An Experimentalstudy of Rutting On Dense Bituminous Macadam of Grading-II Using Crumb Rubber Modified Bitumen and Waste Plastic Coated Aggregates

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Abstract—*The permanent pavement deformity that occurs longitudinally in the path of the wheels is known as rutting. The extent of rutting depends on the traffic repetitions the pavement has undergone, properties of the materials used in construction of the pavement, densification achieved during construction, average temperature of the pavement surface, shape, size & particle size distribution of aggregates, type & amount of bitumen, total air voids and Voids in Mineral Aggregates (VMA) in the mix, total thickness of constituting layer, temperature, methods of production & laying, and environmental conditions. The resistance to consolidation deformation (longitudinal ruts) of any bituminous mix is determined by the properties of the materials used to produce the mix. In this study the properties of bituminous mixes were altered using Crumb rubber and waste plastic. Crumbed rubber when used to modify the properties of bitumen results in Crumbed Rubber Modified Bitumen (CRMB). Waste plastic can be used to alter the properties of aggregates of bituminous mixes. When compared to mixes containing only one of the two waste materials, bituminous mixes prepared with proper proportions of crumb rubber and waste plastic produced better results. Due to their excellent rut resistance potential the mixes prepared using crumb rubber modified bitumen along with plastic coated aggregates resulted in higher stability than conventional mixes. Hence such mixes are more suitable in areas prone to high rut depth on DBM (Dense Bituminous Macadam) mixes which are mainly used in base or binder and profile corrective courses. The modified mixes prepared using CRMB & waste plastic coated aggregates showed minimal rutting even during considerable temperature changes. Hence traditional DBM mixes can be successfully replaced by modified mixes prepared using crumb rubber modified bitumen as a binder and LDPE (Low Density Polyethylene) coated aggregates. This would also result in cost savings, improved performance, and environmental benefits.*

Keywords—Rutting, CRMB, DBM, VMA (key words)

I. Introduction

The common pavement permanent deformations caused due to repetitive traffic loads is known as rutting. The small deformations of pavement materials accumulate and appear as longitudinal depressions within the wheel paths of roadways as a result of rutting.

Rutting can be caused by a variety of factors, including:

1. Inadequate compaction of conventional Hot Mix Asphalt layers during laying.
2. Rutting of the subgrade
3. Incorrect mix design or production.
4. Inappropriate aggregate gradation.
5. Lac of stability in the mix to support traffic, etc.

The following are some of the solutions for preventing rutting in bituminous pavement:

1. The use of high-quality aggregates and bitumen of suitable grade.
2. Proper Aggregate gradation.
3. Use binder content as per the mix design
4. Sufficient drainage.
5. Use of modified bitumen such as CRMB and PMB in place of conventional bitumen.

Any bituminous mix's rut resistance potential is determined by the properties of its constituents. Crumb rubber and waste plastic were used to alter the properties of the constituents in this study. The term "crumb rubber" refers to granulated rubber made from scrap rubber. The polybags generally used to carry different grocery items etc. was used as waste plastic in this study. The availability of both of these materials is abundant, and using them would be much more beneficial because it would reduce the solid waste disposal problem. Crumb rubber was used to modify bitumen, which is referred to as crumb rubber modified bitumen (CRMB). Crumbed Rubber Modified Bitumen has a lot of advantages such as lower susceptibility to daily and seasonal variations in temperature, decreased deformation at high pavement temperature, increased fatigue resistance value, improved adhesion between aggregates and binder etc. Melted waste plastic was used to form a coating around aggregates. In this study, rutting was evaluated in the lab using wheel tracker equipment, which measures rut depth on specimens while simulating field traffic and environmental conditions.

Fig1.1 Rutting phenomenon occurrence in bituminous pavement

The sample of bituminous mix prepared with the help of the Wheel Rut Shaper & the rut on the sample is created using wheel tracker which is also known as the wheel rut tester. According to studies, wheel tracker devices are the most reliable equipment for measuring rutting in the laboratory.

