aggregate surface much readily. It enables production and compaction temperature 30-60 ºF lower than HMA. It improves moisture resistance and prevent stripping.
- **Nanobond:** Nanobond is chemical additive of WMA produced by Opal Paints Products Private Limited, Noida, Uttar Pradesh. It enables production and compaction temperature 20-40 ºF lower than HMA. It improves moisture resistance and prevent stripping.

IV. METHODOLOGY AND RESULTS

In this study Bituminous Macadam (BM II) mix is selected for which Marshall Mix Design is doen for 19 mm nominal size of aggregate. Warm mix additive i.e., Rediset LQ-1102 is procured from Spectrum Chemicals, Mumbai and Nanobond is procured from Opal Paints Private Limited, Uttar Pradesh. CRMB 60 bitumen is procured from Tikkitar Industry, Mumbai. The aggregates are collected from a stock yard near Kadarenahalli circle, Bengaluru.

Laboratory tests are done on both aggregates and bitumen with and without additive to evaluate the properties of aggregates and to check if all the parameters are within the limits specified by MORTH specifications section 500 clause and IS specifications respectively.

Next thing to be done is to find the Optimum bitumen content (OBC). For this Marshall Mix Design for BM Grade II is selected. The OBC so achieved comes out to be 3.6%. Next step is to find the Optimum dosage of additive which is done by carrying out basic bitumen tests on bitumen blended with varying amount of additive.

- Rediset LQ-1102: 0.5%, 0.6%, 0.7% of weight of bitumen.
- Nanobond: 0.6%, 0.7%, 0.8% of weight of bitumen.

Now that OBC and optimum dosage is set, Marshall specimens are prepared at three different temperature 110ºC, 120ºC, 130ºC at fixed OBC and optimum dosage of additive. The temperature at which the Marshall specimen pans out the highest stability and density with minimal flow value will give the optimum temperature.

Furthermore, for evaluating the performance and comparison with respect to performance of both the additive Marshall test, Retained stability test and Indirect Tensile Strength are conducted on warm mix sample of BM Grade II.

A. Laboratory Investigations

Table 4.1: Physical properties of Aggregate

Properties	Method of test	Obtained results for aggregates (%)	Permissible Limit (as per table 500-14 of MORTH)	Remarks
Impact value	IS:2386(IV)	18.51	30% max	Satisfactory
Abrasion value	IS:2386(IV)	34.23	40% max	Satisfactory
Specific gravity	IS:2386(III)	2.746	2.5-3% max	Satisfactory
Water absorption	IS:2386(III)	0.25	2% max	Satisfactory
Combined Flakiness and Elongation	IS:2386(I)	22.4	35% max	satisfactory

Table 4.2: Physical properties of Bitumen

Properties	Method of test	CRMB 60 bitumen	Permissible Limit	Remarks
Penetration at 25℃, 5sec (mm)	IS:1203-1978	61.33	<50	Not satisfactory
Softening point, ℃	IS:1205-1978	49	60	Not satisfactory
Viscosity at 150 ℃, Poise	IS:1206-1978	5.1	3-9	Satisfactory
Ductility at 25 ℃, (mm)	IS:1208-1978	20.5	35 mm	Not satisfactory

