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A Study on Use of Plastic Coated Aggregates in Bituminous Concrete Mixes of Flexible Pavement

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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 proper maintenance, effective and improved roadway design, use of better quality materials and use of effective and modern construction techniques should be put into practice. 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 bituminous 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 in order to counter environmental pollution as well. There are mainly 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. Physical properties of conventional and plastic coated aggregates were compared. The Marshall method of mix design was adopted using VG-10 grade bitumen for conventional aggregates and plastic coated aggregates (PCA). Marshall Specimens were prepared at bitumen content ranging from 4% to 6% with a increment of 0.5% by weight of aggregates and with waste plastic content of 5%, 7%, 9%, 11%, 13% and 15% by weight of optimum bitumen content. Marshal stability, Flow value, Air voids (Vv), Voids in mineral aggregates (VMA), and Voids filled with bitumen(VFB) were determined and compared with conventional aggregates (without plastic) bituminous concrete mixes. It was found that there was a reduction in consumption of bitumen in bituminous concrete mix by use of plastic coated aggregates also a considerable improvement in the properties of aggregates and bituminous mix leading to provide longer life and better pavement performance.

Keywords: Optimum bitumen content, Marshal Stability, Flow value, Air voids.

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I. INTRODUCTION

Rapid 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 to the bitumen, secondly by coating of shredded thin waste plastic on aggregates and then adding hot bitumen immediately to the plastic coated aggregate (PCA) 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 Concrete: 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 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.

II. LITERATURE REVIEW

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. (Flynn1993). 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.

III. MATERIALS, PROPERTIES AND PROCEDURE

The materials used for preparation of the bituminous mix were

A- Aggregates; Aggregate was obtained from local areas. In order to get required gradation three grades of aggregates (ABC) were chosen. Different proportions are shown below:

Aggregate A- 34%
Aggregate B- 28%
Aggregate C- 36%
Stone dust- 2 % (filler)

Physical properties of the aggregates were tested in laboratory. The test results and grading curve are shown below in table-1 and Fig- 1

Aggregate Gradation: 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.

Table-1
Physical Properties of Aggregates Conventional (0% Plastic) and Plastic coated Aggregate (PCA)

Descriptio of tests	Percentage of Plastic/ additive by weight of OBC					Specifi cations IRC:1 11-2009
	0 %	5 % (PCA)	7 % (PCA)	9 % (PC A)	11% (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
Flakiness Index value	13.48 %	12.48 %	12.48 %	12.48%	12.48 %	Max 35 %
Elongatio n index value	10.3 %	11.3%	11.3 %	11.3 %	11.3 %	Max 35 %
Los Angeles Abrasion value	15.34	10.3%	9%	9.2 %	9.8%	Max 30%

	%					
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%

Table-2 Aggregate Grading and bitumen content

Specification	Bituminous Concrete(BC)	
Grading	Grad-1	
Nominal maximum aggregate size in mm	19 mm	
Layer thickness	50 mm	
IS Sieve size in mm	Cumulative % by weight of total aggregate passing	
	Gradation specified	Gradation adopted
26.5	100	100
19.0	90-100	95
13.2	59-79	-
9.5	52-72	70
4.75	35-55	50
2.36	28-44	35
1.18	20-34	-
0.6	15-27	-
0.3	10-20	12
0.15	5-13	-
0.075	2-8	5
Bitumen content	5.2% by weight of aggregate	