II. OBJECTIVES OF THE STUDY

The objectives of this study are:

1. Determination of Marshall Properties of Dense Bituminous Macadam Grading-2 using the Marshall method of bituminous mix design for various modified and conventional bituminous mixes (DBM).
2. Determination of the optimum dosage of crumb rubber and waste plastic in the bituminous mix.
3. To analyze the effect of temperature on rut depth in both modified and conventional bituminous mixes containing the optimal proportion of crumb rubber and waste plastic. In addition, the percentage increase in rut depth with increasing temperature as well as the comparison of different bituminous mixes.
4. To investigate the variation in rut depth with increasing wheel passes in a wheel rut tracker at a specific temperature for various modified and conventional bituminous mixes with the best proportion of crumb rubber and waste plastic.

III. EXPERIMENTAL DETAILS

A. Selection of type of Surface Course for Experimental Study

MORT&H (Ministry of Road Transport & Highways) specification were followed for the gradation of aggregates. As per MoRTH Specifications Dense Bituminous Macadam Layers are divided into two grades: grade I and grade II (Table 500-10). In this study, grading-II (mid-point gradation) was selected to conduct various tests. According to MORT&H Section-505 (Table 500-10) guidelines (2013) the nominal aggregate size for Dense Bituminous Macadam (DBM) gradation-II is 26.5 mm and the layer thickness is between 50-75 mm. The overall grading of aggregates is tabulated in table 1.

Table 1 Composition of Dense Graded Bituminous Macadam (Table 500-10 as per MORT&H guidelines)

Grading	**1**	**2**
Nominal aggregate size	**37.5 mm**	**26.5 mm**
Layer Thickness	**75-100 mm**	**50-75 mm**
IS Sieve	**Cumulative % by weight of total aggregate passing**	
45 mm	100	-
37.5 mm	95-100	100
26.5 mm	63-93	90-100
19 mm	-	71-95
13.2 mm	55-75	56-80
9.5 mm	-	-
4.75 mm	38-54	38-54
2.36 mm	28-42	38-54
1.18 mm	-	-
600 µ	-	-
300 µ	7-21	7-21
150 µ	-	-
75 µ	2-8	7-21
Bitumen % by mass of total mix	Min 4.0	Min 4.5

B. Materials Used

Aggregates

Stone aggregates are one of the major components of road structure. They are used in the bituminous or in the concrete layer, or in other bound form. Unbound aggregates are used for base or sub-base course. Aggregates bear load due to particle interlocking and sustain the wear and tear due to vehicular movement. In general, aggregates for highway construction are obtained from crushing of natural rocks or from naturally occurring gravels.

The physical properties of aggregates used in the study are given table below.

Table 2 Physical Properties of Aggregate

Physical Property Tested	Test Methods	Results	MoRT&H Specifications (2013) (%)
Aggregate Impact Value (%)	IS 2386 Part 4	15.81	Max. 27
Combined Flakiness and Elongation Index (%)	IS 2386 Part 1	16.45	Max. 35
Los Angeles Abrasion Value (%)	IS 2386 Part 4	25.61	Max. 35
Water absorption (%)	IS 2386 Part 3	0.7	Max. 2
Specific Gravity of Aggregate	IS 2386 Part 3	2.74	2.5-3.2

Bitumen

Bitumen is a complex organic material and occurs either naturally or may be obtained artificially during the distillation of petroleum. Bituminous materials are very commonly used in highway construction because of their binding and water proofing properties.

The physical properties of Viscosity Grade-30 (VG-30) bitumen are tabulated below.

Table 3 Physical Property of Bitumen of grade VG-30

Property Tested	Test Method	Results	Specification as per IS Code
Specific Gravity	IS 1202	0.99	0.98-1.02
Penetration (1/10th of mm)	IS 1203	73	45 (min)
Softening Point ^{0}C	IS 1205	51	47 (min)
Ductility, cm	IS 1208	80.3	40 (min)

Filler

Filler fills the voids, stiffens the binder and offers permeability. It is inert mixed with graded coarse and fine aggregate and is very fine (less than 0.075mm). Various materials, such as lime, cement, and fly ash, are now used as fillers. Ordinary Portland Cement Grade 43 with a Specific Gravity of 3.14 is used in this study.

Waste Plastic as a modifier

Low density polyethylene (LDPE) was used as a modifier for the preparation of samples. Specific Polythene had a density of 0.905. The size of shredded waste plastic used in this study was determined by passing it through a 4.75 mm IS sieve and then retaining it on a 300 μ IS sieve with a thickness of 10 μ to 30 μ.