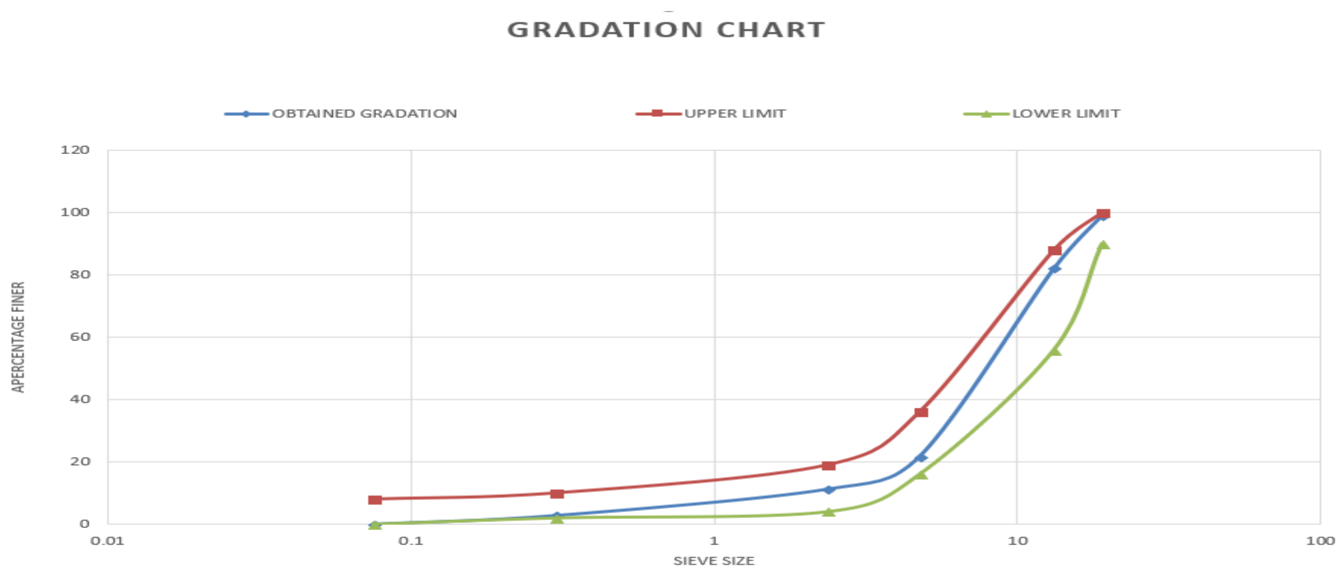

Figure 1: Gradation of aggregate chart (BM Grade II)

It is evident from the above table 4.1 that all the properties of aggregates are satisfactory and within the specified limits. Although, the same cannot be said for the CRMB 60 bitumen as all the basic parameters are not satisfactory. From the obtained results it can be inferred that the CRMB 60 bitumen so obtained had a long shelf life and has lost its vital properties due to aging.

Job mix formula (JMF) and MoRTH specifications for 19 mm nominal size of aggregate are satisfied as from the graph it quite clear that the limits are within the Upper and Lower limits.

B. *Marshall Mix design for optimum binder content (OBC) using CRMB 60*

For determining the Optimum Binder Content, total of 10 Marshall specimens are prepared. Bitumen percentage so selected are 3.4%, 3.6%, 3.8%, 4.0%, 4.2% to the weight of total aggregates. Two specimens are prepared for each percentage of bitumen at blending temperature of 160 ºC according to the system and prerequisites of MoRTH segment 508. The properties of Marshall Mix so obtained are shown in the table below.

Table 4.3: Properties of Marshall Mix Design for DBM Grade II as per MoRTH

% bitumen by weight of mix	Bulk Specific gravity (Gm)	Gt	Stability (kN)	Flow value (mm)	Voids Filled with Mineral aggregate VMA (%)	Voids Filled with Bitumen VFB (%)	Air voids Vv (%)
3.4	2.39	2.44	641.59	5.37	10.00	79.62	2.04
3.6	2.40	2.43	698.49	6.53	9.68	87.57	3.43
3.8	2.39	2.41	627.36	5.37	9.73	91.53	0.82
4.0	2.39	2.40	607.84	5.35	9.75	96.19	0.37
4.2	2.38	2.39	600.70	5.37	10.06	97.60	0.24

Parameters	Binder Content %
Stability (kN)	3.6
Bulk Sp. Gravity	3.6
Avg.	3.6

Optimum bitumen content: 3.6%.

C. Basic bitumen tests on bitumen with Rediset LQ-1102 and Nanobond for determining Optimum dosage

Table 4.4: Physical properties of CRMB 60 with and without Rediset LQ-1102 and Nanobond

Characteristics of tests	CRMB 60	CRMB 60 + 0.5% Rediset	CRMB 60 + 0.6% Rediset	CRMB 60 + 0.7% Rediset	CRMB 60 + 0.5% Nanobond	CRMB 60 + 0.6% Nanobond	CRMB 60 + 0.7% Nanobond	Min. Limit	Code
Penetration at 25℃, 5sec (mm)	61.33	41	37.33	36.33	47.33	49.66	43.33	<50	IS:1203-1978
Softening point, ℃	49	58.5	57.5	54.5	53.5	54	55	60	IS:1205-1978
Viscosity at 150 ℃, Poise	5.1	5.0	5.1	5.6	5.6	4.6	5.87	3-9	IS:1206-1978
Ductility at 25 ℃, (mm)	20.5	16.5	15.5	17.5	19.3	19.4	16.4	35 mm	IS:1208-1978

From the above table based on physical properties of CRMB blended with Rediset LQ-1102, 0.7% dosage is selected as optimum dosage. At 0.7% dosage, the blended bitumen pans out the least penetration (least penetration means it can be used for warm regions), high ductility value leads to high tensile strength for resisting loads and high viscosity value means it will not flow easily when subjected to high temperatures.

Also for Nanobond, 0.5% dosage is selected as optimum dosage as it pans out the highest ductility value and is comparatively best among the three percentages of Nanobond used.

4. Marshall Mix Design for 3.6% CRMB 60 (OBC) plus 0.7% Rediset LQ-1102 & 0.5% Nanobond for optimum temperature

Table 4.5: Marshall test results for CRMB 60 + 0.7% Rediset LQ-1102 & CRMB 60 + 0.5% Nanobond for BM Grade II

Parameters	0.7% Rediset LQ-1102			0.5% Nanobond		
Temperature, ºC	110	120	130	110	120	130
Bulk density	2.37	2.37	2.35	2.36	2.37	2.38
Air voids	2.22	2.58	3.15	1.98	2.78	2.93
VMA	10.85	11.18	11.69	10.63	11.36	11.50
VFB	79.50	77.11	73.09	81.43	75.56	74.65
Stability	334.24	639.84	482.82	358.67	445.22	485.58
Flow value	6.35	5.50	5.6	4.8	5.35	5.2

Graphs for each mix is plotted for different properties and concluded that 120 ºC for Rediset LQ-1102 and 130 ºC for Nanobond is the optimum temperature based on highest stability and bulk density values.