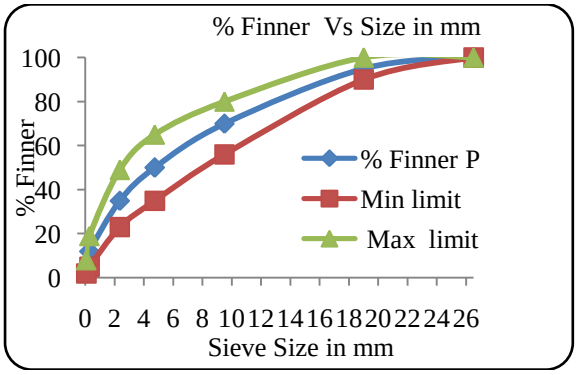

Figure-1 Gradation Curve for aggregates

Incorporation of higher percentage (11%) of waste plastic results in thick coating around aggregates as compared to waste plastic content 7% and 9%. This was responsible for higher fraction of crushing of aggregates as compared to thin coating of waste plastic (7% and 9%). Hence a higher crushing value, and Los angles abrasion value was observed at a higher percentage (11%) of plastic coating over aggregates as compared to lesser percentage of plastic coating. Due to waste plastic coating specific gravity was increased. Due to waste plastic coating voids were sealed and hence no water absorption was observed and aggregates became tougher and stronger, hence no loss of aggregate fraction was observed during soundness test. Due to waste plastic coating a strong adhesion force between plastic coated aggregate and bitumen, no stripping of bitumen was observed after 24 hours of immersion.

B- Bitumen: The bitumen used in the experiment was VG-10 grade and was tested in the laboratory for basic tests, penetration, ductility, softening point, specific gravity and viscosity Results are shown in table-2 below.

Table-3 Properties of penetration grade bitumen

Properties Tested	**Test Method**	**Results**	**Remarks**
Penetration(100 gram, 5 seconds at 25°C) (1/10th 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	86	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	VG-10		

C- Mineral Filler: Filler shall consist 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. The gradation of filler is shown in table below.

Table-4 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

D-Modifiers (Plastic waste): The processed waste plastic carry bags of low density polyethylene (LDPE) and high density polyethylene (HDPE) articles from the garbage of local area in the shredded form were 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 ranging between 10 µ to 30 µ.

Table-5 Properties of Waste Plastic

Property	Values
Size (Range) LDPE	2.36 mm - 600 µ
Density of (gm/cc)	0.91-0.94
Thickness in µ	10 µ -30 µ
Melting Temp. (in °C)	110-130

3.1- 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.

3.2 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 (5%, 7%, 9%, 11%, 13% and 15%) 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. RESULTS AND DISCUSSIONS

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.

4.1 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. The optimum bitumen content (OBC) was calculated by taking the average of the following three values.