Table 4 Properties of WP coated Aggregates

Properties	Results		
	WP-5	**WP-10**	**WP-15**
Aggregate Impact Value %	17.4	13.9	16.6
Los Angeles Abrasion Value %	18.3	16.2	17.4

Fig. 1 Shredded Polyethylene

Crumb Rubber

Scrap tyres were collected to produce crumb rubber. The crumb rubber was prepared using mechanical grinding technology. The crumb rubber must be free of fabric, wire, and other contaminants. The specific gravity of Crumb rubber passing sieve IS 425 (0.425 mm) was used as a modifier for DBM mix in this study. The specific gravity of crumb rubber was found to be 1.15. The physical properties of VG-30 bitumen modified using 5,10 & 15% crumb rubber (by weight of bitumen) are given in table below.

Table 5 Properties of Crumb Rubber Modified Bitumen

Properties	Results		
	CR-5	**CR-10**	**CR-15**
Penetration, at 25^{0}C (0.1mm)	61	52	48
Ductility (cm)	58	51	53
Softening point (R&B), ^{0}C	56	60	63
Specific gravity	0.99	1.01	1.01

Fig. 2 Crumb Rubber

Methodology

The experimental study was carried out in three steps: selection of materials & determination of their physical properties using relevant standard procedure & specifications, design of mixes & preparation of specimens and assessment evaluation test (rut test[1]) using wheel rut tracker.

The quality standards of the materials used were examined in the first step. In the second step mix was designed to obtain material proportions and specimens were prepared for the third stage of evaluation tests. Marshall method of bituminous mix design was used, and the following three types of bituminous mix specimens were prepared for grading-2 of DBM:

1. Mixes containing only VG-30 bitumen as a binder.
2. Mixes having crumb rubber modified VG-30 bitumen (having 5, 10, and 15% crumb rubber)
3. Mixes containing crumb rubber modified VG-30 bitumen (percentage of crumb rubber which produced the most stable mix is selected) and Low Density Poly Ethylene (3%, 6%, 9% by weight of bitumen) coated aggregates.

The above-mentioned mixes were subjected to a Marshall test. By mixing granulated crumb rubber with bitumen at 700 revolutions per minute for 30 minutes at 177°C, bitumen was modified with crumb rubber. Aggregates were graded as per grading-II provided by MORTH - 2013 for the DBM binder course. Out of the 3 proportions (5, 10 & 15% crumb rubber by weight of bitumen) the bituminous mix specimens prepared using 10% crumb rubber modified bitumen were adopted on the basis of stability criteria. Then bituminous mix specimens for Marshall Test were prepared using 10% crumb rubber modified bitumen and Low Density Poly Ethylene (3%, 6%, 9% by weight of bitumen) coated aggregates. LDPE was used in a shredded form with a maximum size of 2 mm. For the coating of LDPE, shredded plastic was mixed with preheated aggregates until a uniform covering was achieved. Specimens containing 6% LDPE were found most stable. The OBC (Optimum Binder Content) was calculated for a conventional mix, a modified mix with 10% crumb rubber, and a modified mix with 10% crumb rubber and 6% LDPE.

Rut tests with a wheel tracker were conducted in the third step. The dynamic compaction technique was used to prepare the specimens in a rut shaper machine. As determined in the second phase, conventional and modified mixes were made with the designed OBC. The density of the specimens was maintained at the same level as in the mix design. To simulate different field conditions in different places, the test temperature is varied from 40°C to 60°C. The measurement & analysis of rut depth with temperature variation & number of wheel passes was carried out.

