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Use of Plastic Waste in Bituminous Mixes of Flexible Pavements by Wet and Dry Methods: A Comparative Study

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ABSTRACT:- *Disposal of waste plastic is a great problem in present scenario due to its non-biodegradable nature and scarcity of landfills. Studied have revealed that it can be successfully utilized in bituminous mixes of flexible pavements. At present there are two methods namely Dry method (DM) and Wet method (WM) are available to utilize waste plastics in bituminous mixes. In this study a comparison has been made by utilizing shredded waste plastic carry bags made of low density polyethylene (LDPE) in bituminous mixes of flexible pavements by wet and dry methods. The Marshall stability value , flow value, indirect tensile strength (ITS) tests were carried out and the results were compared. It was found that dry method (DM) was more effective and is a better option as it is being simple and produces better results.*

Keywords:- *Marshall stability value , flow value, Indirect tensile strength (ITS), Dry method, Wet method.*

I. INTRODUCTION

Disposal of waste plastic is a great problem in present scenario due to its non-biodegradable nature and scarcity of landfills. Studied have revealed that it can be successfully utilized in bituminous mixes of flexible pavements. Studied reveal that waste plastics can be incorporated in bituminous mixes of flexible pavements, resulting in its better performance in terms of better strength, resistance to deformation and economy. Most of the roads in India are of flexible pavement having a wearing or surfacing course with bituminous concrete of suitable thickness depending the nature and amount of loading over it as per specifications of MORTH. The wearing or surfacing of bituminous concrete (BC) layer in suitable thickness is laid over prepared water bound macadam (WBM) granular base course after applying suitable priming and tack coating. The bituminous concrete (BC) layer work may be carried out in single or multiple layer depending upon the requirement of the site and loading. A single layer shall be 25 mm to 100 mm in thickness. As per MORTH Section 500 clause 509 BC should be made with Bitumen Grade VG-30 for nominal aggregate size 19 mm with bitumen content 5-6% has layer thickness 50-65 mm and for nominal aggregate size 13 mm with bitumen content 5-7% having layer thickness 30-45 mm. The polymer have many important properties which can be utilized for betterment of bituminous concrete mixes are summarized below-

- Durable and corrosion resistant
- Economical and longer life
- Maintenance free
- Good thermal insulation
- Reduction in noise pollution

II. OBJECTIVE OF STUDY

- A comparative study of various engineering properties of bituminous mixes of flexible pavements by utilizing shredded waste plastic carry bags made of low density polyethylene (LDPE) by wet and dry methods.
- To find a better option for improvement of quality of road pavement.

III. METHODOLOGY

3.1. Hypothesis: It is hypothesized that waste plastic improves pavement performance by using plastic coated aggregates in the mix. This helps to have a better binding of bitumen with plastic waste coated aggregate due to increased bonding and increased area of contact between polymers and bitumen. The polymer coating also reduces the voids. This prevents the moisture absorption and oxidation of bitumen by entrapped air. This reduces rutting, raveling and there is no pothole formation. The roads can withstand heavy traffic and show

better durability. It is further hypothesized that the waste plastic bitumen mix forms better material for pavement construction as the mix shows higher Marshall Stability value and suitable Marshall Coefficient. The use of waste plastics for pavement is one of the best method for easy disposal of waste plastics.

3.2. Methodology: To achieve study goals, implementation would include the following:

- Literature review of previous studies which include revision of books, scientific papers and reports in the field of recycled polymer modifiers of asphalt mix.
- Study of Marshall Mix design.
- Identifying Optimum Bitumen Content (OBC) using Marshal Mix design procedure.
- Identifying the effects of adding different percentages of waste plastic materials/ modifier on the bituminous mix properties comparing it with conventional mix by using both wet and dry methods of blending.
- Discussion of testing results and drawing conclusions.

Methods Available

There are two type of field trials

1. Dry process
2. Wet process

1. **Dry Process**: The aggregate is heated to 170°C in the Mini hot Mix Plant. The shredded plastic waste is added in specified proportion. Immediately the hot Bitumen VG-30 or VG-10 grade (160°C) is added. The mixture is transferred to the road and the road is laid. This method is very simple and economical. The flow diagram is shown in Fig 1.

