Analysis of Bituminous Concrete Mixes Using H.D.P.E & Crumb Rubber as Admixtures

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Abstract :: Flexible pavements need more attention in selection of Resources and preparation of mixes now a day's temperature is the main criteria which affect the mix quality, strength and durability, the performance of bituminous roads is to be identified that they are poor in high drainage situations. Present scenario about using various additives for improvement of mix in strength and better drainage aspects is not satisfying the expected results. However, the additive that is to be used for modification of mix or binder should satisfy both the strength, durability requirements as well as economical aspects Plastics are using extensively in all over world and developing country like India.,As these are non-biodegradable there is a major problem posed to the society with regard to the management of these solid wastes. Even, the reclaimed polyethylene originally made of HDPE has been observed to modify bitumen. In the present study, an attempt has been made to use HDPE and CRUMB RUBBER as admixtures in nominal bitumen mix to overcome the problem of resistance to weathering actions and repetitive wheel loads Various studies are proposed to be conducted with varying the mix ratio of the admixtures with bitumen keeping the maximum level of admixtures to 10% by volume.

*Keywords — **Admixtures, ,High dense polyethylene, Hot mix asphalt, Marshall mix design, Modified Bitumen, Polymers, Surface course***

I. INTRODUCTION

Highway construction now a days being a tough job for selection of construction resources in industry, resources involves Material, Manpower, Machinery and Time, Finance. Construction agents are highly dedicating their worth in investing about finance and time but they cant involve much better in the better selection of qualitative material and their proportions .they don't have proper knowledge in selection of materials in terms of quality. Though materials was selected now the tough job is to selecting the group of materials.

Construction of a pavement is not a mechanical process, that involves a high concentration on protecting various aspects that are required for achieving better output.

The quality of a pavement that was constructed will be measured by its Durability, the word durability says that resistance to wear and tear and also against weathering agencies. So that the quality construction require high level of durability and resistance to wear and tear, Durability of pavement structure depends upon the material used in the construction and its quality and characteristics. Selection of a good suitable material for construction of pavement based on type of pavement and level of classification of that road.

Flexible pavements generally with bituminous (or asphalt) materials. These can be either in the form of pavement surface treatments(such as a bituminous surface treatment generally found on lower volume roads) or, HMA surface courses. These types of pavements are called flexible since the total pavement structure bends or deflects due to Wheel loads. Pavement structure is generally composed of several layers of materials which can accommodate this flexing.

1.3 MODIFIED BITUMEN:

Proper additives or blend of additives called as bitumen modifiers may improve properties of Binder and bituminous mixes. Bitumen treated with these modifiers is known as modified bitumen. **Polymer modified bitumen (PMB)/ crumb rubber modified bitumen (CRMB)** should be used only in wearing course depending upon the requirements of extreme climatic variations. The detailed specifications for modified bitumen have been issued by IRC: SP: 53-1999. It must be noted that the performance of PMB and CRMB is

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dependent on strict control on temperature during construction. The advantages of using modified bitumen are as follows

- Lower susceptibility to daily and seasonal temperature variations.
- Higher resistance to deformation at high pavement temperature Better age resistance properties.
- Resistance to Fatigue & Resistance to Repetitive loads.

1.1 ADMIXURES

Bitumen admixtures are mostly chemical in nature which temperature sensitive than bitumen. Bitumen will will induce health effects to the workers paving the surface be dissolved in petroleum oils where unlike tar with admixture added bitumen. With this perspective, in this study an attempt is made to utilize waste materials such as **High Density Polyethylene (HDPE)** and **Crumb rubber.**

High-density polyethylene (HDPE) or polyethylene high-density (PEHD) is a polyethylene thermoplastic made from petroleum. It is sometimes called "alkathene" or "polythene" when used for pipes. With a high strength-to-density ratio, HDPE is used in the production of plastic bottles, corrosion-resistant piping, geo-membranes, and plastic lumber. HDPE is commonly recycled, and has the number "2" as its resin identification code.

Crumb Rubber is a product obtained by crushing of waste tyres those can recycled, that tyres can be make into pieces and then to required size. Basically it is to be used after sieving it through 1.7mm sieve for most of all works.

Table 1 Grading Details of selected Aggregates.

Is sieve (mm)	Mass retained (g)	Percentage retained	Cumulative percentage retained	Percentage finer
20	0	0	0	100
12.5	72	6.25	6.25	93.75
10	312	27.08	33.33	66.67
4.75	84	7.29	40.62	59.38
2.36	204	17.70	58.32	41.68
1.18	112	9.72	68.04	31.92
0.6	89	7.72	75.76	24.24
0.3	106	9.20	84.96	15.04
0.15	61	5.29	90.258	9.75
0.075	42	3.64	93.89	6.11
Pan	70	6.07	100	0

1.2 SCOPE AND OBJECTIVE OF PROJECT

- The present study aimed at preparation of Gap – graded mix of bitumen and modified with crumb rubber and to find the variation of conventional properties.
- Study the effect of adding polyethylene on the hot mix asphalt.
- To identify the best mechanism of adding the polyethylene (dry or wet process) to the asphalt mixture to achieve better mixture properties.

