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Assessment of Strength Characteristics of Bituminous Concrete Modified using HDPE

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Abstract

Bituminous Concrete is composite material made by mixing aggregates and bitumen in fixed proportions used for construction of bituminous pavements. Bituminous pavements transfer wheel loads to subgrade by grain to grain transfer mechanism, to transfer loads by this mechanism the bituminous concrete should have high strength. To overcome the problems posed by increased traffic load and deteriorated environmental conditions different types of modifiers are being used in bituminous concrete. Modification of bituminous concrete is done to increase its stability and improve other characteristics. HDPE is one modifier which have been used and being used in bituminous construction. Bituminous concrete modified using HDPE is formed by mixing HDPE in bituminous concrete. In the present study HDPE is used as modifiers for bitumen as well as for bituminous concrete. HDPE were added to bitumen and physical properties of modified bitumen were assessed by conducting penetration value test, ductility value test, softening point, flash & fire point tests on bitumen modified using HDPE. After assessing the physical properties of modified bitumen cylindrical moulds were casted using BC modified by using HDPE, the amount of HDPE was varied from 8% to 10% by the weight of bitumen. Marshall Test was performed on the cylindrical moulds to find stability value and flow value of bituminous concrete modified using HDPE. Results of study revealed that, ductility value and penetration value of bitumen decreased with increment of HDPE content while softening point, Flash & Fire point increased with increment in HDPE content. When HDPE were used in BC and checked for Marshall Stability values, stability increased first reached maximum and then started decreasing. The maximum stability value was obtained for 9% content of HDPE by the weight of bitumen. Economic usage of HDPE in BC was evaluated for 1Km, 7m lane width and 50mm thickness of bituminous concrete pavement. Therefore use of HDPE in bituminous concrete provides a viable solution for the disposal of waste HDPE, this factor alone makes use of HDPE in bituminous concrete very acceptable and admirable.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Bituminous concrete; Increased Traffic Load;HDPE; Stability value; Economic usage; Modified Bitumen

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1. Introduction

Bituminous mixes are widely used all over the world in flexible pavement construction. It consists of bitumen (used as binder) and mineral aggregate which are mixed together, laid down in layers and then compacted. Today's asphaltic concrete pavements are expected to perform better as they are experiencing increased volume of traffic, increased loads and increased variations in daily or seasonal temperature over what has been experienced in the past (Murphy et al., 2001). In addition, the performance of bituminous pavements is found to be very poor in moisture induced situations. Considering this a lot of work has been done on use of additives in bituminous mixtures and as well as on the modification of bitumen. Researches indicate that the addition of polymers to asphalt binders helps to increase the interfacial cohesiveness of the bond between the aggregate and the binder which can enhance properties of the asphalt pavements to help meet these increased demands. However, the additive that is to be used for modification of mix or binder should satisfy both the strength requirements as well as economic aspects. Plastics are everywhere in today's lifestyle and are growing rapidly throughout particularly in a 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. High density polyethylene (HDPE) have been found to be good modifier of bitumen even, the recycled polyethylene originally made of HDPE has been observed to modify bitumen (Kalantar et al., 2013).

Today availability of plastic waste is huge. Use of plastic materials such as carry bags, cups, etc. is increasing constantly. Approximately 50% to 60% of total plastic are used for packing. Once used, plastic packing materials are thrown and they remain as waste. Plastics are durable and non-biodegradable. The improper disposal of plastic may cause genital abnormalities, reproductive problems in humans and animals, breast cancer and much more. Hence plastics are not eco-friendly and they pollute the land, air and water. Under these given circumstances, an alternative way to use these plastic wastes is required (Wahab et al., 2012).

Polyethylene is used in road construction from long time ago and it is well known fact that polyethylene is hydrophobic material means they are very good water repellent. Some aggregates used in bituminous construction are highly hydrophilic (water loving) and during rains they will absorb water and will lead to deterioration of bituminous pavements. Polyethylene is hydrophobic (water hating) in nature so, the addition of hydrophobic polymers either by dry or by wet mixing process to bituminous mix lead to improvement of strength, water repellent property of the mix (Ahmadinia et al., 2012). Poly-ethylene is added to hot bituminous mix and the mixture is laid on the road surface like a normal bituminous road. Modification of bitumen can be considered as one of the solution to improve the fatigue life, reduce the rutting and thermal cracking in the pavement. Polymer modified bitumen is emerging as one of the important construction material for flexible pavements. Use of plastic in flexible pavement construction is gaining importance because of several reasons, polymer modified bitumen shows better properties for road construction and plastics waste, otherwise considered to be a polluting agent, can find its use in this construction process and this will help solving the problem of pollution because most of the plastic wastes are polymers. Researchers suggest that water does not have adverse effects on plastics and therefore plastics used in pavement will by some amount increase water repelling properties of pavements and use of plastics increases strength of bituminous concrete by some extent.

Previous researches suggest that by using waste plastics in bituminous construction the strength characteristics of bituminous concrete can be improved. Strength of bituminous concrete can be evaluated by performing Marshall test on bituminous concrete cubes and finding the stability values or by computing Marshall quotient which is an indicative of strength. Marshall Quotient value increases up to 50% by using waste plastics as modifier in bituminous concrete (Moghaddam et al., 2014)

This work has been done to assess the effects of modification of bituminous concrete by using HPDE in strength characteristics of Bituminous concrete, effects of modification on bitumen by using HDPE on physical properties of bitumen was also assessed. It was also tried to get a possible solution to pollution problem and solution to the problems of insufficient performance of pavements simultaneously. The problem of dumping of waste plastics is very severe and need to be addressed properly. This study also aims to provide a viable solution to problem of waste disposal effectively. The work has been performed by conducting Marshall Tests on the cylindrical moulds prepared by bituminous concrete modified using HDPE. The main objective of the study is to assess strength characteristics of bituminous concrete using HDPE. This paper consists of six sections of which this is the first. The second section presents methodology to evaluate the strength characteristics of bituminous concrete modified using HDPE and the third section present the experimental investigations of materials used and various tests performed on them and the fourth section presents the analysis and result using proposed methodology followed by the fifth section which is economic evaluation of usage of HDPE in bituminous concrete. The last section presents the important conclusions drawn based on this study.

2. Methodology to evaluate the strength characteristics of bituminous concrete modified using HDPE

Assessment of strength characteristics of bituminous concrete modified using HDPE includes various stages such as assessment of physical properties of constituents of bituminous concrete (aggregates, bitumen and filer) as per respective IS codes to check the suitability of materials then finding optimum bitumen content by performing Marshall’s test on bituminous concrete which will be used further in study. After finding optimum bitumen content assessment of strength characteristics of bituminous concrete modified using HDPE was done by performing Marshall’s test on samples made with different percentage of HDPE. The methodology used for this work is presented in Fig 1. The maximum content of HDPE up to which stability of bituminous concrete modified using HDPE increases is termed as optimum dose of HDPE. Optimum dosage of HDPE was found by conducting Marshall’s tests on bituminous concrete modified using HDPE and plotting graph between stability value in KN and percentage of HDPE one at a time. The HDPE dosage corresponding to maximum stability value is termed as optimum dose of HDPE