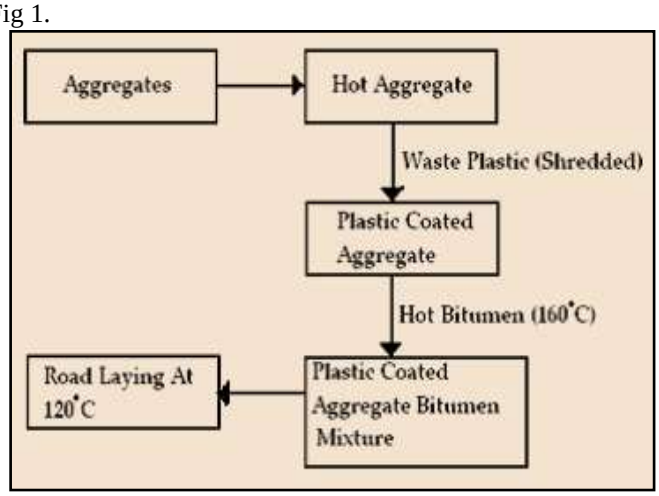

Fig: 1 Dry process steps

2. Wet Process: Waste plastics by direct mixing with hot bitumen at 160°C. Mechanical stirrer is needed. Addition of stabilizers and proper cooling. Since the wet process require a lot of investment and bigger plants. Not commonly used. The flow diagram is shown in Fig 2.

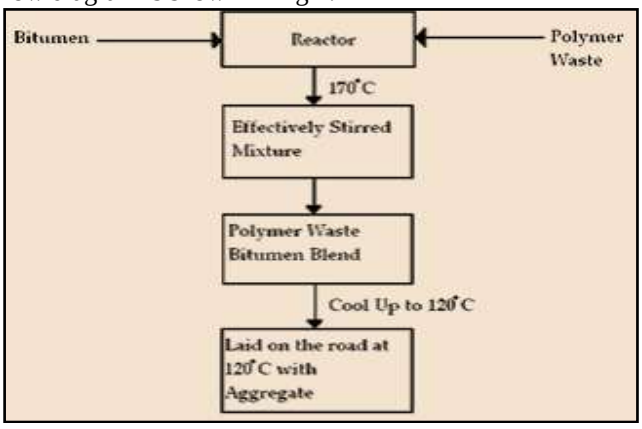

Fig: 2 Wet process steps

In this study Bituminous concrete mix has been design for 19 mm nominal size of aggregate. The Aggregate used in the study is crusher aggregate from Quarry and VG30 grade of Bitumen used as binder. First,

Laboratory testing has been carried out to find the physical properties of aggregate by conducting tests like Grain size analysis, Aggregate Impact value, Abrasion Test, Crushing value test, Flakiness and elongation Index (combined), Water absorption, Specific Gravity etc. Also, by sieve analysis the Gradation of Aggregate has been decided which satisfied the requirement of Gradation of 19 mm nominal size of aggregate for BC design as per MORTH section 509. Similarly, The Bitumen test for VG30 has been done including Penetration test at 25 °C, Softening Point test, Ductility test at 27 °C ,Viscosity at 150 °C, Specific Gravity etc which satisfied the requirement of IS:73-2006. Secondly, will prepare samples for Marshall mix design and determine the Optimum bitumen content for VG30.

Materials Used:-

1) Aggregate

Aggregate of 20mm, 10mm,

2) Bitumen

VG 30 grade bitumen

3) Waste Plastic

Waste plastic in the shredded form, stone dust and cement as filler.

IV. EXPERIMENTS AND RESULTS

Bitumen: The various test results of bitumen are shown in Table-1 below.

Table-1 Test results of VG-30 bitumen

Properties Tested	Test Method	Results	Remarks
Penetration(100 gram, 5 seconds at 25°C) (1/10th of mm)	IS 1203-1978	62	Satisfactory
Softening point, °C(Ring and Ball Apparatus)	IS 1205-1978	48.4	Satisfactory
Ductility at 27°C(5cm/ minute pull) cm	IS 1208-1978	76	Satisfactory
Specific gravity at 27°C	IS 1202-1978	1.02	Satisfactory
Viscosity in seconds	IS 1206-1978	51	Satisfactory
Flash Point	IS 1209-1981	256°C	Satisfactory
Fire Point	IS 1209-1981	276°C	Satisfactory
Grade of binder	VG-30		

Table-2 Physical Properties of Aggregates
Conventional (0% Plastic) and Plastic coated Aggregate (PCA)