5. Comparison of warm mix additive based on Marshall stability test

Table 4.5: Marshall test results for CRMB 60 + 0.7% Rediset LQ-1102 & CRMB 60 + 0.5% Nanobond fro BM Grade II

Property	Limits	0.7% Rediset LQ-1102	0.5% Nanobond
Stability (kN)	Max.	639.84	485.58
Flow Value (mm)	Min.	5.5	5.2
Air voids (%)	Min	2.58	2.93
VFB (%)	Max.	77.11	74.65
VMA (%)	Low	11.18	11.50
Compacted Density	Max.	2.37	2.36

In terms of stability, air voids, VFB, VMA and compacted density 0.7% Rediset LQ-1102 blended with CRMB 60 is performing better than 0.5% Nanobond blended with CRMB 60. Also, Rediset LQ-1102 can potentially reduce the temperature of mix up to 40 ºC where Nanobond can reduce up to 30 ºC compared to conventional HMA.

6. Performance evaluation by Retained stability test

This test is conducted to find the resistance of mix towards moisture damage. It is conducted on Marshall samples and the stability of mix is determined after placing the samples in water bath for 24 hours and half an hour.

$$\text{Retained Stability (\%)} = \frac{\text{Stability after 24 hours in water bath at } 60^\circ\text{C}}{\text{Stability after 30 mins in water bath at } 60^\circ\text{C}} \times 100$$

Table 4.6: Retained stability test results

Retained Stability (kN)	CRMB 60	CRMB 60 + 0.7% Rediset	CRMB 60 + 0.5% Nanobond
Marshall stability at 60 ºC for 30 min	906.44	586.52	733.15
Marshall Stability at 60 ºC for 24 hrs	778.47	538.53	655.836
Retained Stability, %	85.88	91.81	89.45

7. Performance evaluation by Indirect Tensile Strength (ITS) & Tensile Strength Ratio (TSR)

Marshall samples are used for conducting ITS tests. The ITS test was performed by loading a Marshall specimen with a single compressive load, that acts parallel to and along vertical diametrical plane. This loading configuration develops a uniform tensile stress perpendicular to the direction of the applied load and along the vertical diameter. The load at which the specimen fails is taken as the indirect tensile strength (also referred as the dry indirect tensile strength) of the bituminous mix. Marshall specimen for conventional HMA and WMA using Rediset LQ-1102 and Nanobond are prepared for ITS test.

The tensile strength ratio is given by the ratio of the wet to dry indirect tensile strength is recorded as Tensile Strength Ratio (TSR) of the bituminous mix. TSR test is used to determine the moisture susceptibility of the mixes.

Table 4.7: Indirect Tensile Strength & Tensile Strength Ratio for BM Grade II mix

Sr. no	Grade of Bitumen	Indirect Tensile Strength kg/cm^2 at 25 ºC		Tensile Strength Ratio, % (S2/S1)
		Unconditioned S1(dry)	Conditioned S2(wet)	
1	CRMB 60	2.3	0.8	35
2	CRMB 60 + 0.7% Rediset	2.8	1.4	50
3	CRMB 60 + 0.5% Nanobond	2.7	1	37

V. CONCLUSION

1. The physical properties of aggregates are satisfying the IS codes.
2. From Figure 1, aggregate gradation chart shows that the obtained gradation curve falls within the upper and lower gradation line.
3. Basic properties of CRMB 60 is evaluated like penetration test, softening test, ductility test & viscosity test. Among all theses tests viscosity test was found to be satisfactory. The reason for the unsatisfactory result for penetration, ductility and softening value is due to the prolonged shelf life leading to loss of bitumen properties.
4. Marshall mix design is done for BM Grade II and optimum binder content is found to be 3.6% which is satisfying the limits specified by MoRTH section 508.
5. Optimum additive content for Rediset LQ-1102 is found to be 0.7% and for Nanobond is 0.5% based on basic bitumen tests done on CRMB 60 blended with additives of varying percentage.
6. Optimum temperature for Rediset LQ-1102 and Nanobond is found to be 120ºC & 130ºC by conducting Marshall Mix design test utilizing 3.6% CRMB 60 by weight of aggregates blended with 0.7% Rediset LQ-1102 and 0.5% Nanobond.
7. It is found that with the addition of warm mix additive there is and increase in stability for **retained stability** test under normal and wet conditions. This signifies that resistance to moisture induced damage can be increased with the addition of warm mix additive. Also, stripping resistance is found to have increased with the addition of warm mix additive.
8. CRMB 60 mixes containing warm mix additive have significantly higher tensile strength ratio than control mixes. Rediset LQ-1102 showed better resistance to moisture damage than Nanobond.

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