

A Study on Use of Waste Plastic Materials in Flexible Pavements

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ABSTRACT: The continuous increase in road traffic in combination with insufficient maintenance due to paucity of funds has resulted in deterioration of road network in India. To improve this process there are several types of measures which are proven to be effective, like securing adequate funds for proper maintenance, effective and improved roadway design, use of better quality materials and use of effective and modern construction techniques. During last three decades in many countries around the world it has been tested that modification of the bituminous binder with polymer additives enhances the properties and life of asphalt concrete pavements. The present investigation was carried out to propose the use of plastic coated aggregate (PCA) in bituminous mix of flexible pavements in order to improve their performance and also to give a way for safe disposal of plastic wastes to provide a solution to threat of environmental pollution as well. There are two processes available for mixing of waste plastic in bituminous mixes namely wet and dry process. In this study the dry process was used for bituminous concrete mixes. The Marshall method of mix design was adopted using 80/100 grade bitumen to find the optimum bitumen content. Marshall specimens were prepared at bitumen content ranging from 4% to 6% with an increment of 0.5% by weight of aggregates and with waste plastic content of 0%, 6%, 8%, 10%, 12%, 14% and 16% by weight of optimum bitumen content. Marshall stability, Flow value, Marshall Quotient, Air voids (V_v), Voids in mineral aggregates (VMA), Voids filled with bitumen (VFB), and striping value were determined and compared with conventional aggregates (without plastic) bituminous concrete mixes. Comparison was also made by testing the physical properties of conventional and plastic coated aggregates (PCA). It was found that there was a considerable improvement in the properties of aggregates and bituminous mix leading to provide longer life and better pavement performance. The use of waste plastic in bituminous concrete mix thus contributes to construction of green roads and solves the problem of its safe disposal as well.

KEYWORDS: Marshall Stability, Flow value, Marshall Quotient, Air voids.

I. INTRODUCTION

Now-a-days continuous increase in traffic load and drastic variations in climatic conditions have compelled the technologists to upgrade the specifications for bituminous mixes to obtain higher mechanical stability for bituminous concrete roads. As the limits of upgrading bituminous concrete mixes with conventional mixes has reached out so there has to be a modification of bituminous mixes. There are mainly two options i.e. firstly to modify the bituminous mix by adding polymers, secondly by coating of plastic on aggregates by dry process. Modification of bituminous mixes has many advantages such as decreased thermal susceptibility and rutting, minimization of low temperature cracking, greater adhesion to the aggregate, increased tire traction etc.

Bituminous mixes consists of mineral aggregates, filler and optimum binder mixed in a hot mix plant and laid at hot condition results in a superior type of asphaltic pavement. Well graded aggregates and mineral filler resulting in maximum density when mixed with optimum quantity of bitumen. The amount of aggregate in asphalt mixture is generally 90 to 95 percent by weight and 75 to 85 percent by volume and they are primarily responsible for the load carrying capacity of pavement. This mix shows a high stability and its life is about 6-8 years. Excellent grading material and low air voids (3-5%) is responsible for its highly impervious nature. Because of better interlocking, high density and flexural modulus of elasticity it can support heaviest traffic density and axle load. The loads are spread

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downwards and outward, resulting in reduced stresses on layer beneath. Due to high degree of control in grading, proportioning of materials and the binder content, a better non-skid surface is obtained.

The objectives of present topics are-

- To evaluate properties of Plastic coated aggregates (PCA) and comparing it to conventional aggregates.
- To determine optimum bitumen content (OBC) of Bituminous Concrete Mix and Optimum plastic content (OPC) by adding thin plastic (by weight of OBC) to obtain plastic coated aggregates for Bituminous Concrete Mix (Dry Method) by Marshal method of mix design and comparing it with conventional Bituminous Concrete Mix.
- To evaluate the Marshal stability, Flow value and volumetric properties bituminous Concrete (BC) Mix by Marshal method of mix design.