Description of tests	Percentage of Plastic/ additive by weight of OBC					Specifications IRC:111-2009
	0%	5% (PCA)	7% (PCA)	9% (PCA)	11% (PCA)	
Aggregate Crushing strength	18.2%	14.1%	12.6%	10.7%	11.2%	Max 30 %
Impact value	16.4%	14.6%	12.3%	10.6%	11.4%	Max 24%
Specific gravity	2.64	2.67	2.70	2.72	2.78	2.5-3.0
Los Angeles Abrasion value	15.6%	14.8%	11.2%	9.10%	10.6%	Max 30%
Flakiness Index value	15%	13.8%	12.6%	12.6%	12.6%	Max 35 %
Elongation index value	10.5%	11%	11.2%	11.2%	11.2%	Max 35 %
Water absorption value	0.62%	Nil	Nil	Nil	Nil	Max 2%
Soundness value	6%	Nil	Nil	Nil	Nil	Max 12 %
Stripping value	5%	Nil	Nil	Nil	Nil	Max 5%

Mineral Filler

Filler shall consists pof fly ash or rock dust . The gradation of filler is shown in table below.

Table-3 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

Modifiers (Plastic waste)

The processed waste plastic (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 between 2.36 – 600 µ

Table-4 Properties of Waste Plastic

Property	Values
Size (Range)	2.36 mm – 600 µ
Thickness	20 µ to 30 µ
Density (gm/cc)	0.98
Melting Temperature in °C	130- 160
Decomposition Temperature °C	275 – 350
Ignition Temperature °C	> 700

Marshall Mix Design: The mix design should aim at an economical blends, with proper gradation of aggregate and adequate proportion of bitumen so as to fulfill the desired properties of the mix bituminous concrete is the one of the highest and costliest types of flexible pavement layer used in surface course the desirable properties of a good bituminous mix are stability, flexibility, skid resistance, durability, workability. Marshall Stability test Carrey out find the stability, flow value, air voids, voids fill with bitumen, density. Finally consist of an OBC, optimum plastic content and using gyratory compactor prepare performance evolution test sample.

Gradation Requirement Of Aggregate: Grading of aggregate has been carried out before mix design. For this purpose sieve analysis of aggregate has been done having size 20mm, 6mm and stone dust. Grading requirement of BC for this study should satisfy the MORTH section 509 Table 500-18 for 19 mm nominal size of aggregate. The aggregate has been sieved and final blend of aggregate has to be obtained by hit and trial. Grading requirement of aggregate shown in Table-5.

Table-5 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 minimum.	

