

# **Experimental Study on the Behavior of Flexible Pavements with Partial Replacement of Bitumen with Plastic Waste**

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**ABSTRACT:** Disposal of plastic waste is a serious problem worldwide due to its non bio-degradability. The plastic waste when mixed with bitumen improves mechanical properties in particular road mix. Bitumen is used as a binding material in construction of flexible pavement, when waste plastic is mixed with bitumen it increases its water resistivity capacity and stability. The use of waste plastic as a partial aggregate replacement in bituminous mix products often suffers from weak bonding between the plastic surface and the bitumen. The replacement of bitumen by plastic is by 5%,7%,9%,11% & 13%. This work reports on the use of plastic waste and chemical additives in order to improve the performance of the mechanical properties of bituminous mixtures. The plastics were treated using a strong oxidising mixture of dichromate and sulphuric acid while the bitumen was treated with a cross linking agent, polyethyleneimine. This improvement is attributed to an increase in the bonding forces between the aggregates and the bitumen.

## **I. INTRODUCTION**

Several studies have proven the health hazard caused by improper disposal of plastic waste. Although plastic has come to occupy an indispensable place in human life because of its properties like durability, low production cost, light weight, etc., it is also a villain in disguise as it plays a vital role in the occurrence of many public health problems. The health hazard includes reproductive problems in human and animal, genital abnormalities etc.,. Looking forward the scenario of present life style a complete ban on the use of plastic cannot be put, although the waste plastic taking the face of devil for the present and future generation. We cannot ban use of plastic but we can reuse the plastic waste. According to recent studies, plastics can stay unchanged for as long as 4500 years on earth with increase in the global population and the rising demand for food and other essentials, there has been a rise in the amount of waste being generated daily by each household. Plastic in different forms is found to be almost 5% in municipal solid waste, which is toxic in nature. It is a common sight in both urban and rural areas to find empty plastic bags and other type of plastic packing material littering the roads as well as drains. Bitumen is a useful binder for road construction. Different grades of bitumen like 30/40, 60/70 and 80/100 are available based on their penetration values. Today the availability of waste plastics is enormous as plastic materials have become part and parcel of daily life. They either get mixed with Municipal Solid Waste and/or thrown over land area. If not disposed or recycled properly, their present disposal is either by incineration or land filling. But, both the processes have a major impact on the environment in a long term basis. Under this circumstance, an alternate method for the proper disposal of waste plastics is needed.

So the use of plastic along with the bitumen in construction of roads not only increases its life and smoothness but also makes it economically sound and environment friendly. Plastic waste is used as modifier of bitumen to improve some of bitumen properties. Use of plastic waste in the construction of flexible pavement is gaining importance because

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of several reasons. Roads that are constructed using plastic waste are known as Plastic Roads and are found to perform better compared to those constructed with conventional bitumen. The plastic modified bitumen shows better properties for road construction & plastics waste, otherwise considered to be a pollution menace.

its use in this process and this can help solving the problem of pollution. Further it has been found that such roads were not subjected to stripping when it comes in contact with water. Use of higher percentage of plastic waste reduces the need of bitumen by 10%. It also increases the strength and performance of the road. Plastic increases the melting point of bitumen and hence mixing can be done in more better and easier way. Inclusion of plastic waste in road construction eliminates the plastic shrinkage cracking of road surface and reduces the drying shrinkage to some extent. The uses of plastic waste helps in substantially improving the abrasion and slip resistance of flexible pavement and also allows to obtain values of splitting tensile strength satisfied the specified limits while plastic waste content is beyond 30% by weight of mix. If the consistent mixing time and mixing temperature are not provided for bitumen–modifier mix, modified bitumen cannot exhibit good performance in situ, thus premature failures will occur. Therefore, there are certain recommended mixing time, mixing temperature and modifier content for all the polymers with a trademark. This all should be taken in mind while missing and laying of roads is to be done using plastic waste. Plastic road would be a boon for India. In hot and extremely humid climate durable and eco-friendly plastic roads are of greatest advantages. This will also help in relieving the earth from all type of plastic waste.

Waste plastic	Origin
Low density Polyethylene (LDPE)	Carry bags, sacks, milk pouches, cosmetic and detergent bottles.
High Density Polyethylene (HDPE)	Carry bags, bottle caps, house hold articles etc.
Polyethylene Teryphthalate (PET)	Drinking water bottles etc.
Polypropylene (PP)	Bottle caps and closures ,wrappers of detergent ,biscuit, water packets, microwave trays for readymade meal etc.,
Polystyrene(PS)	Yoghurt pots, clear egg packs, bottle caps, foamed Polystyrene:foodtrays,eggboxes,disposable cups,protective packagine etc.
Polyvinyl chloride(PVC)	Mineral water bottles ,credit cards ,toys,pipes and gutters; electrical fittings, furniture ,folders and pens ,medical disposables., etc.