II. RELATED WORK

Use of Re-cycled Plastic as Additives in Bituminous Mixes: Many researchers have shown in past that performance of bituminous concrete mixes used in surfacing of flexible pavements can be improved by adding suitable additives. These additives may be processed waste plastics, mainly polythene, can be used in manufacturing of polymer-modified bitumen. It has been proven that adding of recycled polythene, low density polythene carry bags in bituminous pavement was responsible for its reduced rutting and low temperature cracking of flexible pavement surfacing. (Flynn 1993). Other researchers, Zoorab and Suparma (2000) used plastics which were mainly composed of polythene and low density polythene(LDPE) in bituminous mixes and this resulted in better durability and fatigue life. A increase of 20% in stability and about 30% in Indirect tensile strength (ITS) was observed with mixes modified by using plastic wastes. Shridhar et al (2004) showed that fatigue life of modified bituminous concrete mixes were doubled as compared to conventional one. Rutting characteristics of bituminous concrete mixes had significantly reduced by adding 5 to 10% recycled plastics to binder. Further investigations on Indirect tensile strength (ITS) and fatigue have shown that there is a improvement in modified mixes as compared to conventional one. In mixes containing more than 5% of plastic waste the fatigue was considerably reduced. Kumar et al (2003) by laboratory investigation has revealed that weight loss of modified mix was less as compared to conventional mixes of without plastics. The stability value was increased about 1.65 times by addition of 8% recycled plastics to bituminous concrete mixes. Improvement in stability, tensile strength and moisture resistance of Asphalt mixes was observed by Bose et al (2004) by the addition of 8% waste plastic (by weight of bitumen) Vasudevan et al (2006) showed that coating plastics over hot aggregates in dry process gives better strength to the mixture, than blending it with asphalt in wet process. Ravi Shankar et al (2013) also added shredded waste plastic in bituminous concrete mixture by mixing them directly with the hot aggregates. Out of many different plastic dosages a mix with 6% (by weight of bitumen) plastic content showed better results. In 2013 Rahman et al reported that 10% waste polyethylene modifier can be used from the point of view of stability, stiffness and voids characteristics in the asphalt mixtures for flexible pavement construction in a hotter regions. When waste plastic added in dry process, for preparation of SDBC (Semi dense bituminous concrete) mixes it resulted in improvement of stability by 30% and ITS by 32% (Ravishankar, et al. 2008). Also evaluations on rutting also indicated that the waste plastics modified mixes are less susceptible to rutting than conventional SDBC mixes, by dry process. In this research an attempt is made to study the properties of Bituminous Concrete (BC) mixes Grading-1 Indian Roads Congress (IRC:111-2009) using waste plastics by dry process.

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III. MATERIALS AND METHOD

The materials used are as follows.

- Aggregates
- Bituminous Binder
- Mineral Filler
- Plastic waste material (LDPE)

Aggregates: Aggregate having sufficient strength, hardness, toughness, specific gravity and shape were chosen and the prescribed tests on conventional aggregates and plastic coated (PCA) aggregate was performed. Aggregate gradation that satisfies the requirements of IRC 111-2009 for grading-1 was selected. From Figure-1 below, it can be observed that the selected aggregate gradation is within the specified range for hot asphalt mix design.

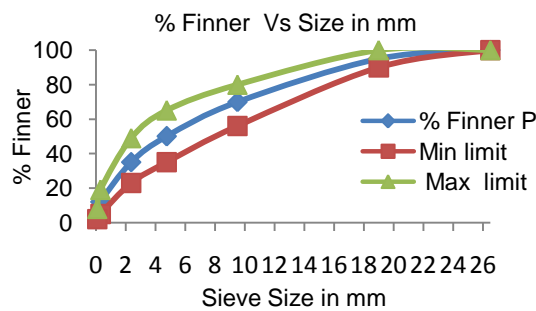


Figure-1 Gradation Curve for the aggregates

The permissible grading in between maximum and minimum limit as shown in above figure-1 was adopted to achieve maximum density and economical blend as well..

Mineral Filler: Filler shall consists of finally divided mineral such as rock dust or hydrated lime or cement. The use of hydrated lime is encouraged because of its very good anti-stripping and anti-oxidant properties. It is added to the hot mix asphalt, to increase the density and enhance the strength of the mixture. The gradation of filler is shown in table below.

Table-1 Grading requirement of Mineral filler

IS sieve size in mm	Cumulative % by weight of total aggregate passing
0.6	100
0.3	95-100
0.075	85-100

Bitumen: The bitumen used in the experiment was 80/100 grade and was tested in the laboratory for basic tests, penetration, ductility, softening point, specific gravity and viscosity.

Modifiers (Plastic waste): The processed waste plastic bags(LDPE) from the garbage of local area in the shredded form was used as additive. The shredded waste plastic was cut into pieces of uniform size passing through 2.36 mm IS sieve and retained on 600 μ IS sieve. Thickness between 10 μ to 30 μ .