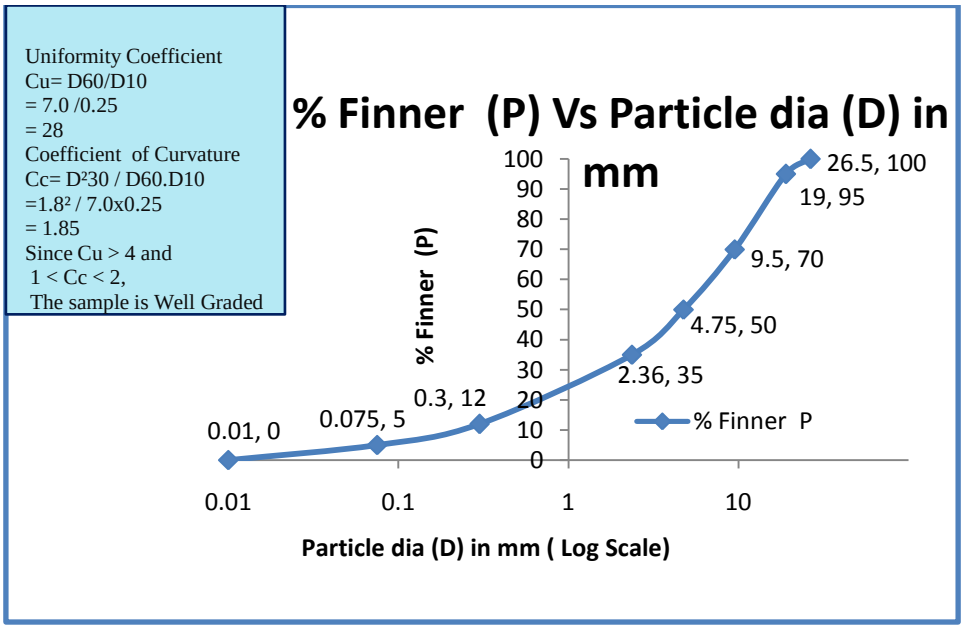

Fig-3 Particle size distribution (PSD) curve for aggregates

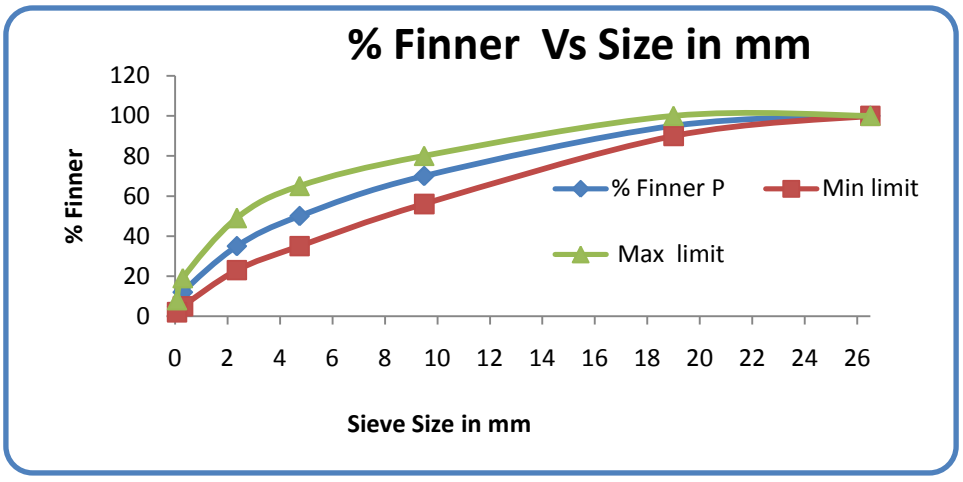

Fig-4 Gradation Curve for the aggregates

Determination of Optimum bitumen content (OBC) of the Conventional mix (CM) : Conventional bituminous concrete mix was prepared by using the various aggregates as described above along with bitumen VG-30 and filler with bitumen content varying from 4% to 6% with an increment of 0.5%. The optimum bitumen content of CM was determined by taking the average of bitumen content at highest Marshall stability, highest bulk density and at 4% air voids.

Table - 6 Marshall Test results for Conventional Mix (without plastic)

% Bitumen Content	Theoretical maximum specific gravity (Gmm)	Bulk specific gravity (Gmb)	% of Air voids (Vv)	% of voids filled with bitumen Air voids (VFB)	Marshall Stability Value (Kg)	Flow value (mm)
4	2.350	2.226	5.28	72.74	1680	6.88
4.5	2.380	2.272	4.54	74.96	1858	4.52
5	2.420	2.325	3.93	76.42	2012	3.28
5.5	2.410	2.32	3.73	78.37	1814	3.60
6	2.390	2.302	3.68	79.93	1788	4.12

For determination of optimum bitumen content three curves viz % Bitumen Vs Marshall Stability, % Bitumen Vs. Bulk specific gravity and % Bitumen Content Vs.% of Air voids were plotted, which are shown in Fig 5,6 &7.