The classification of plastic as per IRC SP98 is as follows

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**Table: Properties of 80-100 Bitumen as per IS:702-1961**

Test	Result
Specification Gravity @25/25 °C	1.01-1.06
Penetration @ 25 ° C	80/100
Softening Point ° C	42/52
Ductility @ 25 ° C CMS	100 MIN
Loss on Heating (wt.)%	0.5 MAX
Flash Point °C	225 MIN
Solubility in CS@ (wt.)%	99 MAX
Density @25° C	1.01/1.06

### PLASTIC:

Non-Uniform Shredded PET Bottle waste collected from Ambattur Industrial Estate.



**Fig. Shredded plastics**

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**Table: Test Result of Aggregate:**

### VFB (Voids Filled with Bitumen)

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 percent of the volume of the VMA that

Test	Code	Limits	Observed value
Sieve analysis	IS:2386(PART I) – 1963	Max 5% passing 0.075mm sieve	4.8% passing
Impact test	IS:2386 (PART IV)- 1963	Max 20%	17.98%
Specific gravity	IS:2386(PART III) – 1963	2.5 to 3	2.77
Flakiness index & Elongation index	IS:2386 (PART I) - 1963		32.59%

is filled with bitumen. VFB is inversely related to air voids and hence as air voids decreases, the VFB increases.

$$VFB = \text{-----} \times 100$$

Where, VA is air voids in the mix and VMA is the voids in the mineral aggregate. The decrease of VFB indicates a decrease of effective bitumen film thickness between aggregates, which will result in higher low-temperature cracking and lower durability of bitumen mixture since bitumen perform the filling and healing effects to improve the flexibility of mixture. The samples were tested for the percent air voids (Va); voids in mineral

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aggregate (VMA) and voids filled with bitumen (VFB) were calculated using the following relationships:

- % binder by weight of aggregate = 5(say)
- % binder by weight of mix =  $(5 \times 100) / (5 + 100) = 4.76$
- % aggregate by weight of mix =  $100 - \% \text{ binder by wt. of mix}$
- Bulk density of specimen(g) =  $\text{weight in air} / (\text{wt. in air} - \text{wt. in water}) \text{ g/cc}$
- % volume of binder =  $(\text{Bulk density} \times \% \text{ binder by wt. of mix}) / \text{avg. specific of binder.}$
- % volume of aggregate =  $(\text{Bulk density} \times \% \text{ aggregate By wt. of mix}) / \text{avg. specific gravity of aggregate}$
- Total ( volume of binder + vol. of aggregate) % air voids =  $100 - \text{total}$
- % VMA (voids in mineral aggregate)=  $100 - \% \text{ vol. of aggregate}$
- % VFB (voids filled with bitumen) =  $(\% \text{ vol. of binder} \times 100) / \% \text{ VMA}$

## II. PREPARATION OF MIX

Two types of mix were prepared namely conventional mix of Bituminous

Concrete grade II and the Plastic modified bituminous concrete mix of grade II. Two samples were prepared for conventional mix and 10 samples were prepared for modified mix.

### PROCEDURE OF CONVENTIONAL MIX PREPARATION

The mix used in this study is a bituminous concrete mix. Approximately 1200gm of aggregates and filler is heated to a temperature of 175° C to 190°C. Bitumen will be heated to a temperature of 121 to 125° C with the first trial percentage of bitumen to the heated aggregates and thoroughly mixed at temperature of 154°C to 160°C. The mix will be placed in a preheated mould

and compacted by a rammer with 75 blows on either side at temperature of 138°C to 149°C. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of  $63.5 \pm 3$  mm. By varying the bitumen content in the next trial by +0.5% and the above procedure will be repeated. The properties that are of interest include the theoretical specific gravity  $G_t$ , the bulk specific gravity of the mix  $G_m$ , percent air voids  $V_v$ , percent volume of bitumen  $V_b$ , percent void in mixed aggregate VMA and percent voids filled with bitumen  $V$

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## PREPARATION OF MARSHALL SAMPLES



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**Table: Properties of Conventional Mix**

Contents	Sample 1	Sample 2
% of binder	5.8	5.8
% of aggregate	94.2	94.2
BD of specimen	2.435	2.443
% volume of binder	9.07	9.88
% Air voids	4.49	3.80
% VMA	13.56	13.68
% VFB	66.89	72.20
Stability, KN	10.63	10.77
Volume correction factor	1.03	1.03
Corrected stability,	11.66	11.80
Flow	3.05	2.98
Average Specific Gravity of Aggregate	2.77	2.77
Average Specific Gravity of binder	1.02	1.02

**Fig. Preparation of Marshall Sample**

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### PREPARATION OF PLASTIC MODIFIED BC MIX

The use of plastic in wet process for preparation bituminous concrete grade II mix has been carried out in this study. 5%, 7%, 9%, 11% and 13% of plastic by weight of bitumen is added to the mix. The materials used are as per MORTH specification: Aggregate + 80-100 grade of bitumen + filler material + plastic (PET).