Figure.1: H.D.P.E Granules (Blow grade, Re- cycled)

Figure.2 :Crumb rubber powder

Figure .3 . Aggregate composition for mix design

The gradation of aggregates is followed as per the MORT & H specification

Table 2 : Details of materials per sample

Coarse aggregate content in mix (%)	40.625%
Fine aggregate content in mix (%)	53.29%
Filler content in mix(%)	6%
Binder content	5%, 6% and 7% (of total aggregate content)

II. LITERATURE REVIEW

Sandhya Dixit (2013) concluded that using of waste recycled material which harms the environment leads to protection of environment against the pollution and environmental im- balance , it is mentioned that resistance to wear and tear from the repetitive loads can be challenged by adding such type polymer additives in the mix properly, it is said that increase in impact value of aggregates was found on increase in additive percentages is very crucial in certain levels of percentages of additives.

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Dr. Muhammad Bilal Khurshid stated that adding of shredded plastics in various percentages may leads to change in marshal test results, most prominently upto 8% it is observed that high rise in the values of abrasion and impact values of aggregates that which in turn leads to increase in stability values of mixes and layers when the roads are paved. Dry process is eminent than Wet process that adding the polymers by after heating the aggregates to certain temperature , these modified mixtures are in turn proving greater resistance against the fatigue and drainage also as the results obtained from these modified bituminous mixes is greatly changing the parameters of both inert and binder material. Finally it was concluded that addition of polymers may leads to great change in the strength parameters of bituminous mix and also the surface resistance for the pavement.

Mohammad T(2007) experimentally proved that, the optimum content of additive is important, however the 5.4% of polymer content among total weight of aggregates results in good improvement in fatigue resistance and plastic deformation. Reducing the effect of pavement deformation is a better achievement in durability criteria of bituminous pavement construction. Increasing the additive content more than 12 % results in decreased mixing temperatures that are a eminent factor affecting on pavement mix preparation.

H.M.R.D. Silva (2011) concluded using varieties of plastic wastes in the nominal bituminous mix as partial replacement to the better results in concluding the emerging trends in one hand and environmental balance on the other hand. Commercial scenario of th e pavement construction can balance their outstanding results on using high quality additives as replacements but economical aspect cannot be balanced for them and for that scenario.

S.K.Palit, K. (2004) discussed that adding crumb rubber as an additive in binder can be profitable mix since the binder content is decreasing but the problem raised when these mixes are exposed to Higher temperature leads to failure of surface resistance and balance against variations of temperatures as warping effect of bituminous pavement is the major problem . It is observed that increased stability factor and tensile strength ratio by using the crumb rubber content as that consists of higher plastic value, stripping of characteristics is also one of the achievement in this with changing temperature differential.

Miss Apurva J Chavan(2013)concluded that , the stripping of characteristics results in inferior surface performance of any pavement as ravelling factor will increase as the bitumen is stripping off from the aggregate it looks very irregular surfacing even though the higher grades of materials has been used .The coating of polymer deceases the effect of ravelling in all temperature differentials and also the effect of rutting and pot holes formation consequently. As the heavy traffic leads to inferiority in surface protection it is the better alternative by using the plastics waste in the mixes so that environmental balance is also happening. Better durability will be held with these modified bituminous mixes.

Rokade S (2012) concluded that, increase of strength properties of bituminous mix up to 8% to 10%Crumb Rubber then the value is going down as the deformation in mix is increasing consequently the deflection has been increasing the flow value rapidly with 8% to 12% of crumb rubber contents.

Nobinur Rahman, (2013) The percentage of polymer content should be affective based on the region at which the pavement construction is to be an consecutive temperature differential at that place irrespective of various sub soil conditions.10% of the modifier content shall be used for the regions of warmer and stiffness and void characteristics can be observed separately with the materials.

K.Rajesh kumar and Dr. N.Mahendran: Concluded that using of H.D.P.E granules which is obtained from recycling process of the waste H.D.P.E pipes and other materials is a better way of improving the mix quality and strength aspects, he considered that nominal mix which is prepared by using conventional material such as aggregate, binder with filler material may results in poor performance in exceptional drainage and exposure conditions and may cause to early deterioration.

It is proved that with adding additives will improves the properties of bituminous mixes ,taking this as reference we are going to use HDPE and Crumb rubber as admixtures in various percentages to the surface course mixes especially.

III. EXPERIMENTAL STUDY

The work has been started with various gradations of aggregates and binder contents The optimum binder content and aggregate content is then worked out using Marshall Stability mix design process on control/conventional HMA samples. Crumb rubber modified bitumen and aggregates quality tests are then performed to explore the effects of variation of polymer (HDPE) content (i.e. % by weight of optimum asphalt content) on the performance of these materials. HDPE modified samples are then prepared by adding HDPE in the mix in different percentages by weight of optimum asphalt content and optimum HDPE content (i.e. % by weight of optimum asphalt content) is then determined basing of Marshall Stability criterion.

a) Wet Process: : In the wet process, shredded HDPE was added to bitumen at 160° C. This process did not yield a homogenous bituminous mix with prominent separated solid deposits/pieces of mix. Therefore wet process was not adopted for this study. Hence another waste material (crumb rubber) has been selected to add it to the bitumen. The proportion of crumb rubber has been selected as 10% by weight of binder contents.

b). Dry Process : In this process aggregates are heated to 170°C and then above mentioned percentages of shredded HDPE are added and mixed to coat the aggregates. These coated aggregates have been used for the preparation of the bituminous mixes.