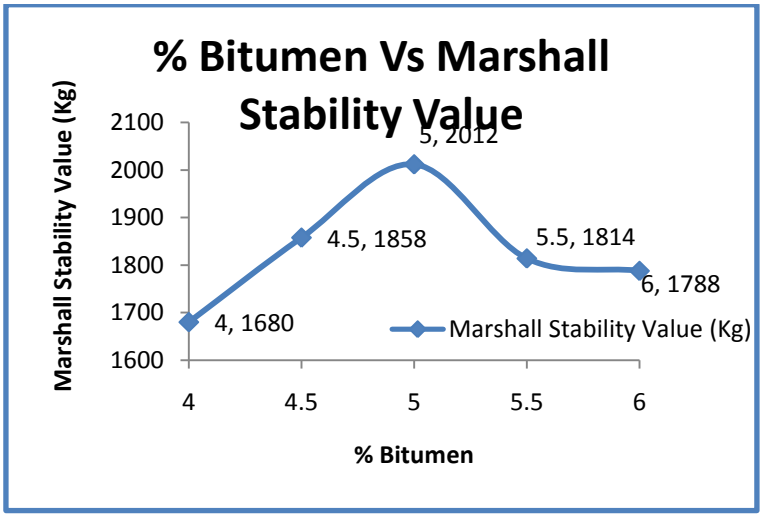

Fig-5 % Bitumen Vs Marshall Stability Value

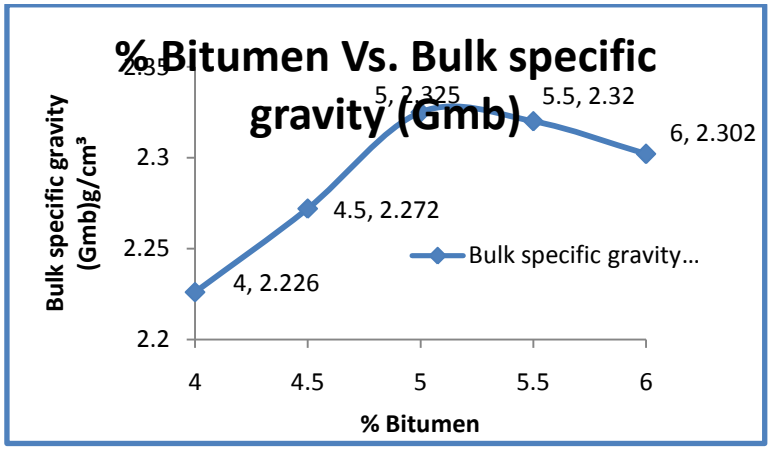

Fig-6 % Bitumen Vs Bulk specific gravity

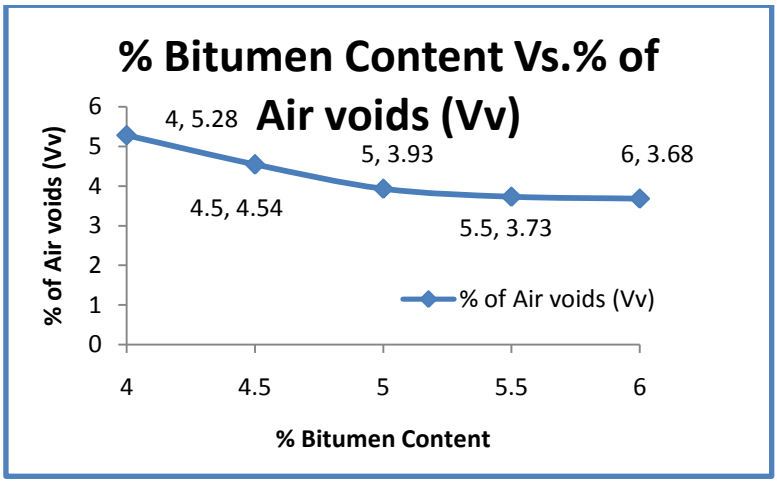

Fig-7 % Bitumen Content Vs.% of Air voids

Optimum bitumen content (OBC) = (5+5.1+5)/ 3 = 5.033% (rounded to 5.0%)

Incorporation of plastic waste into bituminous mix: The shredded plastic was incorporated by wet and dry process in percentages ranging from 5% to 11% by weight of OBC of conventional mix with an increment of 2%. The Marshall stability , flow value and other parameters were obtained by conducting laboratory testing as per specified procedures and norms. The results are shown in Table 7 .

Table - 7 Marshall Test Results for Wet Method and Dry method

% Waste Plastic by weight of Optimum Bitumen Content (OBC) of CM	Theoretical maximum specific gravity (Gmm)	Bulk specific gravity (Gmb) g/cm³	% of Air voids (Vv)	% of voids filled with bitumen Air voids (VFB)	Marshall Stability Value (Kg)	Flow value (mm)
Wet Method (WM)						
5	2.425	2.325	4.12	75.23	1782	4.10
7	2.428	2.330	4.04	77.86	1876	3.30
9	2.426	2.331	3.92	80.38	2452	2.54
11	2.422	2.329	3.84	82.37	1888	2.88
Dry Method (DM)						
5	2.428	2.33	4.04	75.50	2185	3.40
7	2.426	2.331	3.92	78.48	2490	3.18
9	2.414	2.332	3.40	82.95	2786	2.34
11	2.406	2.331	3.12	85.64	2010	2.00

It was observed that the maximum value of Marshall stability was observed at plastic content of 9% for both dry and wet mixes .It was also observed that here was an increase in Marshall stability value of 21.87% for wet mix and 38.47% for dry mix as compared to conventional mix of bituminous concrete. This shows that resistance to withstand at higher loads and to resist deformation the dry mix shows better results and is better option to improve the quality and performance of pavement. These results are plotted in Fig 7 below.