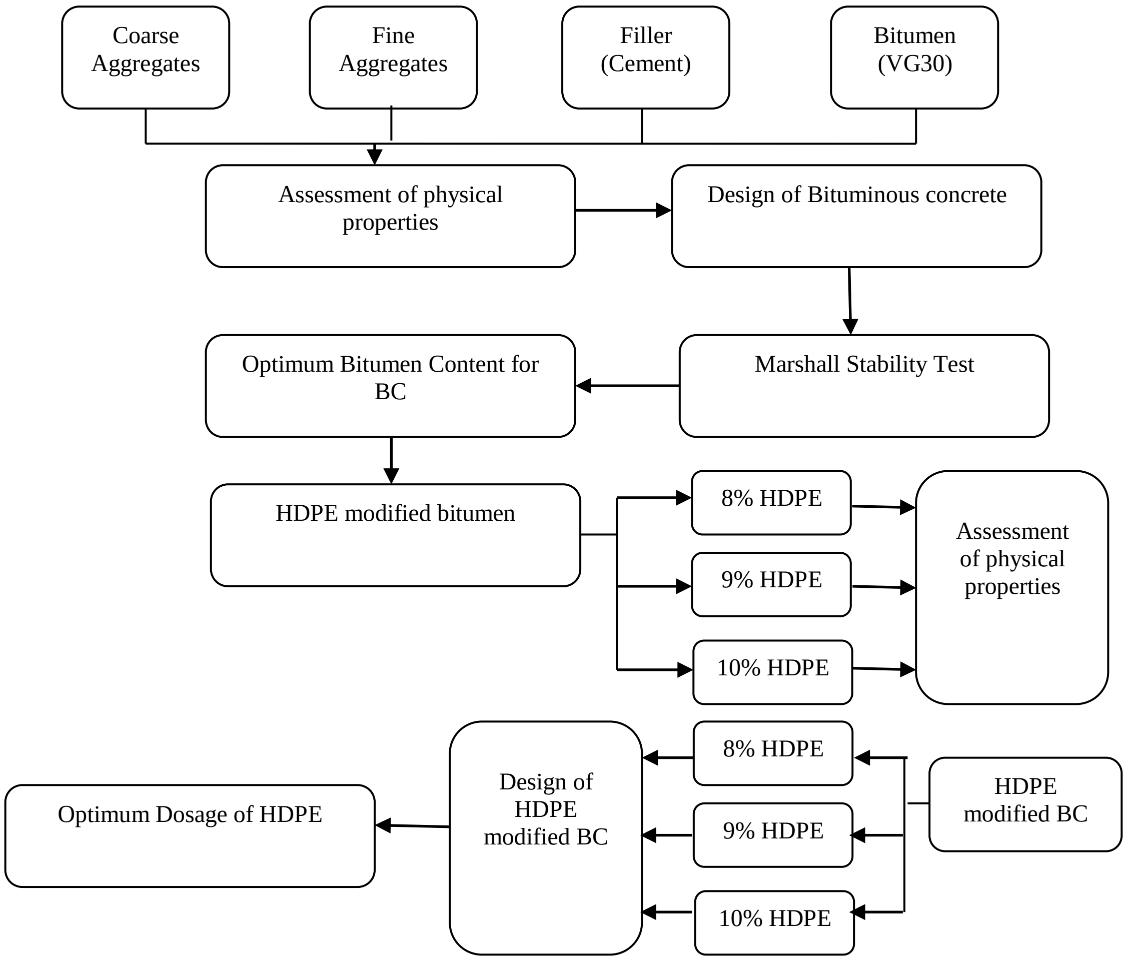

Fig. 1. Methodology for the Assessment of Strength Characteristics of BC Modified Using HDPE.

For better assessment of utilization of HDPE in bituminous concrete effects of HDPE on bitumen so, penetration value, ductility value, flash and fire point, softening point tests were performed on bitumen modified with HDPE should be known. After assessing the physical properties of bitumen modified using HPDE the same modified bitumen was used to prepare bituminous concrete which is termed as Bituminous concrete modified using HPDE. Marshall test was performed on the bituminous concrete modified using HDPE, Marshall stability and Marshall flow values were found out. Per cent air voids, voids in mineral aggregates, voids filled with bitumen were also calculated. Content of both HDPE were varied from 8% to 10% by the weight of bitumen. Trends for different characteristics were plotted against the contents. Calculations were done to compute specific gravity and theoretical specific gravity of the specimens, the trends for specific gravity was also found from the graph between specific gravity and HDPE content. After assessing strength characteristics optimum dosage of HDPE were obtained from graph plotted between Marshall Stability and HDPE dosage. The optimum dose was decided based on the graph between stability value and HDPE contents. Optimum bitumen content was used to analyse the economic viability of use of HDPE in bituminous concrete. Amount of the bitumen was replaced by HDPE content and the reduced cost was computed. The reduction in cost was presented as percentage of actual cost of construction for conventional bituminous concrete. Upcoming sections will present the experiments performed, results of the experiments, economic evaluation of the work and conclusions made from the study.

3. Experimental investigations of materials used and various tests performed on them

This section contains the tests methods and standard test procedures for the tests performed on materials used in study and bituminous concrete. The tests were performed to evaluate physical properties of all the constituents of bituminous concrete namely coarse aggregates, fine aggregates, bitumen, HDPE. In next step bituminous concrete moulds were prepared to obtain optimum bitumen content, moulds were prepared by with varying bitumen content and Marshall stability was found, the bitumen content corresponding to maximum stability value is termed as optimum bitumen content. To evaluate the physical properties of bitumen modified using HDPE with varying content of HDPE tests on modified bitumen were performed, the tests performed were penetration value, ductility value, softening point and flash & fire point. The strength characteristics of bituminous concrete modified using HDPE was then assessed by performing Marshall test, moulds were prepared by using bitumen equal to optimum bitumen content and modifying the bituminous concrete using different contents of HDPE. Upcoming sections contain the details of tests which were performed to carry out the study and their respective Indian standards specifications with standard test methods.

3.1 Aggregates

Aggregates are major components of bituminous concrete and they bear high magnitude of load stresses which occurs on the pavements. Tests were performed to compute the strength properties to check that how aggregates will perform under wheel loads. Various test methods of aggregates as per IS codes are presented in Table 1.

Table 1. Test Methods of Aggregates as per IS Codes

S. No.	Name of Test	Test Method
1	Aggregates Impact Value Test	IS: 2386 - Part 4
2	Specific Gravity	IS: 2386 - Part 3
3	Los Angeles Abrasion Value Test	IS: 2386 - Part 4
4	Aggregates Crushing Value Test	IS: 2386 - Part 4
5	Combined Flakiness and Elongation Index	IS:2386 - Part 1
6	Water absorption	IS:2386 - Part 3

3.2 Bitumen

Bitumen is petroleum product obtained by the distillation of petroleum crude mainly used in construction of flexible pavements along with mineral aggregates. It is widely used as binder in flexible pavements construction because of its binding properties and visco-elastic nature. Bitumen has been used as binders since long time and it has been performing satisfactorily in the pavements, it is the material which can be modified and the strength and other characteristics of the whole bituminous concrete can be improved. The assessment of physical properties of bitumen is very important for the reason that it is very key component of the mix and it affects the properties of mix and later affects the performance of pavements. Physical properties of bitumen used for the research work has been determined as per the norms of Indian standards and the same is presented in Table 2.

Table 2. Tests Performed on VG-30 Grade Bitumen and Test Methods

S. No.	Name of Test	Test Method
1	Specific gravity at 27^{0}C	IS: 1202
2	Ductility at 27^{0}C	IS: 1208
3	Softening Point	IS: 1205
4	Penetration at 25^{0}C	IS: 1203
5	Flash Point	IS: 1209
6	Fire Point	IS: 1209

3.3 Cement

Portland Pozzolana cement confirming to IS 1489-1991 (Part-1) make ACC cement is used in the present experimental work. Cement used study was checked for its packing, appearance and colour, the specific gravity of the cement used was 3.15 as provided by the manufacturers.

