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Performance of Crumb Rubber Modified Bitumen Added with WMA Additives under Freeze-Thaw Action

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Abstract: Winter is a “hard” time for asphalt Pavements, literally. Asphalt pavements are produced and constructed at high temperature when the asphalt binder is a liquid so it can be easily mixed with the rocks and sand. During the spring, summer, and fall seasons, asphalt is flexible and stretchy in the warm weather, helping to prevent cracks from forming. However, as temperature decrease during winter, the asphalt becomes harder and stronger, but also more brittle. Extreme cold temperature can cause pavements to crack, but the most damage to pavements is caused by freeze-thaw cycles.

The abundance and increase of waste tyre disposal is a serious problem that leads to environmental pollution. Crumb rubber obtained from shredding of those scrap tires has been proven to enhance the properties of plain bitumen. Use of crumb rubber leads to excellent pavement life, driving comfort and low maintenance.

Majority road network in India comprises of flexible pavement in which Hot Mix Asphalt (HMA) is used in the bituminous layer. However, Warm Mix Asphalt (WMA) is helpful in certain situations where the problems associated with HMA may need to be reduced. Warm mix asphalt lowers the mixing temperatures at which asphalt pavement materials are mixed and laid on the road. The advantages of WMA are reduced emissions, improved workability and reduced energy consumption.

Keywords: Bitumen, CRMB, Crumb Rubber, Marshall Stability Test, WMA Additives, Freeze Thaw cycles.

I. INTRODUCTION

Road construction plays a vital role in the development of a sustainable infrastructure for all economies. Countries without roads and highways will find themselves underdeveloped and will struggle to attain a level of wealth that is generally reached in the developed world.

The construction of roads and highways has been a priority in the world since Roman times.

Bitumen has been used in the construction of flexible pavements for more than a century. The durability properties of the bitumen binder, is the key factor for the binder characterization in Bitumen mixes, and hence pavement performance. Enormous advances have been made in the use of the bitumen as binder in pavement construction and rehabilitation. The bituminous layer itself may display a significant amount of permanent deformation in hot climatic factors such as temperature, moisture and repeated loads.

Now-a-days disposal of different wastes produced from different Industries is a great problem. These materials pose environmental pollution in the nearby locality because many of them are non-biodegradable. Traditionally soil, stone aggregate, sand, bitumen, cement etc. are used for road construction.

The necessary specifications should be formulated and attempts are to be made to maximize the use of solid wastes in different layers of the road pavement. The practice of disposing waste tyres in landfills and open burning is becoming unacceptable because of rapid depletion of available landfill sites and clear environment respectively. The conventional bituminous mix includes stone aggregate and 3 to 5 percent bitumen by weight of the aggregate. The scrap tyre rubber can be incorporated into bitumen, often abbreviated as modified bitumen and granulated or ground rubber or crumb rubber can be used as a portion of the fine stone aggregate. The use of waste in hot bituminous mixes enhances pavement performance, protect the environment and provide low cost and quieter roads.

Crumb Rubber can be used as a bitumen modifier instead of expensive polymers such as styrene butadiene styrene (SBS) and styrene butadiene rubber (SBR) to reduce construction costs and energy consumption. This technique can also help reduce environmental pollution by recycling waste tires (Chiu and Lu, 2007; Lee et al, 2008). Interestingly, in addition to the above-mentioned benefits, the combination of CR with bitumen improves the performance and engineering properties of asphalt pavement (Leite et al. 2001; Palit et al 2004; Shanker & Prasad 2009; Ibrahim et al. 2013).

II. NEED FOR STUDY

Presently in India bitumen is modified with various types of modifier such as crumb rubber, natural rubber, reclaimed polyethylene and polymers are being used for construction of bituminous roads. A number of products are also available in the market, with which bitumen has been modified with a blend of modifiers.

Readily blended type of Polymer modified bitumen, crumb rubber modified bitumen and natural rubber modified bitumen are also available in the market in commercial form.

As per IRC: SP: 53-2010 these products shall be evaluated for their suitability in an approved laboratory by conducting various tests to know its properties. Limited work has been reported on the various factors such as the effect of temperature, freezing-thawing, addition of WMA additives, mixture stiffness, aggregate type and gradation and method of testing on behavior of polymer modified bituminous mixes.