Crumb rubber is term usually applied recycled rubber from automotive and truck scrap tires. During the recycling process steel and fluff is removed leaving rubber as consistency. Continue processing with a granulator and or cracker mill, mechanical means for further reducing the size of the particle. The size is based on the dimension or

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MESH (holes per inch).

Table no 3: Summary of test results on aggregates

s.no	Test	Maximum permissible value	Normal aggregates	6% HDPE coated aggregates	8% HDPE coated aggregates	10% HDPE coated aggregates
1.	Specific gravity	2.75	2.6	2.44	2.44	2.44
2.	Water absorption	2	1.9%	0.4%	0.4%	0.4%
3.	Impact	30	24.09%	12.4%	10.98%	9.87%
	Crushing value	45	26.29%	18.68%	16.48%	15.18%
5.	Abrasion	35	30%	14.2%	12.6%	9.2%

Table No. 4 : Summary of test results on bitumen

PROPERTIES	SPECIFIED	NORMALBIT	MODIFIED
Specific gravity at 27°C	0.97	1.02	1.05
Flash point	175	220	250
Softening Point. °C	35°C to	47	48
Penetration at 25°C 100gm, 5 sec.	80 to	91	89
Ductility (cm)	100	54	80

3.1: MARSHALL TEST

The most widely used method of bituminous mix design is the Marshall method developed by the U.S. Corps of Engineers. Stability and flow, together with density, voids and percentage of voids filled with binder are determined at varying binder contents to determine an Optimum Bitumen Content for Stability, Durability, Flexibility, Fatigue resistance etc.,

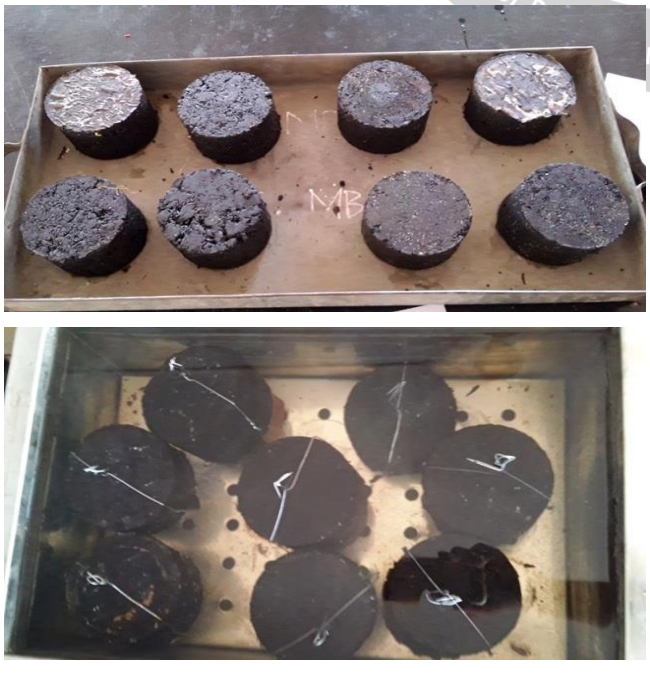

Figure: 4 : Samples prepared

Table No: 5 Marshall test Samples at glance

Mix name	Bitumen	Aggregates	Binder contents	No.of samples
A	Normal	Normal	5 6 7	9
MB-A6	Normal	6% HDPE coated aggregates	5 6 7	9
MB-A8	Normal	8% HDPE coated aggregates	5 6 7	9
MB-A10	Normal	10% HDPE coated aggregates	5 6 7	9
CRMB-A6	10% CRMB	6% HDPE coated aggregates	5 6 7	9
CRMB-A8	10% CRMB	8% HDPE coated aggregates	5 6 7	9
CRMB-A10	10% CRMB	10% HDPE coated aggregates	5 6 7	9
CRMB	10% CRMB	Normal	5 6 7	9

IV. TEST RESULTS AND DISCUSSIONS

Table no: 6: Stability and flow values of Various samples

Mix	Bitumen content (%)	Sample no.	Stability (kg)	Flow value in 0.25 mm units
Control mix	5	1	1677.4	17.22
		2	1755	18.56
		3	1832.6	14.62
	6	1	2178.75	14.60
		2	1999.15	15.21
		3	1919.75	18.19
	7	1	2893.32	19.28
		2	2217.80	17.11
		3	2378.25	17.61
		1	2630.27	8.7