3.4High Density Polyethylene (HDPE)

HDPE is a non-linear visco-elastic plastic material with time-dependent properties prepared from ethylene by a catalytic process. IRC SP 98, 2013 limits the size of HDPE used from 2.36mm to 600micron. Size has been limited because if HDPE used is very large in size it will not mix properly with bitumen and bituminous concrete and hence modification will not be efficient. The HDPE was collected from waste of boy’s hostel and was washed, dried and cut to the specified size. The proportions of different size of HDPE used for the work are presented in Table 3.

Table 3. Composition of HDPE

S. No.	Sieve Size (mm)	% passing
1	4.75	100
2	2.36	60
3	1.18	15
4	0.6	5
5	0.3	0

The aspect ratio is another factor which influence the mixing because if the HDPE used is flaky or elongated the mixing will not be effective. The aspect ratio used in the study was 2.

3.5 Bituminous Concrete Mix Design

The performance of bituminous concrete depends on the pavement design factors considered at the design stage and the prevailing or actual factors including the traffic loads and their repetitions, the climate and drainage factors. The performance and the life of pavement depends on the adequacy of the pavement structure including the subgrade support, properties of the materials used and the thickness of the various pavement layers with reference to the traffic and climatic factors. The main objectives of the bituminous mix design are to arrive at a suitable mix which could fulfill the following requirements:

- Adequate stability or resistance to the deformation of the mix to withstand distortion or permanent deformation under expected traffic loads.
- Sufficient bitumen binder content to properly coat aggregate particles and to provide adequate durability.
- Sufficient voids in the compacted mix to allow expansion of the binder due to temperature increase and a little additional compaction under traffic loads, without causing bleeding of bitumen.
- Restrict the maximum voids contents to permeability and moisture induced damages.
- Sufficient workability of the mix during placement of the mix/paving and compaction.

3.6 Design requirement of bituminous concrete

The MORT&H has specified the grading specification for bituminous concrete to be used on surface course of flexible pavements and mix design specification to be fulfilled by compacted specimens of bituminous mixes compacted with 75 blows on either side of Marshall test specimens. The grading is important because if the aggregates used are single size graded or graded in such manner that there are large no of voids than the mix which will be prepared will be not compact, excess number of voids causes less compressive strength of the mix, compressive strength is measured by stability values, if there are too many voids in the mix the stability values will be less and the pavement will not be able to perform satisfactorily under the wheel load. Performance under the wheel load will determine the suitability of the mix. Table 4 presents the specifications given by MORT&H for the Composition of Bituminous Concrete Pavement Layers

Table 4. Composition of Bituminous Concrete Pavement Layers

Nominal Aggregate Size	19mm
Layer Thickness	50mm
IS Sieve Size (mm)	Percentage by weight of total aggregate passing
26	100
19	90-100
13.2	59-79
9.5	52-72
4.75	35-55
2.36	28-44
1.18	20-34
0.6	15-27
0.3	10-20
0.15	5-13
0.075	2-8

Sieve analysis was performed using Indian Standard sieves from size 26mm to 75micron for each of four types of aggregates used, size range of first type of aggregate used was from 26mm to 12.5mm, IInd type of aggregates has size between 12.5mm to 7.5mm, next aggregates size ranged from 7.5mm to 4.75mm and for 4th type it ranged below 4.75mm. After getting the proportions of every size particles in all four types of aggregates proportion of each type was decided by hit and trial method and it was ensured that blend of all aggregates have all the particles size in the range specified by MORT&H 2013 Table 5 presents the specifications given by MORT&H for bituminous concrete which will be used in surface course.

Table 5 Specifications for Bituminous Mix Properties

S. No.	Mix properties	Limits as per MORT&H 2013 (Fifth Revision)
1	Minimum Marshall stability value	9KN
2	Marshall flow value	2mm – 4mm

3	Air voids in total mix (V_v)	3% - 5%
4	Voids filled with bitumen (VFB)	65% - 75%
5	Voids in mineral aggregates (VMA)	13% - 15%
6	Marshall Quotient	2 – 5

3.7 Tests on Bitumen Modified Using HDPE

Tests were performed on the bitumen modified by using HDPE to assess the physical properties because physical properties of binder play important role in the strength of bituminous concrete. If physical properties of the binder used for bituminous construction are as specified by IS: 73 then it can be assured that bituminous concrete constructed by using this bitumen will have good physical properties. Tests performed on the bitumen modified using HDPE were the same tests which were performed on the virgin bitumen so that a comparative study can be done on the properties of virgin bitumen and bitumen modified using HDPE. Table 6 presents the tests which were performed on the modified bitumen and test methods

Table 6 Tests Performed on Modified Bitumen and Test Methods

S. No.	Name of Test	Test Method
1	Specific gravity at 27^0C	IS: 1202
2	Ductility at 27^0C	IS: 1208
3	Softening Point	IS: 1205
4	Penetration at 25^0C	IS: 1203
5	Flash & Fire Point	IS: 1209

3.8 Marshall Method of Bituminous Mix Design

The Marshall method of mix design is a design philosophy which used to design the proportions of different constituents of bituminous mixes. There are many methods available for mix design varying in the compaction, size of the test specimen, and other test specifications. Marshall method of mix design is the most popular one out of them, the Marshall stability and flow value give an idea about the performance of Marshall mix design. The stability of the test measures the maximum load supported at failure by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure, and the maximum load in Kg or KN is designated as stability. An attached dial gauge measures the specimen's plastic flow (deformation) due to the loading; the flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded. About 1200gm of aggregates and filler is heated to a temperature of 170^0C – 190^0C; bitumen is heated to a temperature of 120^0C - 140^0C with the first trial percentage of bitumen (say 4.8% or 5% by weight of the mineral aggregates). The heated aggregates and bitumen are thoroughly mixed in mixing pan at a temperature of 160^0C - 170^0C then the mix is placed in a preheated mould and compacted by a rammer with 75 blows on either side at temperature of 140^0C to 150^0C. Marshall tests is performed on the prepared moulds and Marshall stability and flow are recorded, this procedure is repeated by varying the bitumen content and Marshall stability and flow values are recorded. Graphs are plotted between bitumen content and stability value, from the graph max value of stability is found out and bitumen content corresponding to max stability is called optimum bitumen content optimum bitumen content. Readings are noted down from the dial gauges for load and flow simultaneously then stability and flow values are obtained by interpolating the dial gauge readings with standard readings. After preparing mould weight of mould in air and in water is taken which is further used to determine bulk specific gravity of mould. Some important terms which are used in Marshall method of mix design and method to compute them are described below:

- Theoretical Specific Gravity of the Mix (Gt)

Theoretical Specific Gravity of the Mix is calculated by the formula given in Equation 1

$$Gt = \frac{W1+W2+W3+Wb}{\frac{G1}{W1}+\frac{G2}{W2}+\frac{G3}{W3}+\frac{Gb}{Wb}} \quad (1)$$

Where,

W1 is weight of coarse aggregates,
W2 is weight of fine aggregates,
W3 is weight of filler,
Wb is weight of bitumen,
G1 is specific gravity of coarse aggregates,
G2 is specific gravity of fine aggregates,
G3 is specific gravity of filler and
Gb is specific gravity of bitumen respectively.