In the present study an attempt is made to investigate the influence of varying freeze-thaw cycles on bituminous mixture with crumb rubber modified bitumen and WMA additives viz. Sasobit and Zycotherm by carrying out experimental investigations such as Marshall mix design test to evaluate stability flow and void characteristics of samples.

Moreover, the focus has been on exploring options to enhance the condition of pavements and save subsequent maintenance and frequent overlaying expenses in cold regions such as Kashmir where the asphalt pavements undergo accelerated deterioration due to seasonal freezing-thawing.

III. REVIEW OF LITERATURE

Alloza et.al, 2013 studied the effect of four viscosity-reducing additives (Sasobit, Asphaltan A, Asphaltan B and Licomont BS 100) on a bitumen modified with 15% rubber. The results of this study indicate that these additives successfully reduce viscosity, increase the softening temperature and reduce penetration. However, they do not have a clear effect on the test for elastic recovery and ductility at 25 C. [1]

Prof. Justo et.al, 2002 at the Centre for Transportation Engineering of Bangalore University compare the properties of the modified bitumen with ordinary bitumen. It was observed that the penetration and ductility values of the modified bitumen decreased with the increase in proportion of the plastic additive, up to 12 percent by weight. Therefore the life of the pavement surfacing using the modified bitumen is also expected to increase substantially in comparison to the use of ordinary bitumen.[2]

Behl et.al, 2013 Studied how a commercially available chemical additives can be used to bring down the mixing and compaction temperature of CRMB mix as compared to the hot mix CRMB. Various mix tests were carried out to indicate to how the lower production and

Compaction temperatures affect the properties and performance characteristics of the mixes. After the laboratory evaluation it was found that CRMB Warm mix can be successfully produced at temperature as low as 110°C and can be compacted at 80-90°C as compared to CRMB hot mix (155°C). [3]

Sharma et.al, 2018 Warm mix asphalt (WMA) is an energy-saving and environmental-friendly technology with a broad prospect for application in highway construction. When compared with hot mix asphalt(HMA), WMA reduces the mixing and compaction temperatures (by 25–30°C) and hence reduction in energy consumption and emissions of harmful gases while maintaining the workability of HMA. In this study, three different additives, namely, Sasobit (organic wax additive),Evotherm (emulsion-based chemical additive) and Zycotherm (anti-stripping chemical additive) were evaluated for their laboratory performance under repeated weathering actions.[4]

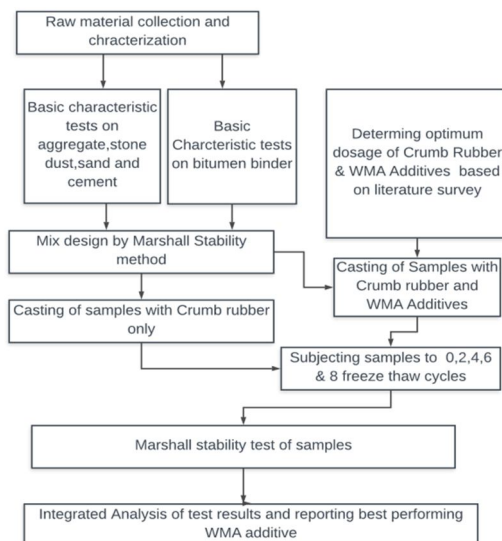
Kim et.al, 2017 addresses the laboratory experiment of performance properties of recycled CRM binders containing artificially aged CRM binders with wax additives.

The warm CRM binders were produced using two wax additives (LEADCAP and Sasobit) and then short term and long-term aged using the rolling thin film oven (RTFO) and pressure aging vessel (PAV) procedures. [5]

Deshmukh & Kshirsagar, 2017 compares the properties of bitumen with crumb rubber modified bitumen, it was observed that the use of waste crumb rubber in road construction as a pavement surface has a better skid resistance, fatigue crack resistance and increased rut resistance. The expectations from the study are to develop bitumen with waste crumb rubber that would minimize the costs of bitumen and providing better physical properties compared to the convention bitumen based on the tests that was conducted.[6]

IV. METHODOLOGY

The present investigation aimed at the laboratory evaluation of bituminous concrete (grading-II) with bitumen type as paving grade bitumen (VG-10) and crumb rubber. The aggregate gradation for bituminous concrete (grading-II) recommended by Ministry of Road Transport and Highways (MoRT&H) is used. Various standard tests on the aggregates, bitumen, fillers, HMA and WMA CRMB (BC-II) mixes were performed.