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Table-2 Properties of Waste Plastic

Property	Values
Size (Range)	2.36 mm - 600 μ
Density (gm/cc)	0.95
Melting Temperature in °C	130- 160

Thermo gravimetric analysis has shown that there is no gas evolution in the temperature range of 130-180°C. Moreover the softened plastics have a binding property.

Marshall Mix design: In the present research the aggregate mix was heated to 140- 175°C and the shredded plastic waste was added to the aggregate in specified percentage. The waste plastic initially coats the heated aggregates. In next stage heated bitumen at specified temperature was added to the aggregates and the plastic coated aggregate was mixed with hot bitumen for 15 seconds and in result modified bituminous concrete mix was obtained. Addition of bitumen was made by weight of mix and plastic were added in different percentages to the mix by weight of bitumen.

Design of Bituminous Concrete mix: In this study the addition of bitumen was made by weight of mix and plastic were added in different percentages (6%, 8%, 10%, 12%, 14% and 16%) to the mix by weight of bitumen. The Marshall samples were prepared of both conventional and plastic modified bituminous mixes and the prescribed tests were performed. When the Marshall specimen are kept in water bath at 60 ±1°C for 24 ± 1 hours called conditioned specimen and the specimen kept thermostatically controlled water bath maintained at 60 ±1°C for 30 to 40 minutes are called unconditioned specimen. Plots of bitumen content against volumetric properties were drawn for all mixes. OBC for each mix was calculated by taking the average of bitumen content values corresponding to maximum stability, maximum density and 4% air voids.

IV. EXPERIMENTAL RESULTS

In this research the properties of Bituminous Concrete (BC) mixes Grading-1 Indian Roads Congress (IRC:111-2009) using waste plastics by dry process was evaluated and comparison was made with conventional mix (0% plastic) properties. Results of various tests performed on conventional and plastic coated aggregates (PCA) are shown in table - 3 below.

Table-3 Physical Properties of Aggregates

Description of tests	PCA = Plastic coated Aggregate					Specifications IRC:111-2009
	Percentage of Plastic/ additive by weight of OBC					
	0%	6% (PCA)	8% (PCA)	10% (PCA)	12% (PCA)	
Aggregate Crushing strength value	16.27%	11.8%	9.3%	10.3%	11%	Max 30 %
Impact value	15.77%	11.5%	10%	10.5%	10.8%	Max 24%
Specific gravity value	2.63	2.7	2.8	2.85	2.86	2.5-3.0
Los Angeles Abrasion value	15.34%	10.3%	9%	9.2%	9.8%	Max 30%
Flakiness Index value	13.48%	12.48%	12.48%	12.48%	12.48%	Max 35 %
Elongation index value	10.3%	11.3%	11.3%	11.3%	11.3%	Max 35 %
Water absorption value	0.62%	Nil	Nil	Nil	Nil	Max 2%
Soundness value	10%	Nil	Nil	Nil	Nil	Max 12 %
Stripping value	5%	Nil	Nil	Nil	Nil	Max 5%

Aggregate Crushing strength, Impact value and Los Angeles Abrasion value of conventional specimen was reduced for Plastic coated Aggregate (PCA). Low value indicates strong aggregates, as the crushed fraction is low and also shows the toughness of aggregates to face heavier impacts. Water absorption was also reduced from 0.62%

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(conventional aggregates) to nil for plastic coated aggregates (PCA) due to effect of plastic coating on its surface. Specific Gravity of the aggregate was also increased due to plastic coating. Due to waste plastic coating a strong adhesion force between plastic coated aggregate and bitumen, hence no stripping of bitumen was observed after 24 hours of immersion.

Table-4 Properties of penetration grade bitumen

Properties Tested	Test Method	Results	Remarks
Penetration(100 gram, 5 seconds at 25°C) (1/10 th of mm)	IS 1203-1978	93	Satisfactory
Softening point, °C(Ring and Ball Apparatus)	IS 1205-1978	56.8	Satisfactory
Ductility at 27°C(5cm/ minute pull) cm	IS 1208-1978	95.3	Satisfactory
Specific gravity at 27°C	IS 1202-1978	1.02	Satisfactory
Viscosity in seconds	IS 1206-1978	50	Satisfactory
Flash Point	IS 1209-1981	272°C	Satisfactory
Fire Point	IS 1209-1981	286°C	Satisfactory
Grade of binder	80/100		

The various test performed on bitumen sample showed that the results were with in permissible limits as per norms prescribed by the concerned IS codes.