- Bulk Specific Gravity (Gm)

The bulk specific gravity or the actual specific gravity of the mix Gm is the specific gravity considering air voids and is found out by Equation 2.

$$Gm = \frac{\text{Weight of specimen in air}}{\text{Weight of specimen in air} - \text{Weight of specimen in water}} \quad (2)$$

The specific gravity is directly related to unit weight of material, the variation of unit weight of bituminous mix with bitumen content always follows a standard pattern and all mix which are designed should follow the pattern. Fig 2 presents the standard graph between unit weight of bituminous mix and bitumen content used to prepare the mix

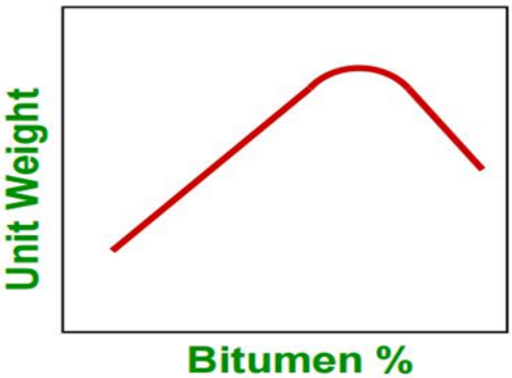

Fig. 2. Variation of unit weight of Bitumen Content

- Air Voids (Vv)

It is the total volume of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted bituminous mixture. The amount of air voids in a mixture is extremely important and closely related to durability, stability and permeability. Vv of a mix can be calculated by using formula presented in Equation 3

$$Vv = \frac{\text{Gt}-\text{Gm}}{\text{Gt}} * 100 \tag{3}$$

Where,

Gt is theoretical specific gravity of the mix and
Gm is bulk specific gravity of mix.

Fig 3 presents the standard graph between percentage air voids and bitumen content

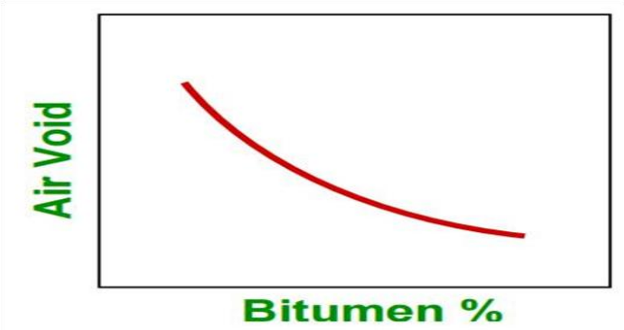

Fig. 3. Variation of air voids with Bitumen

- Voids in Mineral Aggregates (VMA)

The total volume of voids in the aggregate mix (when there is no bitumen) is called Voids in Mineral Aggregates (VMA). In other words, VMA is the volume of inter-granular void space between the aggregate particles of the compacted paving mixture. It includes the air voids and the volume of bitumen content used for construction of bituminous concrete. VMA can be calculated by simply adding per cent air voids (Vv) and bitumen content (Vb) is expressed as a percentage of the total volume of the mix

- Voids Filled With Bitumen (VFB)

VFB is the voids in the mineral aggregate frame work filled with bitumen binder. This represents the volume of the effective bitumen content. It can also be described as the per cent of the volume of the VMA that is filled with bitumen. VFB is inversely related to air voids and hence as air voids decreases, the VFB increases. VFB can be calculated as shown in Equation 4.

$$VFB = \frac{\text{Bitumen Content}}{\text{VMA}} * 100 \tag{4}$$

Figure 4 represents the standard variation of voids filled with bitumen and bitumen content.

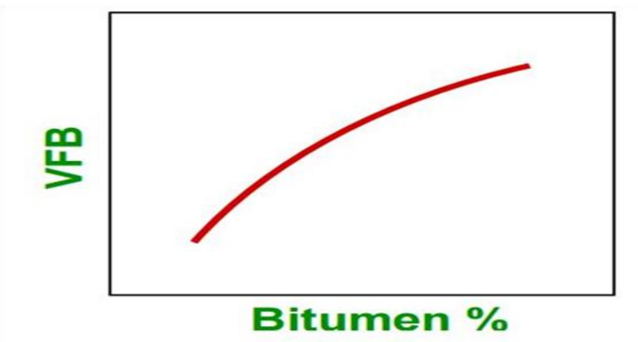

Fig. 4. Variation of VFB with Bitumen content

All the above mentioned variables need to calculate and based on that it is decided that whether the design is satisfactory or not. If all variables are well within the range laid down by MORT&H, 2013 than the design is satisfactory and if the variables do not satisfy the limits than the design should be checked and redesigned.

4. Analysis and result using proposed methodology.

This section presents the analysis and test results of bituminous concrete modified using HDPE. This section also presents the results of various tests conducted on the materials used for the tests. Further the section also discusses the results for the tests conducted on bitumen modified with HDPE. Tests were performed to assess physical properties of virgin bitumen, bitumen modified using HDPE and strength characteristics of BC modified using HDPE. Standard procedures to perform tests were adopted and all tests were performed as per the guidance of relevant Indian standards. First of all, physical properties of aggregates, bitumen, HDPE were assessed then tests were performed of bitumen modified using HDPE. After assessing the physical properties of modified bitumen bituminous concrete was prepared and Marshall Test was performed and strength characteristics of BC modified using HDPE were assessed. The order of testing was maintained so that if there is any problem in material it is replaced and there is no loss of time in conducting further experiments. Results of the tests are discussed in the following sections.

4.1 Results of Tests on Aggregates

To check that whether the aggregates used for study are suitable for the study or not physical tests on aggregates were conducted as per MORT&H 2013 (fifth revision) specifications. Table 7 presents the results of tests conducted on aggregates and respective limits as per MORT&H 2013 (fifth revision).

Table 7 Results of test on aggregates

S. No.	Name of Test		Results	MORT&H 2013 (fifth revision) Specification
1	Aggregates Impact Value Test		18%	Max. 24%
2	Specific Gravity	25 – 12.5 mm	2.76	-
		12.5 – 7.5 mm	2.73	
		7.5- 4.75 mm	2.67	
		Below 4.75 mm	2.74	
3	Los Angeles Abrasion Value Test		23%	Max. 30%
4	Aggregates Crushing Value Test		22%	Max. 30%
5	Combined Flakiness and Elongation Index		28%	Max. 35%
6	Water absorption		0.99%	Max. 2%

The above results of physical properties of aggregates shows that all the properties were found to be within the permissible limits as per MORT&H 2013, so the aggregates can be used in study.

4.2 Results of Tests on Virgin Bitumen

Bitumen acts as binder in the bituminous concrete so it’s necessary to check suitability of bitumen and for that we need to do physical tests on bitumen. Table 8 contains the results of physical tests conducted on virgin bitumen and respective IS specifications.

Table 8 Results of test on bitumen

S. No.	Name of Test	Results	IS 73, 2013 Specifications
1	Specific gravity at 27^0C	1.01	Min. 0.99
2	Ductility at 27^0C (cm)	85	Min. 75
3	Softening Point (^{0}C)	53	40^0C - 55^0C
4	Penetration at 25^0C (1/10^{th} mm)	67	60 – 70
5	Flash Point (^{0}C)	220	Min. 175^0C
6	Fire Point (^{0}C)	255	Min. 175^0C

The results shows that bitumen possess good physical qualities and the specific gravity, ductility, softening point, flash point, fire point and penetration value are in the range specified by IS 73, 2013.

4.3 Results of Tests on Bitumen Modified Using HDPE

This section presents the results of the tests conducted on bitumen modified using HDPE. Tests were performed as per the guidelines of Indians standards code and the specifications were confirmed from IRC SP-53, 2010. Table 9 presents the tests results and IRC SP-53, 2010 specifications for the tests conducted on bitumen modified using HDPE. Most of the tests are performed at specified temperature of 27^0C.