Flow chart showing methodology of work implemented for the study.

V. MATERIALS USED

The materials that were procured in order to perform this study such as aggregates, bitumen binder, fillers, crumb rubber, WMA additives etc have been discussed in the proceeding sections.

A. Aggregate

The coarse aggregate used in this study were collected from local crusher in Srinagar. Fine aggregates are collected from the crusher with fractions retained on 0.075 mm IS sieve and passing 4.75 mm IS sieve, consisting of stone crusher dust were collected. These aggregates should be free from organic matter, clay particles, loam and clean screened quarry dust. It fills the voids in the coarse aggregate and stiffens the binder. The required tests on aggregates were conducted in the laboratory and the results were obtained.

B. Filler

Materials passing through 0.075 mm IS sieve are treated as filler in bituminous mix. It helps to fill the voids and stiffens the binder which provides better resistance to permeability in mix. Filler shall consist of finely divided mineral matter such as rock dust, hydrated lime or cement. The filler shall be free from organic impurities and have plasticity index not greater than 4. The plasticity index requirement shall not apply if filler is cement or hydrated lime. In present study OPC has been used as a filler

C. Asphalt Binder

Generally bitumen acts as a binding material in mix and is treated as a visco-elastic material which shows both elastic and viscous at the normal service temperature. It acts like an elastic material at low temperature and behaves like a viscous fluid at high temperatures. Bitumen used in this study is paving grade bitumen (VG-10) on which the required tests were conducted and the results were obtained.

D. Bitumen Modifier: Crumb Rubber

Modified bitumen is generally recommended for the roads with heavy traffic and locations of extreme climatic conditions. The selection of modified bitumen will be based on climatic, traffic, performance reports and life cycle cost analysis. The bitumen modifier used in this study is crumb rubber corresponding to mesh size 80 and the amount of crumb rubber was taken as **15%** by weight of bitumen (optimum) based on literature survey to make HMA mix. (Tefera et al. 2018, Sun & Li 2010)

E. Warm Mix Asphalt (WMA) Additives

Warm Mix Asphalt (WMA) technology allows mixing, transporting, paving and compaction of asphalt at lower temperatures compared to Hot Mix Asphalt (HMA), thereby saving energy costs, allowing longer hauls and giving out lesser emissions.

WMA was prepared for this study using the following chemical additives:

- 1) *Sasobit*: Sasol Wax International released Sasobit wax in 1997 which is fine crystalline, long-chain aliphatic polymethylene hydrocarbon refined from coal gasification using the Fischer–Tropsch process. It has the ability to lower the viscosity of the asphalt binder. Sasobit has a melting temperature of about 102°C and is completely soluble in asphalt binder. In this study Sasobit added to CRMB mix was taken 1.5% by weight of bitumen (optimum) based on literature survey to make WMA mix designated henceforth as S-CRMB. (Shaw 2007, Arshad et al. 2012)
- 2) *Zycotherm*: Zycotherm(antistripping chemical additive) creates a hydrophobic zone over the aggregate surface and therefore works as a water repellent and improves potential against moisture-induced damage. Zycotherm additive is an odourlessnanoorganosilane additive used for bituminous mixes. Zycotherm gives better chemical bonding for extended moisture resistance and it ensures 100% coating of bitumen at low temperature.