Determination of Optimum Bitumen Content (OBC): A number of 15 samples each of approximately 1200 gm in weight were prepared using five different bitumen contents (from 4 - 6% with 0.5 % incremental) in order to obtain the optimum bitumen content (OBC). Curves were plotted between % bitumen versus parameters like Stability value, Bulk Density, Air voids content and Flow value.

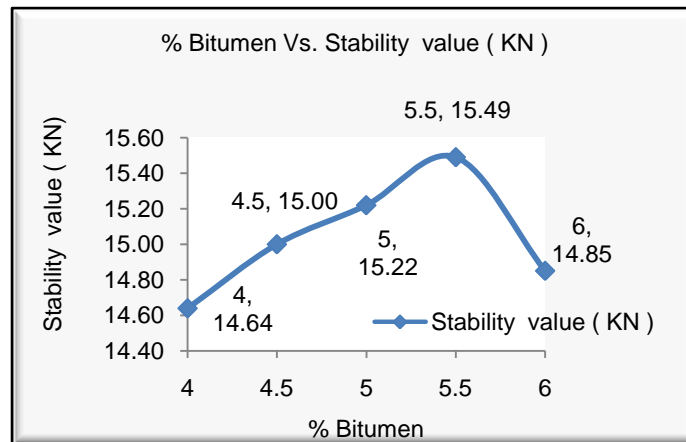


Figure-2 - % Bitumen Vs. Stability value

Stability is the maximum load required to produce failure of the specimen when load is applied at constant rate 50 mm / min. In Figure-2 stability results for different bitumen contents are represented. Stability of asphalt mix increases as the bitumen content increase till it reaches the peak at bitumen content 5.5% then it started to decline gradually at higher bitumen content.

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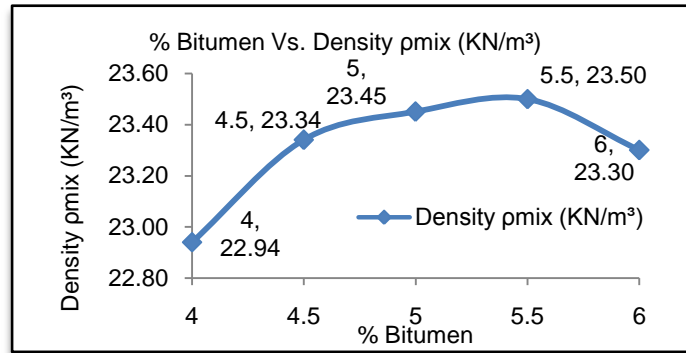


Figure-3 - % Bitumen Vs. Density

Bulk density is the actual density of the compacted mix. In Figure-3 above Bulk density results for different bitumen contents are represented. Bulk density of asphalt mix increases as the bitumen content increase till it reaches the peak value at bitumen content 5.5 % then it started to decline gradually at higher bitumen content.

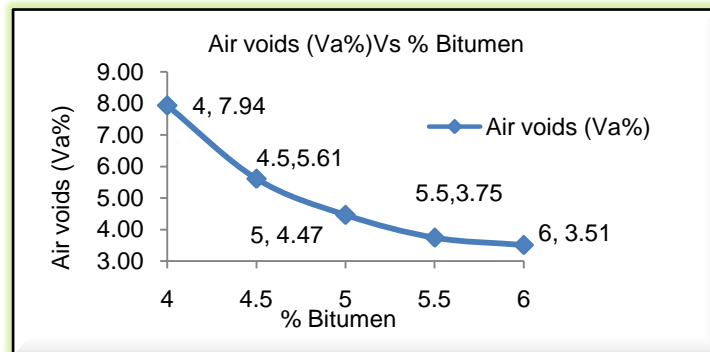


Figure-4 - % Bitumen Vs. Air voids

Va % is the percentage of air voids by volume in specimen or compacted asphalt mix. In Figure-4 Va% results for different bitumen contents are represented. Maximum air voids content value is at the lowest bitumen percentage (4%), Va% decrease gradually as bitumen content increase due to the increase of voids percentage filled with bitumen in the asphalt mix.