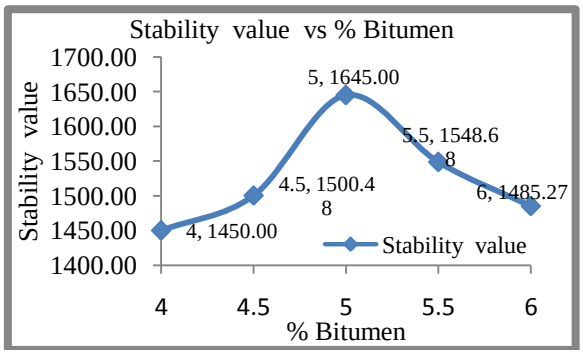

Fig-2 - % Bitumen Vs. Stability value

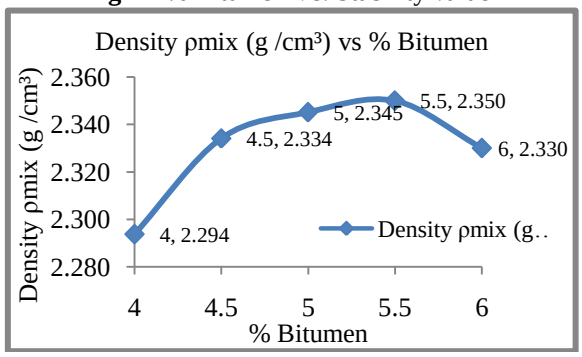

Fig-3 - % Bitumen Vs. Density

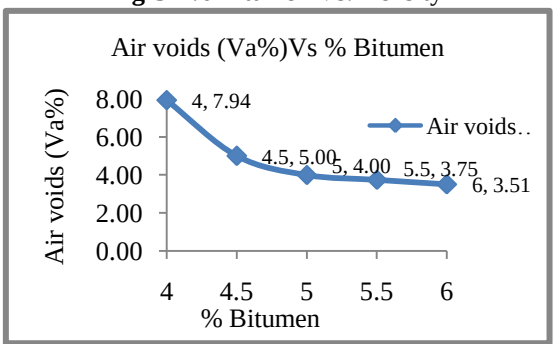

Fig-4 - % Bitumen Vs. Air voids

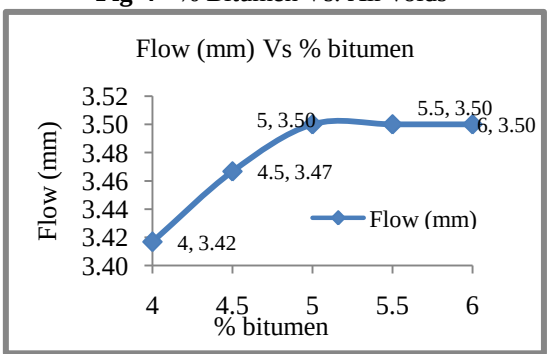

Fig-5 - % Bitumen Vs. Flow value

- 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%

Optimum Bitumen Content (OBC) = $\frac{5.0+5.5+5.0}{3}$

= 5.17 %

Table - 6 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. 5.17%						
		0	5	7	9	11	13	15
1	Marshall Stability (Kg)	1534.40	1621.64	1891.00	2006.38	2212.01	1962.77	1872.40
2	Flow value , mm	3.510	3.20	3.50	4.0	4.25	4.0	3.50
3	Marshall Quotient, Kg/mm	437.15	506.76	540.28	501.59	520.47	490.73	534.97
4	Theoretical max density (Gt) (g/cm³)	2.45	2.44	2.43	2.44	2.43	2.41	2.41
5	Bulk density (Gb) (KN/m³)	23.6	2.335	2.338	2.354	2.344	2.335	2.324
6	Volume of air voids(Va)%	3.70	4.48	4.00	3.59	3.54	3.11	3.43

1.2 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. Curves were plotted below. The optimum plastic content (OPC) was calculated by taking the average of the following three values.