VI. ANALYSIS OF TEST RESULTS & DISCUSSION

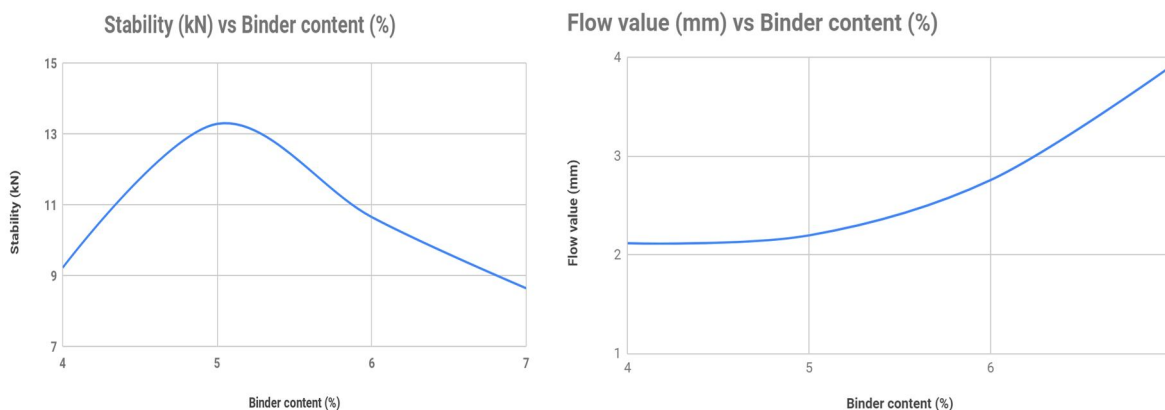
This chapter describes the various tests carried out on bituminous concrete mixes prepared using crumb rubber modified bitumen (VG-10). The optimum bitumen content was determined by Marshall Method of mix design. The aggregate and bitumen was tested for their gradation. The study aims at the performance of crumb rubber modified bitumen added with WMA additives under freeze thaw action. The samples prepared were tested for stability and flow. The crumb rubber modified bitumen was also compared with crumb rubber modified added with WMA additives under different freeze thaw cycles. The results, thus obtained were analyzed as follows and the causes for the obtained trend were investigated.

All the results values of tests of aggregates, Bitumen(VG-10), Crumb rubber modified bitumen are within the limits of MORTH & IRC.

- 1) *Marshall Method of Mix Design*: Marshall Mix design method is the recommended method for characterization of bituminous mixes in India. The impact compaction due to the absence of Kneading and Shearing action used in standard Marshall Method does not simulate mix densification as it occurs in a real pavement during field compaction by road rollers and by traffic. Because of this standard Marshall Compaction is gradually being replaced by gyratory compaction in many countries, as it is possible to obtain similar degree of reorientation of aggregate particles caused by the shearing action imparted to the bituminous mix in the field. A low cost option to gyratory compaction was first reported in South Africa. This consists of modification for the face of the Marshall Hammer by providing indents on the compaction face.

Sample no.	Bitumen content (%)	Stability (kN)	Avg. Stability (kN)	Flow (mm)	Avg. flow(mm)
1	4	8.84	9.22	1.94	2.12
2		9.18		2.1	
3		9.64		2.32	
1	5	12.46	13.28	1.9	2.20
2		14.88		2.1	
3		12.50		2.6	
1	6	10.28	10.65	2.96	2.76
2		10.12		2.5	
3		11.55		2.82	
1	7	8.88	8.64	3.54	3.92
2		8.68		3.88	
3		8.36		4.34	

Calculation of Marshall stability and flow for mix design.



Process of Freeze-Thaw

In this research, the detailed processes of freeze-thaw were designed and listed as follows:

- The samples were divided into several groups. Each group consisted of three samples. One group of samples was placed at room temperature and other groups of samples were immersed into a water bath for 0.5 hours.
- Each sample was taken out of the tank and placed into a plastic bag with 10 ml of water. The bag was put in refrigerator for 16 h at -20°C until all the water in plastic bag was frozen.
- The samples were removed from plastic bags and placed into a water bath for 8 hours with constant temperature 60°C until thawing process was completed.
- After steps (1), (2), and (3), one F-T cycle was completed. In this study, the number of F-T cycles was 2,4,6 and 8 for marshall stability test .



Samples after being put in plastic bags prior to freezing.