Modification of Bitumen and Aggregates

Alteration of the binder & the aggregates was carried out prior to the mixing for the preparation of modified mix specimens. Bitumen was modified by substituting crumb rubber for bitumen (5 percent, 10 percent and 15 percent of bitumen weight). Material passing through a 425-micron sieve was collected for use from granulated crumb rubber obtained from the tyre remoulding industry. At a temperature of 177°C, calculated amounts of bitumen and crumb rubber are blended in a mechanical mixer at 700 revolutions per minute for 30 minutes. CRMB refers to the modified bitumen produced by the above procedure. Bitumen was modified in batches just prior to specimen preparation. This bitumen modification process is also known as the wet bitumen modification process. Crumb rubber particles are expected to have formed physio-chemical bonds with bitumen after 30 minutes of mixing. Although such a mixture should be used within 24 hours, crumb rubber settles after that time & results in a poor mix. As a result, alterations in binder were made in stages. Aggregates were preheated to 170°C & then shredded LDPE was added to aggregate in a heating container. Both the materials were then mixed further. At such high temperatures (above 170°C) plastic softens, it forms a film around the aggregates. Although it does not replace bitumen, the amount of LDPE (3 percent, 6 percent, and 9 percent) was calculated as a percentage by weight of bitumen content.

Marshall Test

For preparation of the Marshall specimen, about 1200 g aggregates were weighed and heated up to 154-160°C. Bitumen was separately heated up to 175-190°C and the measured quantity of bitumen was poured in the container where the aggregates were being heated. Aggregates and bitumen were thoroughly mixed in such way that the upper surfaces of the aggregates appeared to be uniformly coloured with bitumen film. The mix was poured into the Marshall mould (64 mm height and 100 mm diameter) and compacted with 75 blows on each face. Then the specimens was taken out from the mould and kept under normal laboratory temperature for 24 hours. It was then immersed in a water bath kept at constant temperature of 60 ± 1°C for 30 minutes and after that it was taken out for testing in the Marshall testing machine. Load was applied at the rate of 50 mm per minute on the sample and the maximum load at which the sample failed was recorded as the Marshall stability value.

The Marshall properties (stability & flow values) for each sample specimen were recorded. The Optimum Binder

Content was calculated by taking the average value of the following 3 bitumen contents obtained from the graphs of the test results:-

1. Bitumen content corresponding to maximum stability
2. Bitumen content corresponding to maximum density
3. Bitumen content corresponding to the median of designed limits of % air voids in the mix (4%)

Similarly, modified mix specimens were prepared with the exception that modified bitumen was used as the binder material instead of virgin bitumen. For DBM grading-2 modified mixes were prepared using crumb rubber in place of bitumen and varying the crumb rubber as 5%, 10% & 15% by weight of bitumen. Thus, different CRMB mix specimen combinations were prepared, and the Marshall test was carried out for the determination of stability and other test parameters. The CRMB mix with 10% crumb rubber resulted in the most stable mix.

Hence the OBC of mixes containing 10% crumb rubber was obtained for grading-2.

This most stable mix containing 10% crumb rubber was further modified by replacing normal aggregates with plastic coated aggregates. 3 Different types of modified mixes were again prepared having aggregates coated with varying amounts of LDPE (3%, 6%, and 9%, respectively). Thus, three types of mix specimen combinations having 10% CRMB & different proportion of LDPE (3%, 6%, and 9% by weight of bitumen) were prepared, and the Marshall test was performed to determine stability and other test parameters. The most stable mixture was obtained 6% LDPE. Thus, the OBC of mixes containing 6% LDPE was obtained for DBM grading-2.

Fig. 3 Sample for Marshall Test

Rut Test[1]

Wheel Rut testing was carried out using a wheel tracking device and a rut shaper. Rut Shaper was used to prepare the specimens. Three types of bituminous mixes were prepared, with the binder content determined as OBC by Marshall Mix design method for DBM grading-2.

1. Typical specimens containing virgin bitumen VG-30 as a binder and normal aggregates
2. Specimens prepared using VG-30 bitumen modified with 10% crumb rubber and normal aggregate.
3. Modified VG-30 bitumen containing 10% crumb rubber and 6% LDPE modified aggregates.

The prepared mix was poured into a cubical mould and compacted in a Rut Shaper. After proper compaction, the mould was left until it reached room temperature.

The mould was then placed in a Wheel Tracker and subjected to a one-hour rut test at three different temperatures (40°C, 50°C, and 60°C). For various mixes, test results were gathered and analyzed.