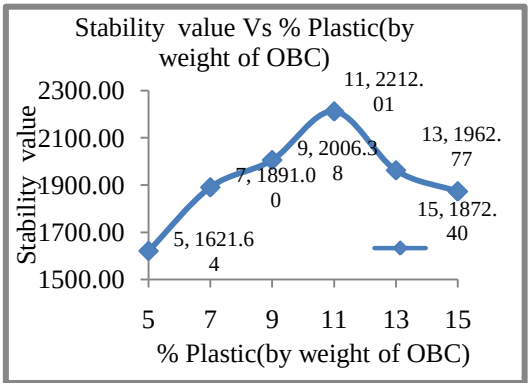

Fig-6 - % Plastic Vs. Stability

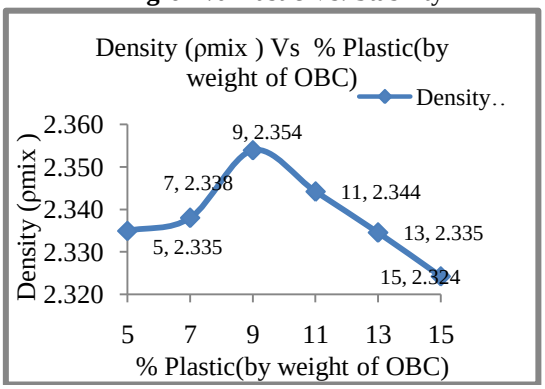

Fig-7 - % Plastic Vs Density

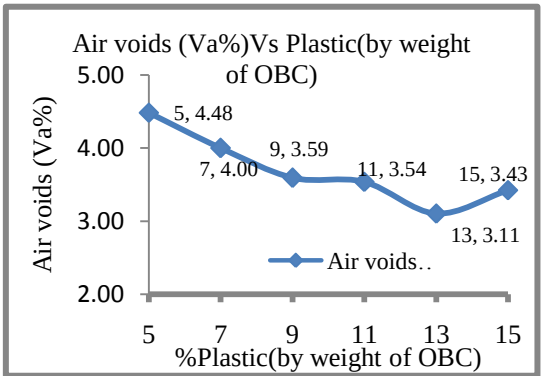

Fig-8 - % Plastic Vs Air voids

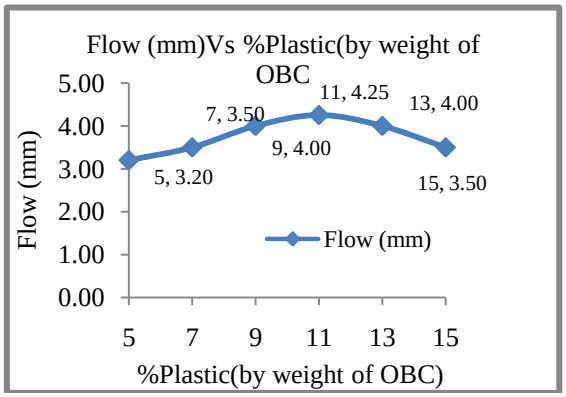

Fig-8 - % Plastic Vs Flow value

- Plastic content at highest stability value = 12 %
- Plastic content at highest value of bulk density = 10%
- Plastic content value at Va % air voids with in allowed range = 7.2%

Optimum Plastic Content (OPC) = $\frac{11+9+7}{3}$

= 9%

Table –7 Comparisons of waste plastic modified asphalt mix and conventional mix properties

Property	Conventional asphalt mix	(9 %) Waste Plastic modified Bituminous Concrete mix (By weight of OBC)	Variation %	Specifications As per	
				IRC: 111-2009	IRC: SP: 98-2013
Optimum Bitumen content	5.17	5.17	-	Min. 5.2	
Stability (kg)	1534.40	2006.38	+ 30.76	Min 900	Min 1200
Flow (mm)	3.51	4.00	+ 13.96	2.5 - 4.0	2.0 - 4.0
Stiffness (kg/mm)	437.15	501.59	+ 14.74	250 - 500	250 - 500
Void in Mineral aggregate (VMA)%	15.63	15.49	-0.89	15.0	16.0
Air voids (Va)%	3.51	3.59	+ 2.7	3 - 5	3 - 5
VFB% (Void filled with bitumen)	76.36	76.80	+0.57	65 - 75	65 - 75
Bulk density (gm/cm³)	2.36	2.34	- 0.84	-	-

It is clearly shown that bituminous concrete mix modified with (9 % OPC by weight of OBC) have higher stability value. Higher Stability value of modified bituminous concrete mix indicates that it can withstand with heavier traffic loads as compared to conventional bituminous concrete mix. Stiffness compared to the conventional bituminous concrete mix is slight more but is within the specified range, other properties of modified bituminous concrete mix are still within the allowed range of the specifications. Slight increase of flow in modified bituminous concrete mix is exhibited. Bulk density of modified mix is slightly reduced this is due to low specific gravity of waste plastic. Other properties are within the specified range for the two bituminous concrete mixes. Melted waste plastic provides a rougher surface texture for aggregate particles in modified bituminous concrete mix that would enhance bituminous concrete mix engineering properties due to improved adhesion between bitumen and plastic coated aggregates (PCA). Improved stability would positively influence the fatigue and rutting resistance of the modified bituminous concrete mix leading to more durable bituminous concrete mix pavement. Indirect Tensile strength test: The Marshall specimen after being extracted from mould immersed in water bath maintained at a temperature 25 ±1°C for a period of 2 hours (unconditioned specimen). When the Marshall specimen are kept in water bath at 60 ±1°C for 24 ± 1 hours called conditioned specimen.