Table 9 Results of Tests Performed of Bitumen Modified Using HDPE

S. No.	**Name of Test**	**Test Results**			**IRC SP-53, 2010 Specifications**
		8%HDPE	**9%HDPE**	**10%HDPE**	
1	Ductility at 27^0C (cm)	80	77	76	Min. 75
2	Softening Point (^{0}C)	65	67	70	Min. 60^0C
3	Penetration at 25^0C (1/10^{th} mm)	42	35	31	30 – 50
4	Flash Point (^{0}C)	280	290	296	Min. 175^0C
5	Fire Point (^{0}C)	310	315	320	Min. 220^0C

Mixing HDPE in to bitumen does not affects flash and fire point greatly as at the temperature of 200^0C and above the HDPE becomes fluid and it allows the bitumen to catch fire but is increases the softening point of bitumen because HDPE requires more heat to get in to molten state and hence softening point increases.

4.4 Variation of Physical Properties of Bitumen Modified Using HDPE

- Ductility Value

Fig 5 presents change in ductility value of bitumen when modified using HDPE.

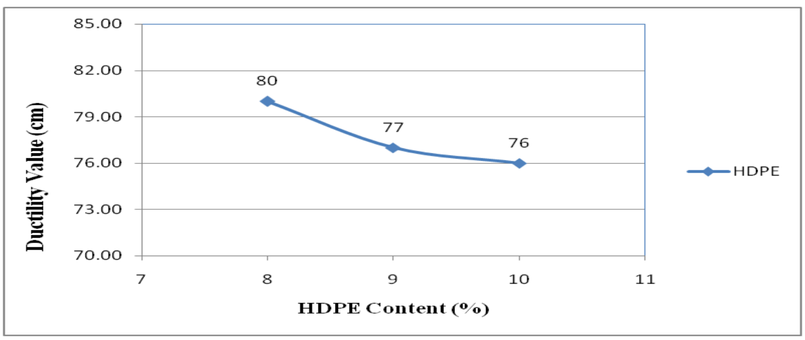

Fig. 5. Ductility Value of Bitumen Modified Using HDPE

From the Fig 5 it can be seen that ductility decreases with increase in content of HDPE, it is because as HDPE is added it reduces the inter particle bond strength between bitumen particles, so this decreasing trend is obtained.

- Softening point

Fig 6 presents change in softening point of bitumen when modified using HDPE.

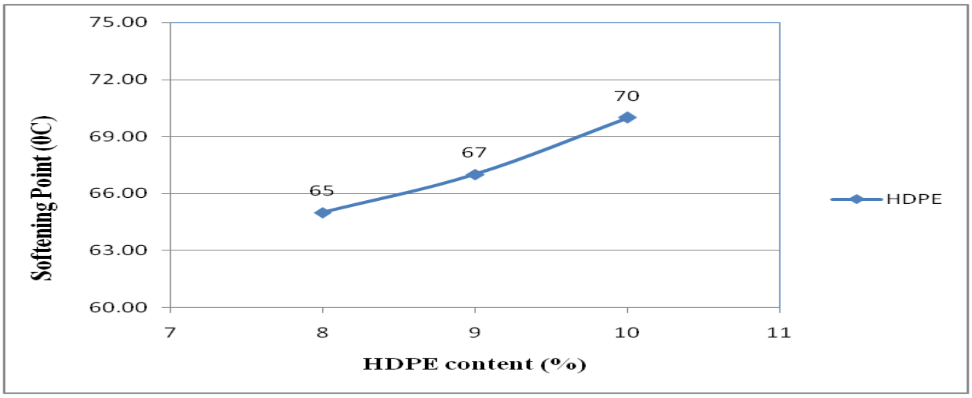

Fig. 6. Softening Point of Bitumen Modified Using HDPE

Trends in Fig 6 show that adding HDPE increases the softening point of bitumen so, this is because of the fact that HDPE added in to bitumen have higher softening points and when they are mixed in bitumen the softening point of the mixture also increases.

- Penetration Value

Fig 7 presents change in penetration value of bitumen when modified using HDPE. It can be seen from Fig 7 that addition of HDPE in to the bitumen decreases the penetration value, this trend is because of the fact that room temperature HDPE remain solid in the mix and offer resistance to the needle used to measure the penetration value this decreases the penetration value.

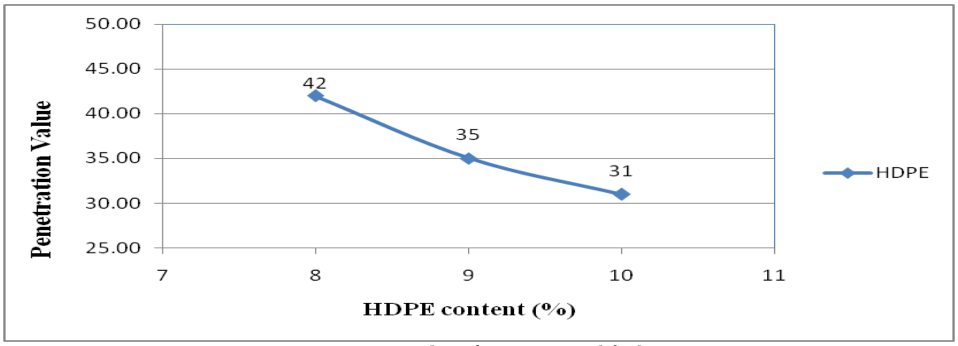

Fig. 7. Penetration Value of Bitumen Modified Using HDPE

- Flash Point

Fig 8 presents change in flash point of bitumen when modified using HDPE. From the Fig 8 it is clear addition of HDPE increases flash point of bitumen which is because of the fact that HDPE added have higher values of flash point so the overall flash point of mix is increased by addition of HDPE in to bitumen.

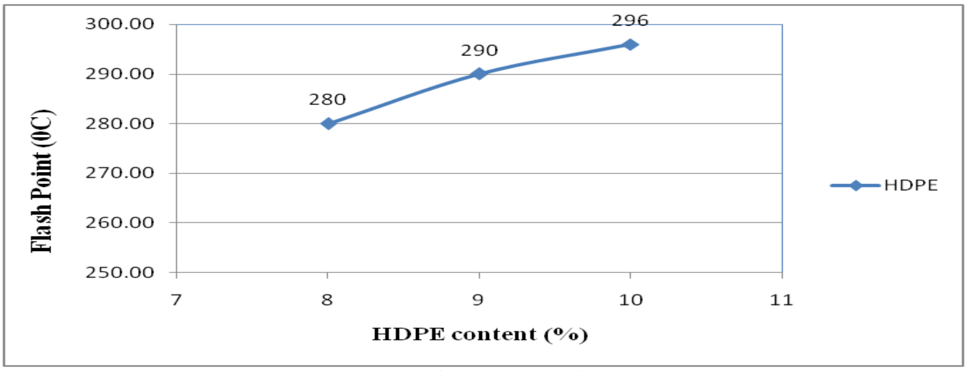

Fig. 8. Flash Point of Bitumen Modified Using HDPE

- Fire Point

Fig 9 presents fire point of bitumen when modified using HDPE

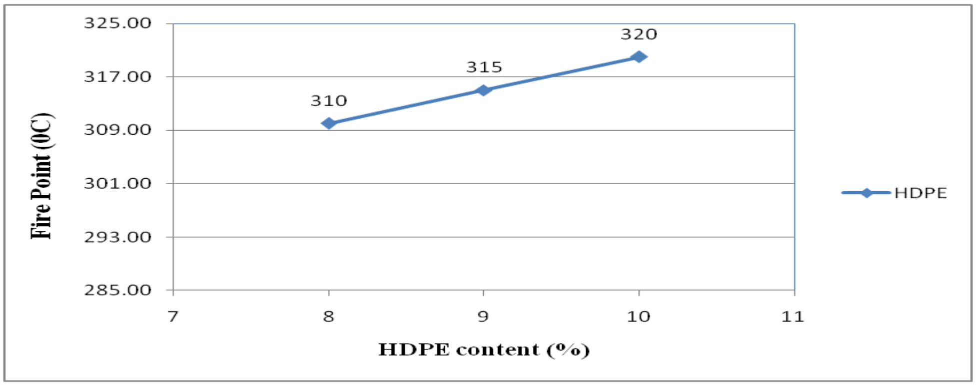

Fig. 9. Fire Point of Bitumen Modified Using HDPE

Trends in Fig 9 show that addition of HDPE increases fire point the reason for this is that HDPE added to bitumen hive higher fire points and when they are added in to bitumen they increase the fire point of mix.