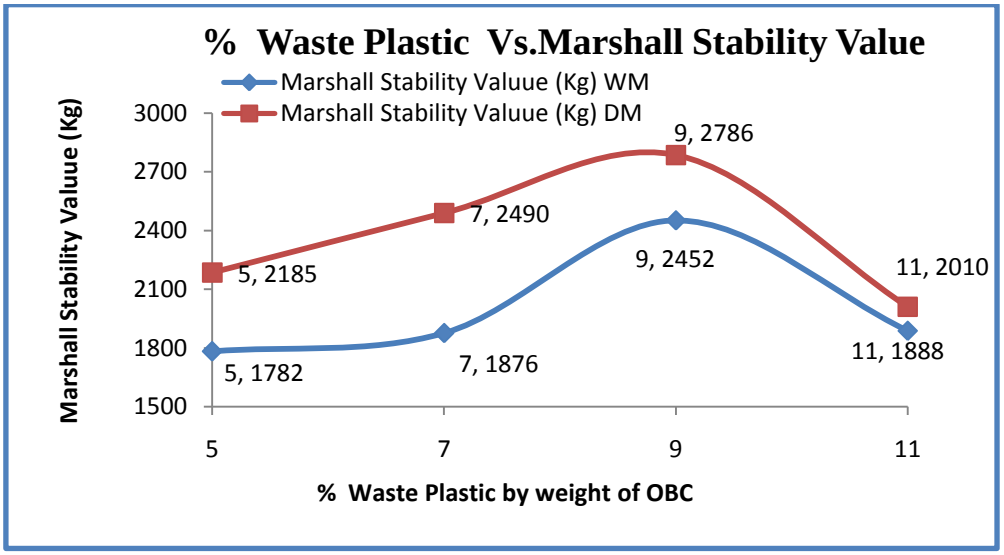

Fig-8 % Waste Plastic Vs. Marshall Stability Value of Wet and Dry Mix

The indirect tensile stress of conventional mix of bituminous concrete at various bitumen content is shown in Table. 8 below. It was observed that maximum stress occurs at optimum bitumen content of 5% by weight of mix and is 0.762 N/mm².

Table - 8 Indirect Tensile Strength (ITS) Test Results for Conventional Mix

% Bitumen Content	Indirect Tensile Stress (ITS) in N/mm²
4	0.288
4.5	0.315
5	0.762
5.5	0.488
6	0.469

The indirect tensile stress of wet and dry mix of bituminous concrete at various plastic content is shown in Table. 9 below. It was observed that maximum stress occurs at plastic content of 9% by weight of optimum bitumen content (OBC) and the value observed was 0.796 N/mm² for wet mix and 0.889 N/mm² for dry mix. The values of indirect tensile stress at various plastic content are shown in the Table. 9 below.

Table - 9 Indirect Tensile Strength (ITS) Test Results for Wet Mix and Dry Mix

% Waste Plastic by weight of Optimum Bitumen Content (OBC) of Conventional mix	Indirect Tensile Stress (ITS) in N/mm²	
	Wet Mix	Dry Mix
5	0.568	0.765
7	0.668	0.786
9	0.796	0.889
11	0.622	0.608