Indirect tensile strength (ITS) $\sigma = 2P / \pi td$

Where σ is Indirect tensile strength in MPa

P= applied load in Newton,

d= diameter of specimen in mm,

t= thickness of specimen in mm

It was observed that at 9% waste plastic addition the ratio Tensile strength ratio (TSR) is maximum i.e. 98.93%.

Table-8 Indirect tensile strength (ITS)

Additive waste plastic by weight of OBC	%	ITS Unconditioned (MPa), S1	ITS Conditioned (MPa), S2	% Tensile strength ratio (TSR)=100* S2/S1
Nil	0	0.8143	0.6598	81.02
Waste plastic	7	1.2141	1.0182	90.45
	9	1.242	1.2287	98.93
	11	1.2149	1.1642	95.83

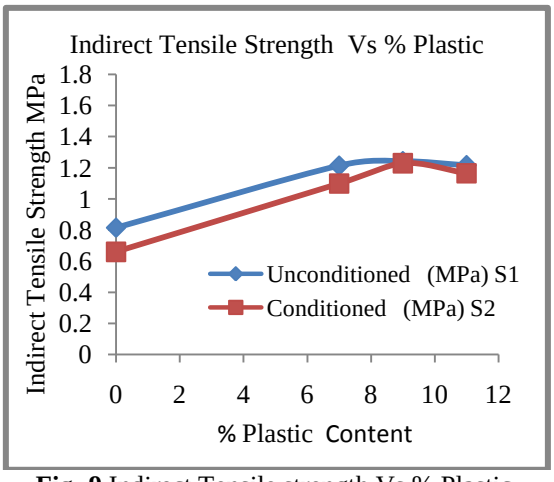

Fig -9 Indirect Tensile strength Vs % Plastic

ECONOMY OF THE PROCESS**:** Based on the experimental evidences and the amount of raw materials used for 20 mm thick Bituminous Concrete Premix carpet (top layer of the bituminous road) with type-A seal coat. One Kilometer long road having width 3.75 meter (3750 Sq. m.) the following calculation has been arrived –

Table -9 Economy of the Process

Material needed	Quantity of bitumen with conventional aggregate	Quantity of bitumen with Plastics coated aggregate (PCA)
VG-10 Bitumen	9150Kg	8260 Kg
Plastic waste	Nil	890 Kg
Cost	Rs 549000	(Bitumen)Rs 495600+ (Plastic) Rs 8900 = Rs 504500
Cost Reduced (per KM) for Single lane road having width 3.75 Meter	Nil	Rs 44500

Cost of Bitumen Approx: Rs 60 per Kg and Waste Plastic: Rs. 10 per Kg (Cost of waste plastic Rs 6 per Kg and Cost of processing Rs 4 per Kg)

Savings of bitumen - 890 Kg

Use of Plastics waste- 890 Kg

Cost Reduced (per KM) for single lane road having width 3.75 Meter = Rs 44500

There is almost no maintenance cost for a period of at least five years. Hence the process is cheap and eco-friendly.

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-

1- 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.

2- The Optimum Bitumen Content (OBC) was found to be 5.17% by weight of aggregates and the Optimum Plastic Content (OPC) to be added as a modifier of bituminous concrete mix was found to be 9 % weight of Optimum Bitumen Content (OBC) of bituminous concrete mix. Bituminous concrete mix modified with waste plastic coated aggregates showed higher (approximately 31%) Marshall Stability and higher flow value as compared to conventional bituminous concrete mix. Marshall Stability value increases with plastic content up to 11% and thereafter decreases. Thus the use of higher percentage of waste plastic/ polythene is not preferable.

3- The stiffness of the modified mix was increased but it was within 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.

4- Plastic waste modified mix is strip resistant even when subjected to worst moisture condition. Physical properties like Aggregate Impact Value, Los Angles 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% by weight of OBC) so it is economical. Hence cost of construction of plastic roads will be less and almost no maintenance cost for a period of at least five years.

5- It was observed that at 9% waste plastic addition the Tensile strength ratio (TSR) is maximum i.e. 98.93%.

The process is cheap and eco- friendly. 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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