Fig. 4 Wheel Rut Shaper

Fig. 5 Wheel Rut Tester

Fig. 6 Rut Mold after rutting test

OBSERVATION AND RESULTS

Marshall Test

Table 6 Maximum Marshall Stability for conventional and modified bitumen mixes

Types of Bitumen mixes	Maximum stability For grading-II
VG30	14.40
5% CRMB	16.78
10% CRMB	18.57
15% CRMB	17.21
10% CRMB + 3% LDPE	19.45
10% CRMB + 6% LDPE	20.74
10% CRMB + 9% LDPE	19.33

The mix containing 10% CRMB with 6% LDPE by weight of bitumen produced the mix with highest marshall stability value. Hence the same was considered as the optimum value for further study.

Wheel rut Test

Table 7 Rut test on conventional mix (G2) with VG-30 as binder and normal aggregate

Number of Passes	Rut Depth(mm) at Temperature of		
	40°C	50°C	60°C
0	0	0	0
500	1.14	1.36	2.47
1000	1.64	2.14	3.13
1500	2.01	2.63	3.65
2000	2.46	3.03	4.15
2500	2.678	3.375	4.343

Table 8 Rut test on conventional mix (G2) with CRMB-10 as binder and normal aggregate

Number of Passes	Rut Depth(mm) at Temperature of		
	40°C	50°C	60°C
0	0	0	0
500	1.03	1.24	1.81
1000	1.23	1.53	2.51
1500	1.63	2.14	2.79
2000	1.89	2.48	3.18
2500	2.378	2.69	3.67

Table 9 Rut test on conventional mix (G2) with CRMB-10 as binder and LDPE-6 aggregate

Number of Passes	Rut Depth(mm) at Temperature of		
	40°C	50°C	60°C
0	0	0	0
500	0.87	0.95	1.14
1000	1.24	1.22	1.53
1500	1.43	1.64	1.89
2000	1.64	1.96	2.22
2500	1.678	2.164	2.528

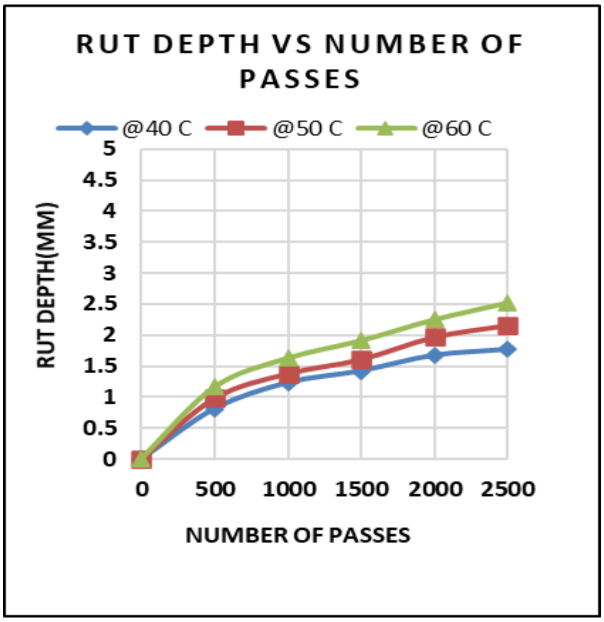


Fig.7 For normal mix (G2)