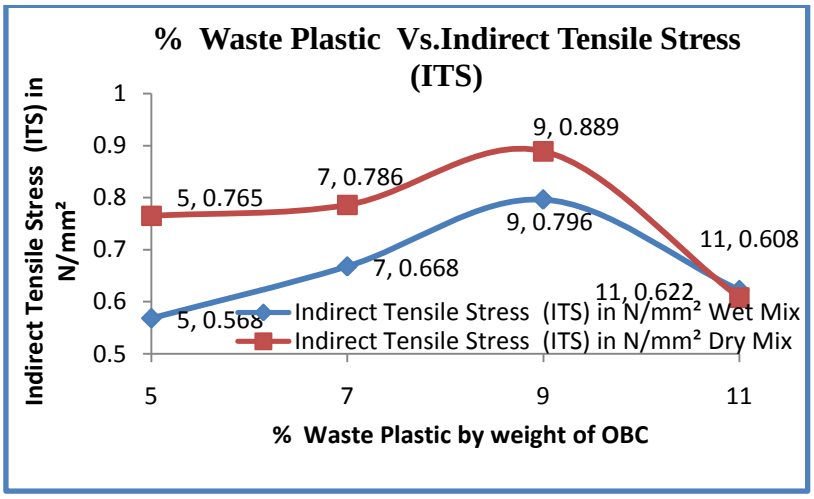

Fig-9 % Waste Plastic Vs. Indirect Tensile Stress of Wet and Dry Mix

The values of indirect tensile stress at various plastic content are plotted in Fig. 9. It was observed from the above plot that dry mix can handle greater stresses and hence it is the suitable option for improvement in quality of flexible road pavements for incorporating waste plastics.

V. COMPARISON OF RESULTS

The data obtained from the experimental investigations of wet and dry mixes were compared to find out the better option to improve the quality of flexible pavement are tabled in Table. 10 below.

Table - 10 Comparison of properties of Wet Mix and Dry Mix

Properties	CM at OBC of 5%	Wet Mix	Dry Mix
%Waste Plastic by weight of Optimum Bitumen Content (OBC) of Conventional mix	**-**	**9**	**9**
Marshall Stability Value (Kg)	**2012**	**2452**	**2786**
Indirect Tensile Stress (ITS) in N/mm²	**0.76**	**0.796**	**0.889**
Flow Value (mm)	**3.28**	**2.54**	**2.34**
% Air Voids (Vv)	**3.93**	**3.92**	**3.40**
% Void filled with bitumen (VFB)	**76.42**	**80.38**	**82.95**

VI. ECONOMY

Based on the experimental evidences and the amount of raw materials used for 20 mm thick Bituminous Premix carpet (top layer of the bituminous road) with type-A seal coat. One Kilometer long road having width 3.75 meter (3750 M²) the following calculation has been arrived –

Table - 8 Economy of Process

Material needed	Quantity of bitumen with conventional aggregate	Quantity of bitumen with Plastics coated aggregate (PCA)
VG-30 Bitumen	9150Kg	8326 Kg
Plastic waste	Nil	824 Kg
Cost	Rs 549000	(Bitumen)Rs 499560+ (Plastic) Rs 8240 = Rs 507800
Cost Reduced (per KM) for Single lane road having width 3.75 Meter	Nil	Rs 41200

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 = 824 Kg
Use of Plastics waste – 824 Kg
Cost Reduced (per KM) for single lane road having width 3.75 Meter = Rs 41200
There is no maintenance cost for a minimum period of five years. Hence the process is cheap and eco- friendly.

VII. CONCLUSION

Based on the study and experimental data for waste plastic modified bituminous concrete wet and dry mix compared with conventional bituminous concrete mix, the following conclusions were 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% 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.
3. The results of wet mix and dry mix were compared to conventional mix in terms of Marshall stability value and Indirect tensile stress. It was observed that the improvement in the performance was obtained at 9% incorporation of plastic wastes in wet and dry mixes as indicated in Table.10 above.
4. It was observed that here was an increase in Marshall stability value of 21.87% for wet mix and 38.47% for dry mix as compared to conventional mix of bituminous concrete. This shows that resistance to withstand at higher loads and to resist deformation the dry mix shows better results and is better option to improve the quality and performance of pavement.
5. It was also observed that here was an increase in Indirect tensile strength by 4.7% for wet mix and 16.97% for dry mix as compared to conventional mix of bituminous concrete. There was a decrease in flow value by 22.56% for wet mix and 28.65% for dry mix as compared to conventional mix.
6. There was a slight decrease in air voids of dry mix as compared to wet mix but the changes are with in the permissible range. There was no appreciable changes in voids filled with bitumen (VFB) parameter.
7. Bituminous concrete mix modified with waste plastic coated aggregates showed higher Marshall stability as compared to conventional bituminous concrete mix. Marshall stability value increases with plastic content up to 9% and thereafter decreases. Thus the use of higher percentage of waste plastic/ polythene is not preferable. 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.
8. 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 with minimum maintenance.

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