4.5 Design of Bituminous Concrete Modified Using HDPE

With the combination of varying percentage of HDPE in the bituminous concrete the bituminous concrete modified using HDPE was prepared. The design of the mix was done as per the guidelines of MORT&H, 2013. VG30 grade bitumen obtained from Hindustan Petroleum Corporation Limited and Portland cement make ACC cement was used in the mix as filler during entire experimental work. Natural coarse aggregates of nominal size 19 mm were used. The HDPE used in the work were obtained from the waste of hostel and they were cut to the size specified by IRC SP 98-2013. Table 10 presents the proportions of the different aggregates used for the experimental work confirming to MORT&H, 2013 (Fifth revision).

Table 10 Proportion of Aggregates Used for study

Sieve size	Percentage Passing					Achieved Grading	MORT&H 2013 (Fifth revision) Specifications
(mm)	25-12.5 mm	12.5-7.5 mm	7.5-4.75 mm	Below 4.75 mm	Cement		
Proportion %	26%	25%	10%	37%	2%	-	-
26.5	100	100	100	100	100	100	100

19	63.90	100	100	100	100	90.61	90-100
13.2	9.50	99.30	100	100	100	76.30	59-79
9.5	0.80	87.70	100	100	100	71.13	52-72
4.75	0	12.40	57.83	99.00	100	47.51	35-55
2.36	0	3.20	25.67	83.50	100	36.26	28-44
1.18	0	1.00	9.5	50.25	100	21.79	20-34
0.6	0	0.60	5.0	34.50	100	15.42	15-27
0.3	0	0.40	3.17	22.50	100	10.66	10-20
0.15	0	0	2.17	15.50	100	7.95	5-13
0.075	0	0	1.67	11.0	100	6.24	2-8

Proportioning of the aggregates was done on the basis of results of sieve analysis performed. MORT&H 2013 has specified range for every particle size, because if aggregates are not proportioned properly there would be voids in concrete and strength will not be good and having more voids permits more water in to it and that will cause fast deterioration of bituminous concrete which will ultimately lead to failure of the bituminous concrete pavements and hence durability will be reduced considerably.

4.6 Results of the Marshall Tests Conducted on BC

Marshall test was conducted on bituminous concrete to find the optimum value of bitumen content which was used for further study. Table 11 contains the results of Marshall test conducted on plain bituminous concrete.

Table 11 Results of Marshall Tests on Bitumen content

S. No.	Properties	Bitumen content (BC in %)				
		4.8	5.0	5.2	5.3	5.4
1	Bulk density (gm/cc)	2.388	2.422	2.436	2.440	2.430
2	Stability value (KN)	8.40	9.10	12.45	11.90	11.35
3	Flow value (mm)	2.20	2.27	2.40	2.55	2.70
4	Air voids (%)	5.71	5.10	4.80	4.34	3.90
5	VMA (%)	12.64	14.01	14.28	13.21	12.03
6	VFB (%)	54.86	63.72	66.41	67.16	67.50
7	Marshall Quotient	3.82	4.01	5.19	4.67	4.20

Results from table 11 shows that all the properties obtained from Marshall tests are within the limits laid down by MORT&H, 2013 (fifth revision). This also indicates that the mix design for BC is correct and based on these proportions of the aggregates further study can be done.

4.7 Results of the Marshall Tests Conducted on BC Modified Using HDPE

This section contains the results of Marshall test conducted on bituminous concrete modified using HDPE. Table 12 presents the results of Marshall test conducted on bituminous concrete modified using HDPE.

Table 12 Results of Marshall Tests on Bitumen Content Modified Using HDPE

S. No.	Properties	HDPE Content			
		0 %	8 %	9%	10%
1	Bulk density (gm/cc)	2.436	2.38	2.40	2.39
2	Stability value (KN)	12.45	15.84	17.92	16.20
3	% Increase in Strength (Stability Value)	-	26.72	43.36	29.60
4	Flow value (mm)	2.40	4.32	4.90	5.2

5	Air voids (%)	4.80	4.57	4.10	3.50
6	VMA (%)	14.28	13.89	13.44	13.11
7	VFB (%)	66.41	67.10	69.50	71.10
8	Marshall Quotient	5.19	3.67	3.66	3.12

From the result we can see an increase in the stability value as compared to conventional mix it shows that HDPE has property of enhancing the stability, bulk density is on lower side then the conventional mix it shows that there is significant change in density because of addition of lighter HDPE to the mix, air voids, VMA and VFB trends also follows the trends of conventional mixes which shows that modification using HDPE can be done as it only improves Marshall properties of mix.

4.8 Variation of Marshall Properties of BC Modified Using HDPE

- Bulk Density

Fig 10 presents bulk density of BC modified using HDPE.

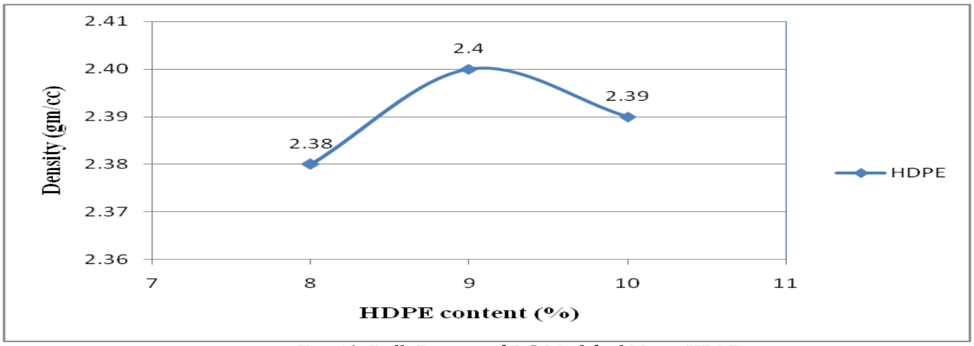

Fig. 10. Bulk Density of BC Modified Using HDPE

Trends in Fig 10 show that bulk density increases up to 9 % content of HDPE then decreases, this trend is because of the fact that addition of HDPE reduces friction between particles present in the mix so when force is applied the mix gets compacted easily when compared with conventional bituminous mix up to a certain content and up to this point density increases, additional HDPE is added density decreases as HDPE has less specific gravity then other ingredients of mix so increasing their content results in relatively lower densities.

- Marshall stability

Fig 11 presents stability values of BC modified using HDPE.