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MB-A6	5	2	2378.22	8.1
		3	2504.89	12.6
	6	1	256932	11.2
		2	2218.78	11.1
		3	2242.25	11.3
	7	1	2465.65	15
		2	2716.10	18.1
		3	3015.55	20.9
MB-A8	5	1	2181.58	14.10
		2	2462.16	16.28
		3	1818.33	15.22
MB-A8	6	1	1930.57	17
	6	2	3105.28	14.86
		3	2881.37	18.54
	7	1	2715.66	16.88
		2	2922.41	16.98
		3	2950.93	17.62
MB-A10	5	1	2565.14	15.6
		2	2017.14	16.28
		3	2683.72	17.32
	6	1	2504.66	18.32
		2	2563.22	14.28
		3	2368.12	20.2
	7	1	2676.20	16.72
		2	2786.58	18
		3	2538.22	18.08
CRMB-A6	5	1	4230.28	14
		2	4652.34	17.6
		3	4441.19	18.2
	6	1	4132.04	17.43
		2	3840.49	19.21
		3	3986.31	19.76
	7	1	4356.21	20.23
		2	4326.57	17.8
		3	4589.79	19.57
CRMB-A8	5	1	4424.65	16.02
		2	4685.55	18
		3	3867.82	18.78
CRMB-A8	6	1	3995.25	17.2
		2	4326.22	18.56
		3	4656.53	20.64
	7	1	4624.82	19
		2	4758.32	18.62
		3	4671.86	19.98
CRMB-A10	5	1	3324.09	18.02
		2	3562.89	16.88
		3	3463.11	17.90
	6	1	3686.52	19.12
		2	3456.28	20.92
		3	3957.20	22.36
	7	1	4122.62	17.2
		2	4288.32	18.40
		3	4471.06	18.80
CRMB	5	1	1593.07	17.54
		2	1785.36	18.28
		3	1689.2	19.36
	6	1	1391.97	21.60
		2	1119.3	18.69
		3	1147.29	18.51
	7	1	911.07	19.6
		2	867.46	22.32
		3	1124.51	22.88

NOTE:- CONTOL MIX: Mix without Admixtures
MB A6 : Modified bitumen with 6% H.D.P.E content coated to aggregate
MB A8 : Modified bitumen with 8% H.D.P.E content coated to aggregate
MB A10 : Modified bitumen with 6% H.D.P.E content coated to aggregate

CRMB A6 : Modified bitumen with 6% H.D.P.E coated to aggregate and Crumb rubber content 10% of total binder content.

CRMB A8 : Modified bitumen with 8% H.D.P.E coated to aggregate and Crumb rubber content 10% of total binder content.

CRMB A10 : Modified bitumen with 10% H.D.P.E coated to aggregate and Crumb rubber content 10% of total binder content.

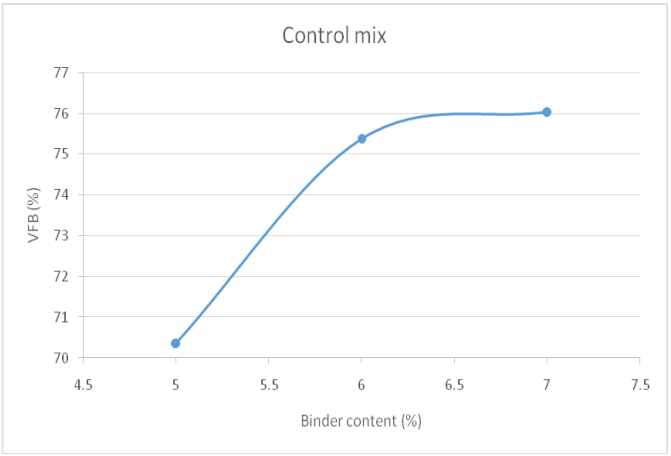
CRMB : Modified bitumen Crumb rubber content 10% of total binder content and normal aggregate.

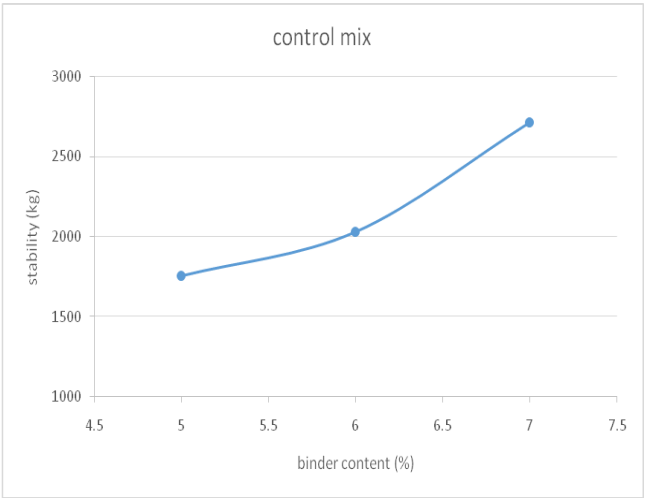
The Optimum bitumen content was set to 5,6 &7 percentages , Marshall mix design samples were prepared, tested in Marshall Test set up after held in water bath for 60minutes.The stability and Flow values obtained for various samples is plotted to graph for finding Optimum and rich mix that gives better Workability and Durability.

The results obtained from graphs is compared with Control mix and Modified bituminous mix that was shown in charts.