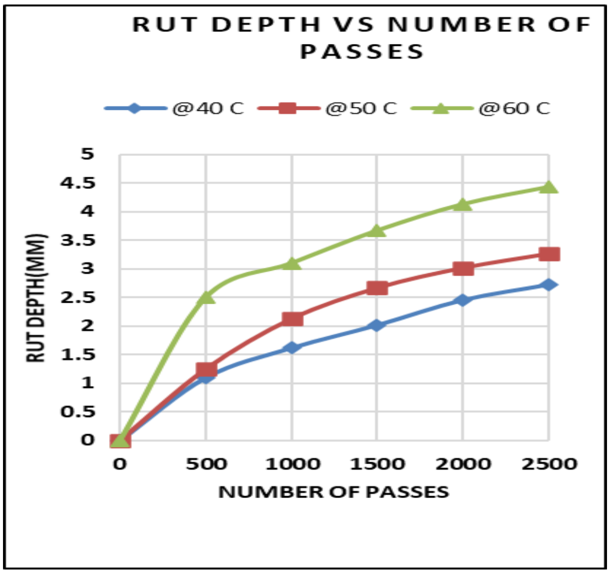


Fig.8 Modified mix (G2) with CRMB-10 as binder and normal aggregate

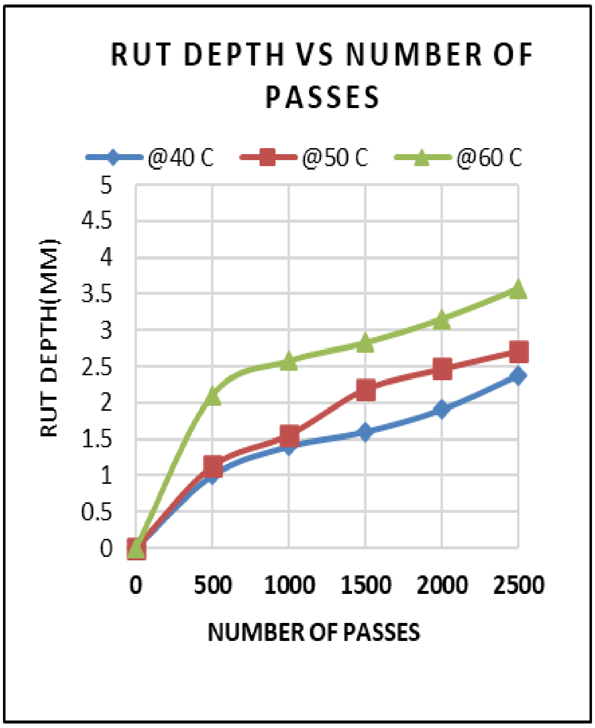
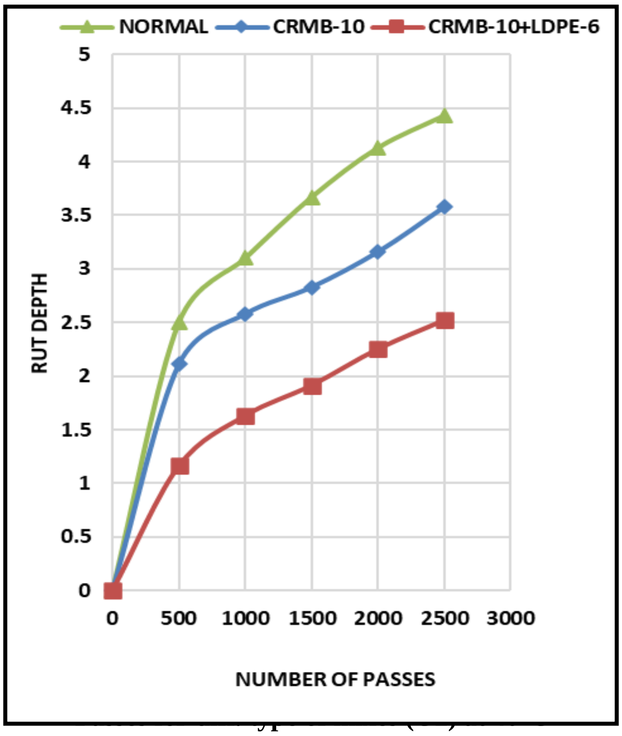