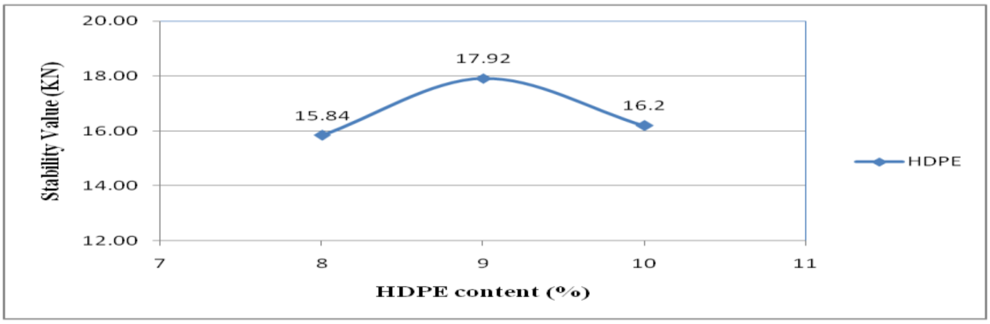

Fig. 11. Marshall Stability of BC Modified Using HDPE

From Fig 11 it is clear that stability increase up to a certain content of HDPE and then starts decreasing, this trend is because of the fact that addition of HDPE increases bond strength of the mix and hence stability increases initially and when extra additives are added they don't disperse properly and forms weak points and leads to decrement in stability value. The HDPE content corresponding to highest stability value is termed as optimum dose.

- Flow value

Fig 12 presents flow values of BC modified using HDPE

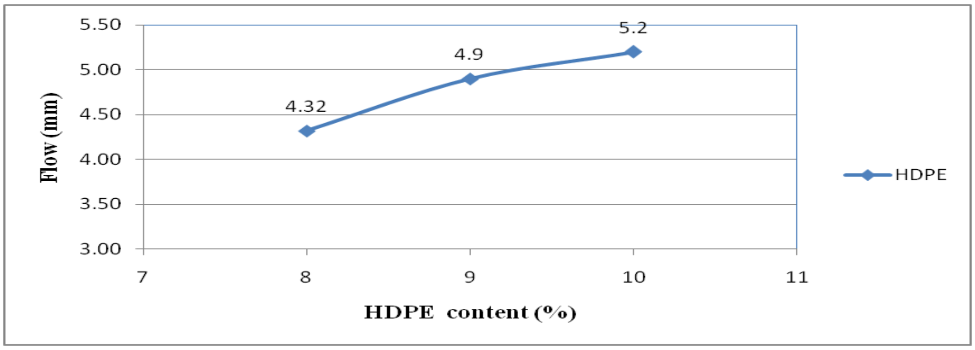

Fig. 12. Flow Value of BC Modified Using HDPE

From the Fig 12 it can be seen that flow value increases with increase in HDPE content. This trend is because of the fact that HDPE reduce the friction between ingredients and hence when load is applied the deformation is increased with respect to conventional bituminous concrete which means flow values of BC modified using HDPE increases with increase in content of HDPE.

- Percentage Air Voids (Vv)

It is clearly visible from the Fig 13 that air voids decreases as we add HDPE to the BC but rate of decrement of air voids shows that initially the decrement is more than it slows down, this is because initially all the HDPE content get absorbed in the voids but as the content increases the voids gets reduced and hence there is decrement in the rate of decrement of air voids.

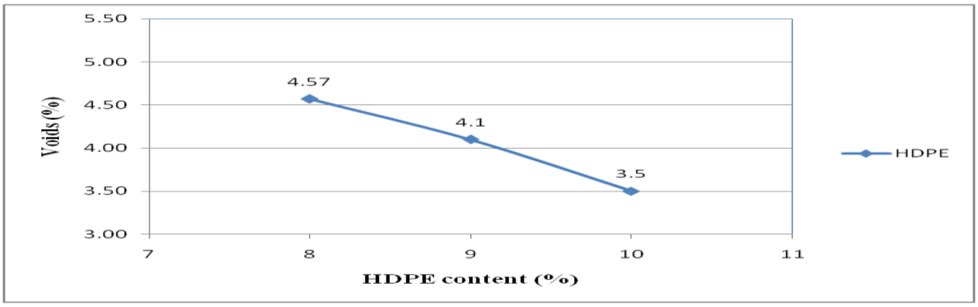

Fig. 13. Air Voids of BC Modified Using HDPE

- Voids in Mineral Aggregates (VMA)

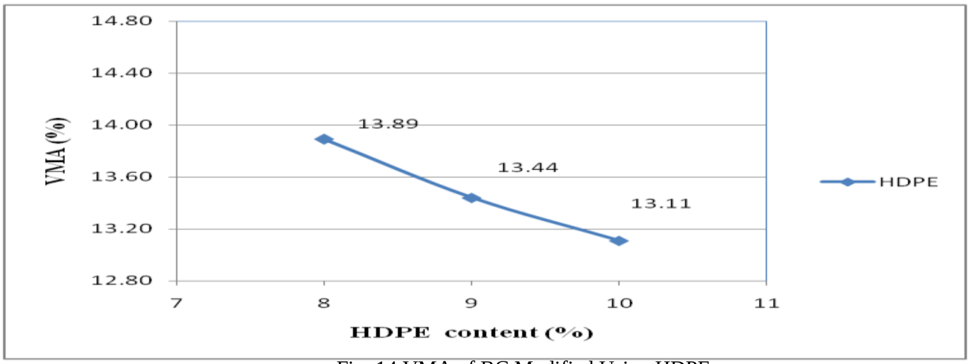

Fig. 14 VMA of BC Modified Using HDPE

From the Fig 14 it is clear that VMA is function of Vv and Vb as in the present study Vb is kept constant and from the Fig 13 it can be seen that Vv decreases with increase in HDPE content, the same pattern is followed by VMA also which proofs that VMA is function of Vv and Vb.

- Voids Filled with Bitumen (VFB)

Fig 15 presents VFB in BC modified using HDPE. From the figure it can be seen that addition of HDPE increases the VFB, increment in VFB indicates that maximum number of voids present in the mix are filled with bitumen, bitumen binds the aggregates and makes the mix strong to wear axle loads.

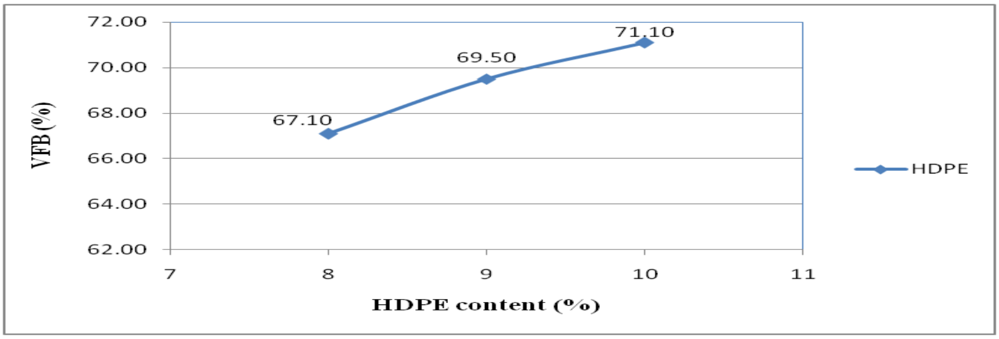

Fig. 15 VFB of BC Modified Using HDPE

- Marshall Quotient (MQ)

Marshall Quotient also known as rigidity ratio is the ratio of stability to flow value of the mixture and the Marshall Quotient values of HMA with different HDPE contents are shown in Fig 16.