4.1: GRAPHS FOR TEST RESULTS

4.1.1: CONTOL MIX





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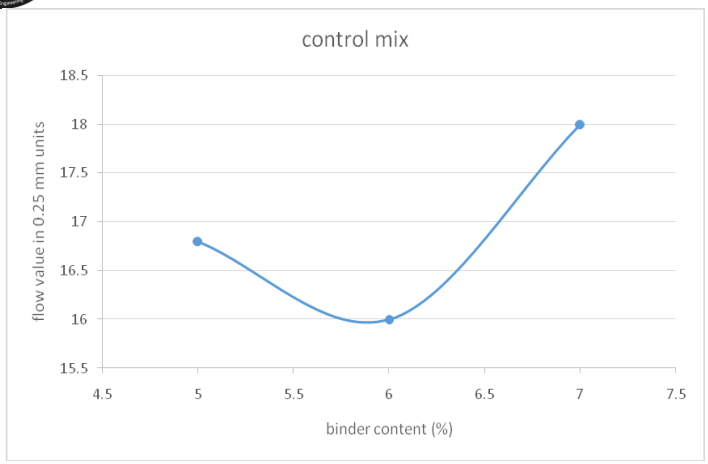
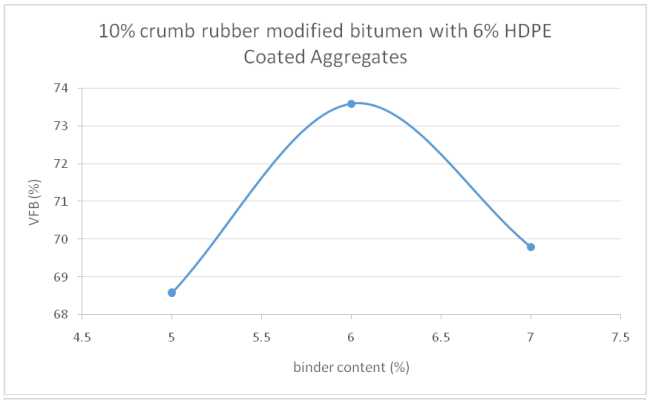
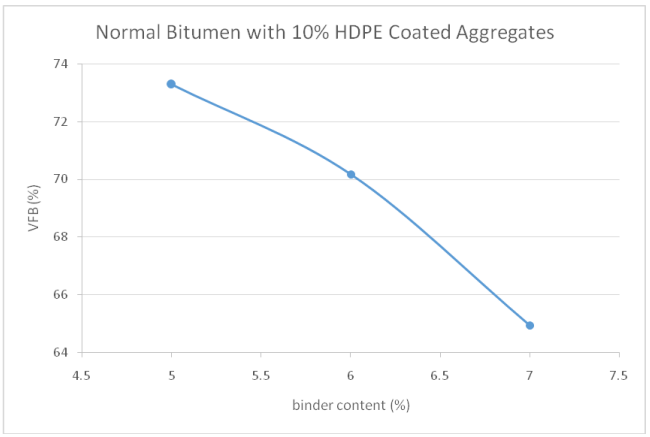
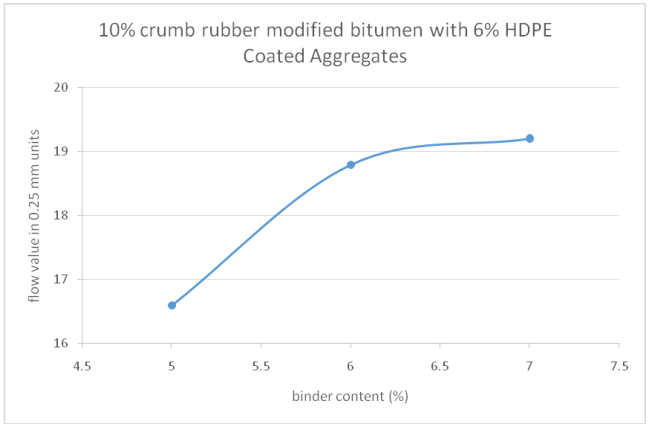
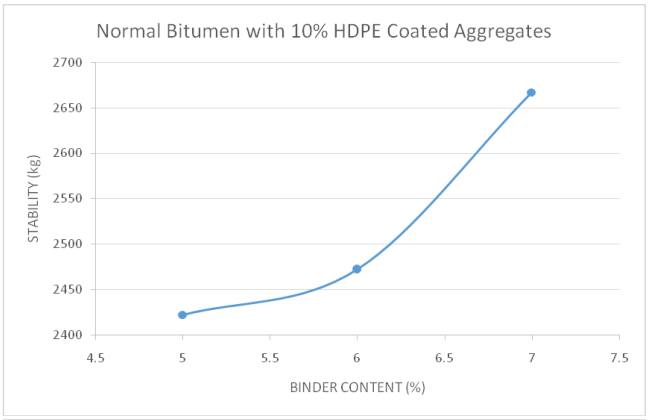