Fig.9 Modified mix (G2) with CRMB-10 as binder and LDPE-6 aggregate



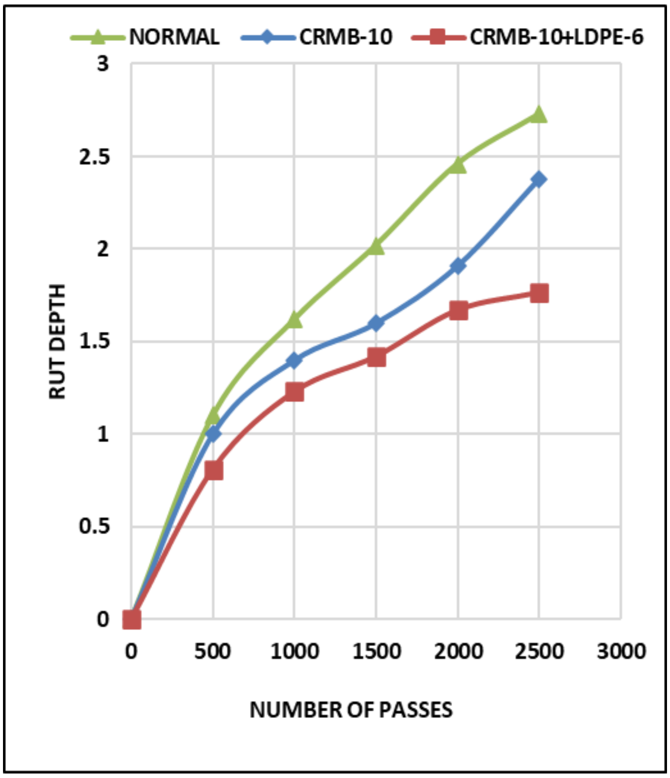


Fig.11 Rut depth variation with no. of passes for different type of mixes (G2) at 50°C

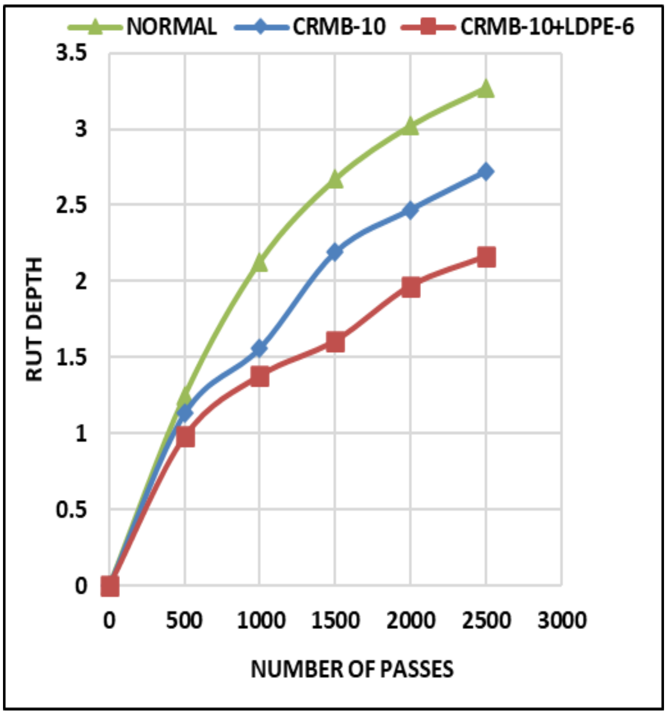


Fig.12 Rut depth variation with no. of passes for different type of mixes (G2) at 60°C

Results and Discussions

Following results were drawn after this study:

1. Marshall Test parameters of traditional DBM mixes were well within limits as given in MoRTH 2013.
2. Only the modification of binder enhanced the stability by 29% when VG-30 bitumen is modified with 10% crumb rubber. Further alteration of this modified mix (CRMB-10) with 6% LDPE coated aggregates (CRMB-10 + LDPE-6) improved the stability values by 44% when compared to normal mix (For grading II).
3. Optimum bitumen content also reduced to 4.92% in case of CRMB-10 mix and 4.86& in case of CRMB-10 + LDPE-6 mix (For grading II) when compared with conventional mix having 5.02% optimum binder content.
4. As the temperature rises from 40^0C to 60^0C the percentage increase in rut depth on conventional mix was 63.22%, for CRMB-10 mix it was 51.03% and for CRMB-10 + LDPE-6 mix this value was 44.93%.
5. After 2500 cycles at 40^0C the decrease in rut depth 13.86% when CRMB-10 mix is adopted instead of conventional mix & 31.42% decrease in rut depth was observed when CRMB-10 + LDPE-6 mix was adopted in place of conventional mix.
6. Similarly, the decrease in rut depth at 2500 cycles 50^0C, was observed as 16.82% for CRMB-10 mix and 33.19% for CRMB-10 + LDPE-6 mix.
7. The reduction in rut depth at 60^0C after 2500 cycles was found to be 18.90% for CRMB-10 mix is 44.10% for CRMB-10 + LDPE-6 mix.