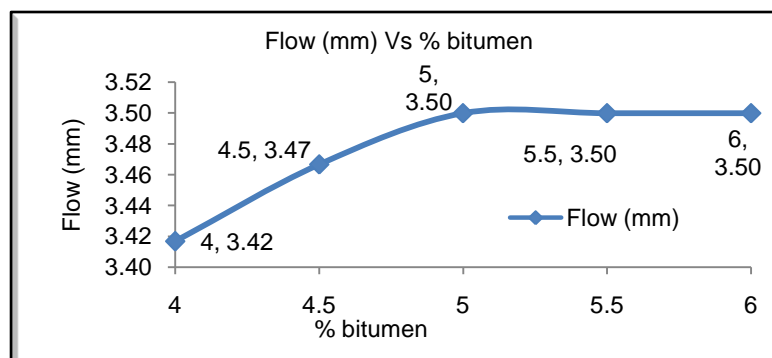


Figure-5 - % Bitumen Vs. Flow value

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Flow is the total amount of deformation which occurs at maximum load. In Figure -5 Flow results for different bitumen contents are represented. Flow of asphalt mix increases as the bitumen content increase till it reaches the peak at the max bitumen content 5%. The optimum bitumen content (OBC) was calculated by taking the average of the following three values.

- Bitumen content at highest stability value = 5.5 %
- Bitumen content at highest value of bulk density = 5.5%
- Bitumen content at 4% air voids value = 5.3%

$$\begin{aligned} \text{Optimum Bitumen Content (OBC)} &= \frac{5.5+5.5+5.3}{3} \\ &= 5.43 \% \end{aligned}$$

Determination of Optimum Plastic Content (by weight of OBC): Determination of Optimum plastic content(OPC) / Waste plastic content(WPC) was obtained by taking the average of Plastic content at highest stability, Plastic content at highest value of bulk density and Plastic content value at Va % air voids within allowed range(4%). It is obtained by plotting these curves of the Marshal Test results.

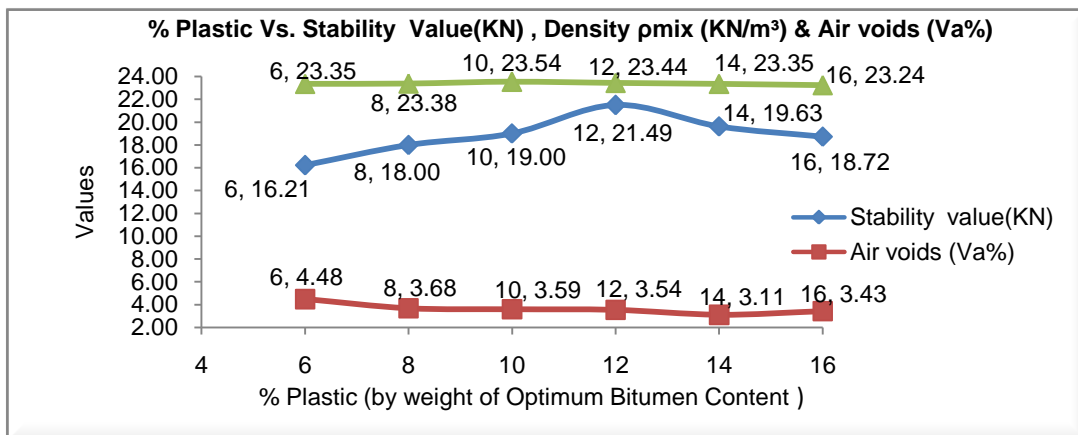


Figure-6 - % Plastic Vs. Stability , Density & Air voids values

The above figure-6 shows that all the values of stability for different modifier percentages are higher than stability of conventional mix. The maximum stability value was found plastic content around 12%. It also shows that the stability of modified asphalt mix increases as the plastic content increases till it reaches the peak at plastic content of 12 % . then it started to decline steeply at higher plastic content. The improvement of stability in plastic modified asphalt mixes can be explained as a result of the better adhesion developed between bitumen and plastic coated aggregates due to intermolecular bonding, these intermolecular attractions enhanced strength of asphalt mix, which in turn help to enhance durability and stability of the asphalt mix. The bulk density of plastic modified asphalt mix is lower than the conventional asphalt mix. The general trend shows that the bulk density decreases as the plastic content increase. The maximum bulk density is at plastic content of 10% and the minimum bulk density is at plastic content of 16%.. This decrease of bulk density can be explained to be as a result of the low density of added plastic material. In general, the air voids proportion of modified asphalt mixes is higher than conventional asphalt mix . Va % of modified asphalt mixes decreases gradually as the plastic content increase up to 14% and then increases at 16% plastic content. The optimum plastic content (OPC) was calculated by taking the average of the following three values.