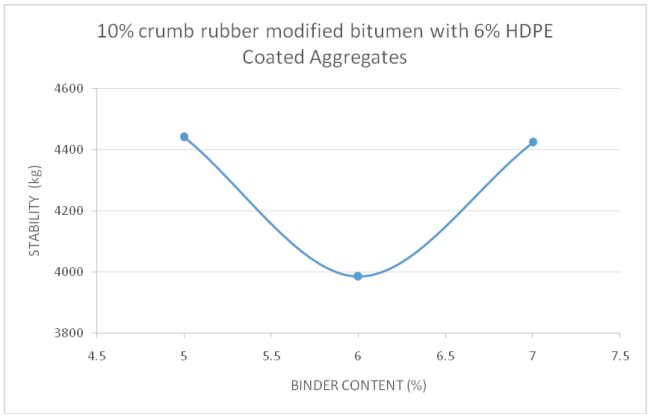


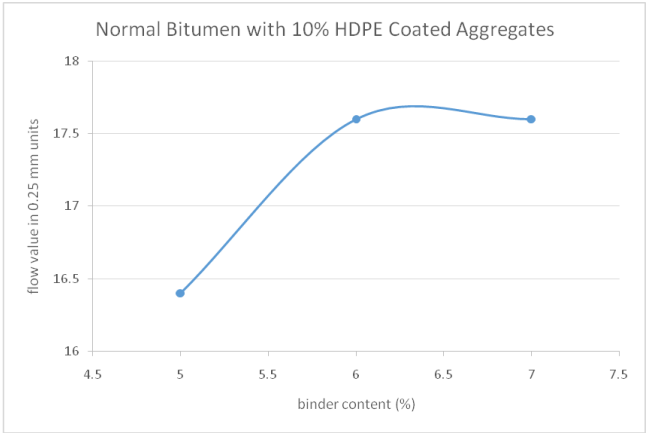
4.1.2: MB A10: 10% H.D.P.E











Various parameters of the bituminous mix such as Bulk density,Void filled with bitumen ,Percentage Airvoids ,Stability and Flow are plotted to graphs with optimum percentages of bitumen and selected group of aggregates it is found that the increased Bulk density in the mix when the H,D,P,E granules were added when compared to control mix(Nominal bitumen).

Comparision of all parameters among various percentages of Binder,H.D.P.E and Crumnb rubber was done and there is good improvement in the results particularly at 8% H.D.P.E with 6% Binder content.

4.2: COMPARISION OF MARSHALL TEST RESUTS

4.2.1. MARSHALL STABILITY

4.1.3:CRMBA6:10%CRUMB RUBBERand 6% H.D.P.E

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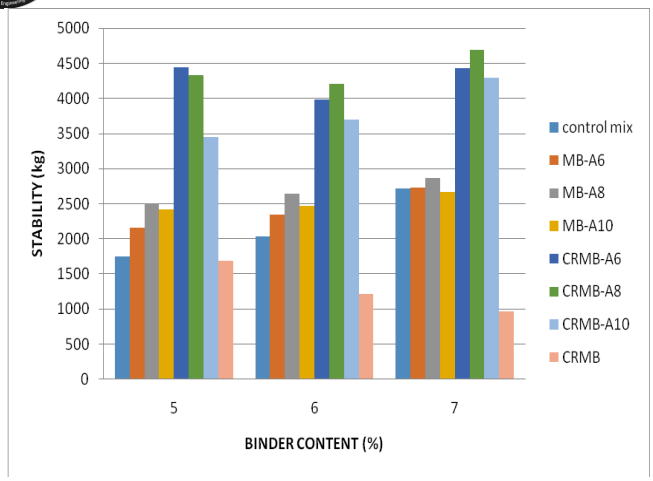
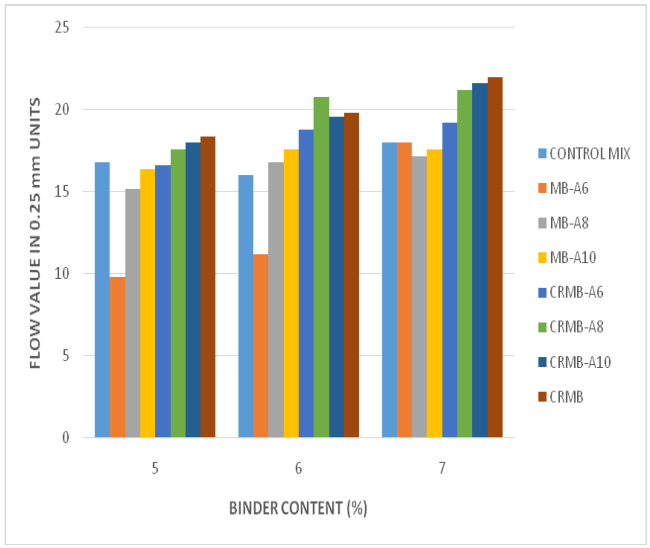
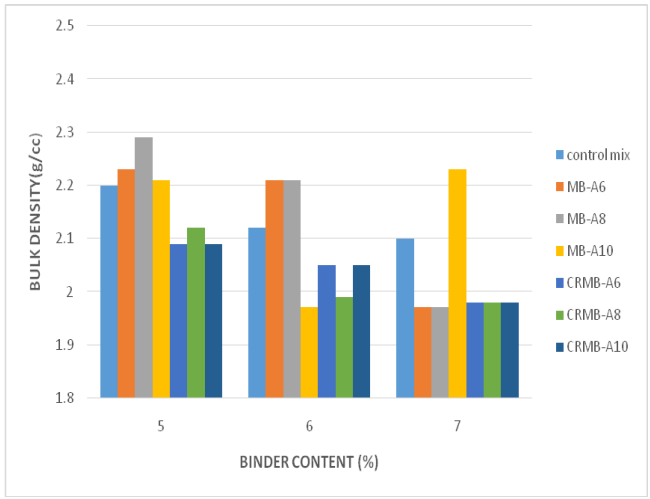