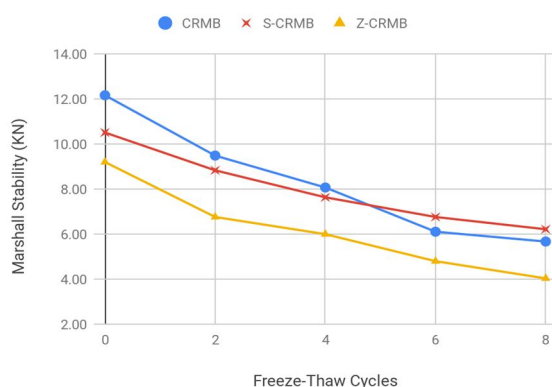
Samples undergoing thawing in a water bath.

Percentage of Crumb rubber and WMA additives used based on literature survey

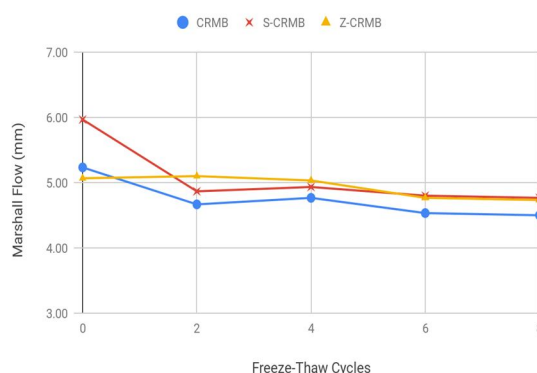
S.No	Additive	Percentage(%)
1	Crumb rubber	15
2	Sasobit	1.5
3	Zycotherm	0.15

Freeze-Thaw Cycles	Marshall Stability (KN)			Marshall Flow (mm)		
	CRMB	S-CRMB	Z-CRMB	CRMB	S-CRMB	Z-CRMB
0	12.16	10.51	9.20	5.23	5.97	5.07
2	9.48	8.83	6.76	4.67	4.87	5.10
4	8.07	7.63	6.00	4.77	4.93	5.03
6	6.10	6.76	4.80	4.53	4.80	4.77
8	5.67	6.21	4.03	4.50	4.77	4.73

Marshall test results for all F-T cycles.



Variation of Marshall stability with F-T Cycles.



Variation of Marshall flow with F-T Cycles.

VII. CONCLUSIONS

Following are the conclusions that were arrived at based on the results obtained from the experiments conducted in this study:

- By studying the test results of the conventional bitumen and crumb rubber modified bitumen it is concluded that the penetration value and the softening value of the conventional bitumen can be improved significantly by modifying it with addition of the crumb rubber which is a major environmental pollutant.
- After putting the mixes through continuous freeze-thaw cycles, the adhesive and cohesive bonds become less effective which resulted in decreasing trend in the Marshall stability of the specimens with the increase in number of freeze-thaw cycles.
- The results show that freezing cycles expand the volume of water in interconnected voids, which may lead to the degradation of the mix resulting in cracking of the pavement.
- With the increase in number of freeze-thaw cycles, air voids in each of the mixes increased significantly except for Sasobit-CRMB mix, which showed a slight increase.
- CRMB alone showed comparatively higher stabilities than S-CRMB and Z-CRMB till 4 freeze-thaw cycle. After 4 freeze-thaw cycles, S-CRMB showed more stability values than CRMB and Z-CRMB.
- The Marshall flow values for all mixes remained in the same range after 2 freeze-thaw cycles.
- Volumetric analysis showed that S-CRMB has lesser air voids in comparison to CRMB alone. This reduction in air voids could be due to the formation of the crystalline structure by Sasobit with the binder.
- After 4 freeze-thaw cycles S-CRMB showed the higher density compared to CRMB and Z-CRMB.
- The results also showed that S-CRMB samples gave the lowest value for Voids in Mineral Aggregate (VMA) after the completion of 8 freeze-thaw cycles.
- The Voids Filled with Bitumen (VFB) for S-CRMB showed greater value than CRMB and Z-CRMB after 4 freeze-thaw cycles.
- S-CRMB showed best performance among the two WMA technologies used in this study as shown by the results of Marshall stability and volumetric analysis.

VIII. ACKNOWLEDGEMENT

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