- Plastic content at highest stability value = 12 %
- Plastic content at highest value of bulk density = 10%

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- Plastic content value at Va % air voids with in allowed range = 7.2%

$$\text{Optimum Plastic Content (OPC)} = \frac{12+10+7.2}{3}$$

$$= 9.73\%$$

Table - 5 Properties of Bituminous Concrete mix using waste plastic additive by weight of Optimum bitumen content(OBC)

Sn	Property of bituminous mix evaluated from tests	Waste plastic expressed as % by weight of Optimum Bitumen Content (OBC) i.e. 5.43%						
		0%	6%	8%	10%	12%	14%	16%
1	Marshall Stability (KN)	15.34	16.21	18.00	19.00	21.49	19.63	18.72
2	Flow value , mm	3.82	3.20	3.50	4.0	4.25	4.0	3.50
3	Marshall Quotient, KN/ mm	4.02	5.07	5.14	4.75	5.06	4.91	5.35
4	Theoretical max density (Gt) (KN/m ³)	24.5	24.4	24.3	24.4	24.3	24.1	24.1
5	Bulk density(Gb) (KN/m ³)	23.6	23.35	23.38	23.54	23.44	23.35	23.24
6	Volume of air voids(Va)%	3.70	4.48	3.68	3.59	3.54	3.11	3.43

Table –6 Comparison of waste plastic modified asphalt mix and conventional mix

Properties	Conventional mix	(9.73%) OPC modified asphalt mix (By weight of OBC)	Limit as per IRC:SP:98-2013
Optimum bitumen content %	5.43	5.43	5.2 Min.
Marshall Stability value (KN)	15.34	18.50	Min. 12
Flow value (mm)	3.82	3.90	2-4
Marshall Quotient (Stiffness) KN/mm)	4.01	4.82	2.50-5.00
Void in mineral Aggregate(VMA)%	15.56	16.1	16
Voids filled with bitumen (VFB)%	76.26	77.50	65-75
Air voids (Va)%	3.7	3.6	3-5
Bulk density (KN/m ³)	23.6	23.4	-

In the above table. It is clearly shown that asphalt mix modified with (9.73 % OPC by weight of OBC) have higher stability value. Stiffness compared to the conventional asphalt mix is more but it is with in the specified range , other properties of modified mix are still within the allowed range of the specifications. Slight increase of flow and VMA% in modified asphalt mix is exhibited. Bulk density of modified mix is slightly reduced this is due to low specific gravity of waste plastic. Higher Stability value of modified asphalt mix indicates that it can withstand with heavier traffic loads as compared to conventional asphalt mix. Other properties are with in the specified range for the two asphalt mixes.

V. CONCLUSION

Based on the study and experimental data for waste plastic modified bituminous concrete mix compared with conventional bituminous concrete mix, the following conclusions can be drawn- The results showed that waste plastic can be conveniently used as a modifier for bituminous concrete mix as it gets coated over the aggregates of the mixture and reduces porosity, absorption of moisture and improves binding property of the mix. The Optimum Bitumen Content (OBC) was found to be 5.43% by weight of aggregates. The Optimum Plastic Content (OPC) to be added as a modifier of bituminous concrete mix was found to be 9.73% weight of Optimum Bitumen Content (OBC) of bituminous concrete mix. Bituminous concrete mix modified with waste plastic coated aggregates showed higher (approximately 21%) Marshall stability and higher flow value as compared to conventional bituminous concrete mix.

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Marshall stability value increases with plastic content up to 12% and thereafter decreases. Thus the use of higher percentage of waste plastic/ polythene is not preferable. The stiffness of the modified mix was increased but it was with in specified norms.

The volumetric and Marshall properties of conventional and modified bituminous concrete mixes were almost satisfying both MORTH and IRC:111-2009 specifications. This shows that plastic waste blended bituminous concrete mix is better one and is more suitable for flexible pavement construction. Plastic waste modified mix is strip resistant even when subjected to worst moisture condition. Physical properties like Aggregate Impact Value, Los Angeles Abrasion Value , Water Absorption Value and soundness etc. of plastic coated aggregates (PCA) were improved appreciably as compared to conventional aggregates (without plastic coating) due to thin plastic coating over aggregates.

Plastic waste modified mix consumes less bitumen (OPC= 9.73% by weight of OBC) so it is economical. Hence cost of construction of plastic roads will be less. One can also effectively use the relatively weak stone aggregates by making them comparatively stronger by providing suitable plastic coating over it by Dry Method.

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