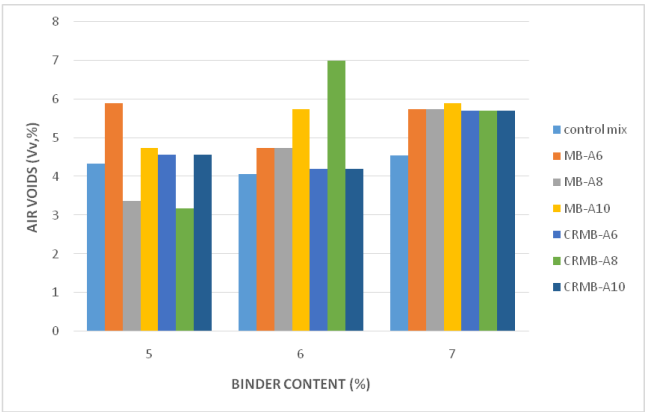
4.2.2. FLOW



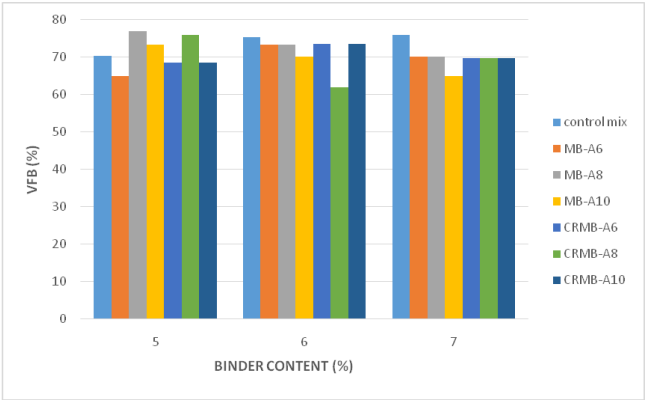
4.2.3. BULK DENSITY



4.2.4. AIRVOIDS



4.2.5. VOID FILLED WITH BITUMEN



V. CONCLUSIONS

- HDPE coating of aggregates increases abrasion, crushing value and impact resistance of aggregates thus improving strength and wear resistance properties of the treated aggregates.
- Modified bitumen with crumb rubber as admixture improves ductility and softening point thus increasing ability of sustaining under high temperatures and plastic deformation.
- Optimum binder content obtained is 7% which is common for both control mix (without admixtures) and modified bituminous mixes (with admixtures).
- Mixture modification using 8% shredded HDPE improves the Marshall Stability of the mixture and thus increasing its rutting resistance and load carrying capability.
- Stability of bituminous mix is increasing on proportional to increasing of HDPE up to 10%
- Greater stability is obtained at lower binder content (ie..5%) for the mix with crumb rubber modified bitumen and normal aggregate.
- The flow values of bituminous mix is remaining constant for the mixes with crumb rubber modified bitumen.
- It is found that maximum stability value obtained for the mixes with 8% HDPE coated aggregate.
- It is observed on adding crumb rubber with HDPE coated aggregates, stability as well as the flow has been improved when compared to crumb rubber added bitumen with normal aggregate.
- Using crumb rubber in mix results higher ductility and increasing the plastic nature of binder.

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- At whole this can be said as the combination of Rubberized and Plastic roads,if the combination of Crumb rubber and H.D.P.E is taken.
- L.D.P.E (low density polyethylene) may cause more harmful emissions as the L.D.P.E is from waste plastics and low quality polymers.
- The use of waste plastics as asphalt mixture modifier ensures its safe, useful and environmental friendly disposal.
- It is observed that using such polymer admixtures emits harmful gases that may cause un healthy environment in surroundings, But taking preventive measure is possible in hot mix plant.
- Use of waste polyethylene in HMA (hot mix asphalt) is expected to yield better and enhanced waste management and better city hygiene and environment.
- The proposed mixes are economical since we are attaining greater strength at very little investment. (HDPE 80/- kg & Crumb rubber 18/- kg)
- By adding proposed admixtures the initial cost of the mix may be high, but overall cost on using them in construction will be economical.