6. Conclusions: Based on the study, following conclusions have been made:

1. The addition of optimum dosage of crumb rubber in the mix enhanced its properties significantly, and further alteration of the mix by using plastic coated aggregates with optimum amount of LDPE resulted in huge improvement in the properties of the mix when compared to conventional mix.
2. Modified bituminous mixes (having crumb rubber modified bitumen along with plastic coated aggregates) are more favourable in the areas subjected to escalated rut depth on DBM base/binder course due to their increased rut resistance.
3. The test experiments also resulted in decrease in bitumen content in the mix by due to mixing of crumb rubber in bitumen and coating of aggregates with waste plastic. As both of these are waste materials, use of modified mixes prepared using such waste materials would result in reduced cost of project along with recycling of waste material.
4. Such modified mixes also resulted in negligible increase in rutting even during considerable temperature swings. Hence such modified mixes are strongly recommended for areas having large temperature variations.

Thus, modified mixes with crumb rubber modified bitumen as binder and LDPE coated aggregates, could be successfully used to replace conventional mix for DBM, with advantage of project cost reduction, improvement in performance and environmental betterment.

References

1. Stacy G. Williams (2003), "The Effects of HMA Mixture Characteristics on Rutting Susceptibility*", paper Prepared for Publication and Presentation at the 2003 Annual Meeting of the Transportation Research Board.*
2. Deepak Baskandi (2015), "Influence of Construction Parameters on Performance of Dense Graded Bituminous Mixes", *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-*

1684, p-ISSN: 2320-334X, Volume 12, Issue 1 Ver. III (Jan- Feb. 2015),

3. Manal A. Ahmed and Mohamed I. E. Attia (2013), "Impact of Aggregate Gradation and Type on Hot Mix Asphalt Rutting in Egypt", International *Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 3, Issue 4, Jul-Aug 2013.*
4. Alex K. Apeagyei (2011), "Rutting as a Function of Dynamic Modulus and Gradation", *1310 / journal of materials in civil engineering © asce / september 2011*
5. Adrian Ricardo Archilla,Samer Madanat (2001), "An Economic Model of Pavement Rutting in Asphalt Concrete Mixes*", UCTC Reprint No. 453 The University of California Transportation Centre University of California at Berkeley*
6. Ghazi Al-Khateeb and Imad Basheer (2009), "A three-stage rutting model utilising rutting performance data from the Hamburg Wheel-Tracking Device (WTD*)", Vol 18 No 3 September 2009 Road & Transport Research.*
7. Satish. B.K and K. Ganesh, "Rutting studies of 100 mm thick bituminous concrete mix with plain and modified binders at varying temperatures*", Indian highways, June 2014.*
8. Ashok Pareek, Trilok Gupta and Ravi K Sharma (2012), "Performance of PMB for flexible pavement*", Int. J. Struct. & Civil Engg. Res.*
9. Dr. K. Ganesh & Sunil kumar. V.Beli (2012), "Studies on Effect of Configuration Temperature and Type of Binder on Rutting Characteristics of Bituminous Concrete Mix*", International Journal of Innovations in Engineering and Technology (IJIET).*
10. Kiran Kumar And Ganesh Kumar (2013), "Rutting Characteristics Of 40 Mm Thick Bituminous Concrete Mix with Plain and Modified Binders at Varying Temperatures Using Treaded Wheel", *IRC 2013.*
11. Amir Golalipoura, Ehsan Jamshidib, Yunus Niazic, Zahra Afsharikiad, Mahmood Khademe (2012), "Effect of Aggregate Gradation on Rutting of Asphalt Pavements", *Procedia - Social and Behavioral Sciences 53 (2012) 440 – 449.*
12. J. Ahmad1, M.Y. Abdul Rahman and M. R. Hainin (2011), "Rutting Evaluation of Dense Graded Hot Mix Asphalt Mixture", *International Journal of Engineering & Technology IJET-IJENS Vol: 11 No: 05.*
13. KumKum Bhattacharya, Sagar Deshmukh (2014), "Study on rutting and surface behaviour of urban flexible pavement", *International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2321-7308.*
14. G.H. Shaf bakhsh, M. Sadeghnejad, Y. Sajed (2014), "Case study of rutting performance of HMA modified with waste rubber powder", *Case Studies in Construction Materials 1 (2014) 69–76, Elsevier journal.*