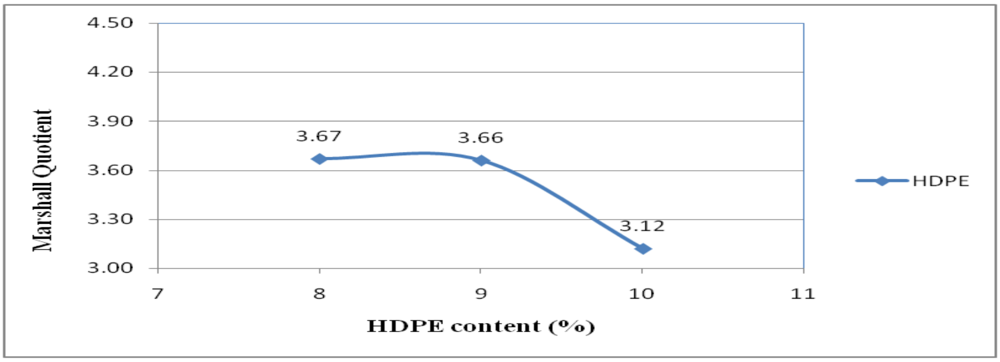

Fig. 16 MQ of BC Modified Using HDPE

From the Figure 16 it can be seen that MQ value firstly increases with increase in HDPE content and then decreases which implies that addition of HDPE in BC makes BC tougher and stronger up to certain content.

It is clear from the results that modification of bitumen using HDPE improves physical properties of bitumen, strength characteristics of bituminous concrete also gets improved by modifying BC using HDPE. It can be seen from the results that there is optimum dose of HDPE up to which strength characteristics improve, if HDPE are added beyond that content there is decrement in the stability value and specific gravity. The optimum dose for HDPE can be found from the graph between stability value and HDPE content. Optimum content of HDPE should be used in bituminous constructions to achieve better performing pavement, to achieve economy in the construction and helping in cause of keeping environment clean and plastics free

5. Economic Evaluation of usage of HDPE in bituminous concrete

This section presents the evaluation of economy induced, assessment of increment in stability and enhancement in life of pavement by using HDPE in bituminous concrete construction.

5.1. Computation of Cost of BC Modified Using HDPE

The cost of construction for grading-1 thickness 50mm - 65mm using VG-30 grade bitumen per cubic meter is given as Rs 8499 in SOR GJ PWD 2013.
Cost of bitumen per tonne = Rs 43681/- as per SOR GJ PWD 2013.
Let us assume that road construction is done for 1km, road width is 7 m and thickness of layer is 50mm then,

Total volume of pavement constructed	= 1000*7*.05 cum = 350 cum
Cost of construction for 1km of pavement	= 350*8499 = 29,74,650 Rs
Bitumen used for construction	= 18.37 cum
Weight of bitumen used	= 18.37*1.01 = 18.56 tonne
HDPE added to the mix	= 9% by weight of bitumen
HDPE added for one Km construction	= 0.09*18.56 = 1.67 tonne
Amount of bitumen replaced by HDPE	= 1.67 tonne
Cost of bitumen replaced	= 1.67*43681 = 72,947 Rs
Cost of HDPE per Kg (collection + processing)	= 10Rs
Cost of HDPE added	= 10000*1.67 = 16,700 Rs
Cost reduction by using HDPE per km length of pavement	= 72,947-16700 = 56,247
Percentage reduction in cost	(56,247/29,74,650)*100 = 1.90 %

It is clear from calculations that by using HDPE in bituminous concrete 56,247 Rs can be saved per Km length of pavements. The percentage reduction in cost comes out to be 1.90% of total cost of construction.

5.2 Economic Analysis of HDPE

Reduction in cost was 1.9% for BC Modified using HDPE. Though the reduction in cost is very less and can be ignored for big projects but the important thing which should be noted down here is that it should be understood that modification of BC by using HDPE was primarily not aimed to reduce cost of construction but it was done to increase the stability of pavement and it has successfully increased the stability. Table 13 presents the total cost, reduction in cost and percentage reduction in cost of construction for bituminous concrete, bituminous concrete modified using HDPE.

Table 13. Economic Evaluation of BC Modified Using HDPE

S. No	Type of Mix	Cost of Construction per Km length of Pavements (Rs)	Reduction in Cost of Construction per Km Length of Pavements (Rs)	% Reduction in Cost of Construction per Km Length of Pavements	% Increment in strength (Stability value)
1	Bituminous Concrete	29,74,650	-	-	-
2	BC Modified Using HDPE	29,18,403	56,247	1.9	43.36

This has been shown mathematically in Table 13 that use of HDPE in BC reduces cost of construction though not that much but it is a significant outcome. Use of HDPE in BC should be encouraged and contribution should be in protecting environment

6. Conclusion: -

Some important conclusions drawn from this study are as follows: -

- The aim of the present study was to assess the strength characteristics of bituminous concrete modified using HDPE and to find the optimum dosage of HDPE. Study revealed that HDPE can be effectively used in Bituminous Concrete as bituminous concrete showed improvements in stability values and other characteristics.
- Ductility and penetration value of bitumen modified using HDPE decreased with increase in HDPE content. The ductility and penetration values of bitumen depends on the composition of bitumen and if any other material mixed with bitumen forms homogeneous mix it will affect penetration and ductility but not as much as when a modifier mixed forms heterogeneous mix, but whatever kind of modifier is mixed it will certainly decrease the penetration and ductility.
- The Marshall Stability of bituminous concrete modified using HDPE increased up to 9% of HDPE by the weight of bitumen then decreasing trend was observed. This gives the optimum dose of HDPE as 9% by the weight of bitumen. Marshall Stability value of bituminous concrete modified using HDPE increased by 43.36% when compared with conventional bituminous concrete. The increase in Marshall stability value is because of the fact that initially when HDPE is mixed it get mix thoroughly with bitumen and form homogeneous mixture which on blending with aggregates, when bituminous concrete is prepared from this blend stability increases.
- Flow values increased with increment of HDPE content. This trend can be explained by the fact that addition of HDPE decreases the inter-particle friction in the mix, when load is applied on specimen because the friction has been reduced the particles move in the direction of applied force and the magnitude of movement is more when compared with flow of conventional bituminous concrete.
- Percentage air voids (Vv) decreased with increment of HDPE. This trend is mainly because of the fact that initially when HDPE is mixed with bitumen and bituminous concrete is prepared by using this modified bitumen the voids are filled by these modifiers, because the inter particle friction is less on compaction modified bituminous concrete gets compacted more and hence there is reduction in air voids.
- Marshall Quotient (MQ) value is indirect measure of toughness of bituminous concrete. MQ initially increased then started decreasing with increment in HDPE content. Maximum Marshall Quotient (MQ) value was observed at 9% of HDPE by the weight of bitumen. The increment in MQ values implicate that bituminous concrete becomes tougher and can wear more impact than conventional bituminous concrete.
- Using HDPE in bituminous concrete saves Rs 56,247 for per 1Km construction of bituminous pavement using Bituminous concrete modified using HDPE. Using HDPE in bituminous concrete can solve problem of disposal of waste HDPE. Approximately 1.67 tonnes of waste of HDPE can be used for 1Km construction of bituminous pavements using bituminous concrete modified using HDPE.
- The strength of bituminous concrete was increased by 43.36% when HDPE was used in the bituminous concrete. The increment in strength will enhance the wearing property of pavement and the pavement will be able to wear higher wheel loads and higher no of repetitions, this will increase life of pavement and reduce the maintenance cost. There was 1.90% reduction in total cost of construction when HDPE was used in bituminous concrete.

It is expected that the methodology proposed in this study will be helpful in not only increasing strength of bituminous concrete pavement but also imparts economy to the construction using HDPE and provides solution to the problem of disposal of waste HDPE which is much bigger factor than reduction in cost of construction.

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