5.1: SCOPE FOR FURTHER STUDY

- Modified bitumen with various varieties of polymers or some other materials which gives better mix properties.
- In this study we have been used the Re cycled H.D.P.E and Crumb rubber as additives which was completely going waste, There are another waste materials such as Plastic waste (Plastic roads) which is causing environmental pollution can be used extensively and can extend this study.
- We can also compare the mix properties achieved by the H.D.P.E and Plastic waste (Domestic).
- We can use Zycosil as a proper additive in the bituminous mix which gives better Plastic properties for the mix and increase Durability of pavements.
- In this study we concentrated on only the mix grades and proportions regarding to the surface course , Bituminous concrete mixes only , But we can extend this study for the mixes used for the base courses also.
- This waste materials can be operated and used successfully in the construction of roads thus avoiding the environmental problems and minimize the cost of construction of roads within the country Various studies are proposed to be conducted with varying the mix ratio of the admixtures with bitumen keeping the maximum level of admixtures to **10%** by volume.

REFERENCES

[1] .Highway Engineering by S. K. KHANNA & C. E. G. JUSTO.

[2].IRC: 29-1988 SpecificationforBituminous mix design forRoadPavement.

[3]. DesignandconstructionofBitumenPavements by MartinJ.ROGERS &WallaceAHUGH.

[4]EffectofAggregateGradationLimitsofFatigueLifeofNeat& SBSModifiedBituminousConcretemixes S.SAWANTHI,M.S.AMARNATH&ProfA.VEERARAGAVAN.

[5]. ASTM D 1559 (1989), "Test Method for Resistance of Plastic Flow of Bituminous Mixtures Using Marshall Apparatus.

[6]. IS: 2386 (1963), "Methods of Test for Aggregates for Concrete (P-IV): Mechanical Properties", Bureau of Indian Standards, New Delhi.

[7]. Standardtestslike,penetration,softeningpoint,flash point,firepoint,viscosity,ductilitytestetc.,wereconductedonth ebitumensampleaccording to IS: 120-1978 to IS: l2l2-1978 and results compared with values specified in IS: 73-199.

[8]. Researchers conducted by Marais, 1979; Chen and Lin, 2005; Amit and Animesh 2004; Tapkin, 2008, Simpson et al. (1994), Serfass and Samanos (1996), Bindu and Beena, 2009, Austoroads , Miller and Traxler, Bidgen, Nevitt and Csanyi, Tunnicliff.

[9]. Experimental Studies on Modified Bituminous Mixes Using Waste HDPE and Crumb Rubber by K.RAJESH KUMAR and Dr. N.MAHENDRAN.

[10]. Ministry of Road Transport and High Ways, Manual for construction and supervision of Bituminous works, New Delhi, November 2001.

[11]. Vasudevan, R., Utilization of waste plastics for flexible pavement, Indian High Ways (Indian RoadCongress), Vol. 34, No.7. (July 2006).

[12]. Justo C.E.G., Veeraragavan. A "Utilization of Waste Plastic Bags in Bituminous Mix for Improved Performance ofRoads", Centre for Transportation Engineering, Bangalore University, Bangalore, India, 2002.

[13]. AslamShahan-ur-Rahman "Use of Waste Plastic in Construction of Flexible Pavement", New Building Materials & Construction World, 2009.

[14]. Sandyadixit "Studies on the improvement of characteristics of bitumen with use of waste plastic" International Journal of Emerging Technology and Advanced Engineering (ISSN 22502459, ISO 9001:2008 Certified Journal, Volume 3, Issue 3, March 2013).

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APPENDIX

SAMPLE CALCULATIONS FOR CONTROL MIX WITH 6% OF BITUMEN

(a) Percentage of air voids or volume of voids (Vv)

Weight of mix in air (W_m)
= 1.211 Kg

Weight of mix in water (W_w)
= 0.64 kg

Bulk Density (G_b) = 1.217 / (1.217- 0.6)
= 2.12g/cc

Percentage by weight of coarse aggregates in total mix (W_1)

W_1 = ((72+312+84)/1152)*100
= 40.625%

Percentage by weight of fine aggregates in total mix (W_2)

W2 = ((614)/1152)*100 = 53.29%

Percentage by weight of filler in total mix

(W_3) = (70/1152)*100 = 6%

Percentage by weight of bitumen in total mix

(W_4) = 6%

Apparent specific gravity of coarse aggregate (G_1)
= 2.6

Apparent specific gravity of fine aggregate (G_2)
= 2.6

Apparent specific gravity of filler (G_3)
= 2.55

Apparent specific gravity of bitumen (G_4)
= 1.02

Theoretical specific gravity of compacted specimen mixture (G_t)

G_t = 100/ (W1/G1+W2/G2+W3/G3+W4/G4)

G_t = 100/((40.6/2.6)+(53.2/2.6)+(6/2.55)+(6/1.02))
= 2.21

V_v = ((Gt–Gm) /Gm)*100 = ((2.21–2.12) /2.21)*100
= 4.07%

(b) Percentage of voids in mineral aggregates (VMA)

Volume of bitumen (V_b) =Gm*(W4/G4) = 2.12*(6/1.02)
= 12.47 %

VMA = V_v+Vb = 4.07+12.47
= 16.54%

(c) Percentage of voids filled with bitumen (VFB)

V F B = 100*(V_b / V M A)

= 100*(12.47/16.54)

= 73.59%

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