#### Procedure for the preparation of plastic modified mix

Shredded PET plastic is gradually added to the heated bitumen at 160°C in the blender namely, mechanical stirrer and effective stirring takes place for homogeneous blend. The aggregate mix is heated to 160°C in the oven and then it is effectively mixed with aggregate.



Figure: Preparation of Modified Binder

#### Design of Modified BC mix by Marshall Method:

Marshall Method of mix design is performed to determine the optimum binder content (OBC) of plastic. The mix was designed using 75 blows in each side by Marshall Method and with different binder contents by the weight of aggregate, to sustain heavy traffic. The target mixing and compaction temperatures were 175°C and 143°C respectively. Plastic mixtures were prepared with a stabilizing additive at the rate of 5, 7, 9, 11 and 13 present (by the weight of total mixture) for Topical with 80/100 paving grade bitumen.

The proportions of the aggregate taken are listed in the table below:

Content	Percentage by weight of mix	Weight(grams)
16 – 10 Mm Aggregate	21 %	252



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10 – 3 Mm Aggregate	40 %	480
Stone Dust (<3mm)	38 %	456
Lime	1 %	12

The samples were prepared for 5%, 7%, 9%, 11% and 13% plastic contents. The samples are shown in the figure below



**Fig: Plastic Modified Sample**

### III. TEST RESULTS FOR MODIFIED BITUMEN

The increase in the percentage of polymer decreases the penetration value. This shows that the addition of polymer increases the hardness of the bitumen. The softening point increased by the addition of plastic waste to the bitumen. Higher the percentage of plastic waste added, higher is the softening point. The influence over the softening point may be due to the chemical nature of polymers added. The increase in the softening point shows that there will be less bleeding during summer. Bleeding accounts, on one side, increased friction for the moving vehicles and on the other side, if it rains the bleedings accounts for the slippery condition. Both these adverse conditions are much reduced by polymer-bitumen blend. The increase in the ductility value may be

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explained as follows. The long polymer molecules when mixed hot, physically interlock the material and this may help to reduce cracking at the surface.

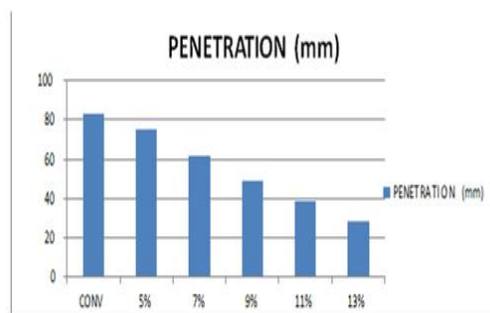


Fig. Plastic content vs Length

### Results Of Softening Test On Bitumen

Content	Ball 1 (°c)	Ball 2 (°c)	Softening Point
Original	40.5	41.1	40.25
5%	46.3	47.5	46.75
7%	49	49.5	49.25
9%	56.3	57.2	56.5
11%	62.1	62.8	62.25
13%	68	69.1	68.5

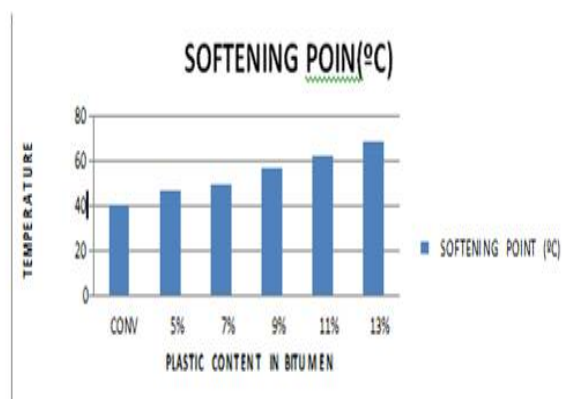


Fig. Plastic Content Vs Temperature

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### DUCTILITY TEST

The addition of plastics to the bitumen decreases the ductility value, thereby increasing the quality of bitumen. The observed values for ductility test are tabled below.

Table 4.3 Results Of Ductility Test On Bitumen

Content	Test 1		Test 2	
	Initial cm	Final cm	Initial cm	Final cm
Original	0	74.30	0	74.80
5%	0	63.50	0	64.30
7%	0	57.1	0	56.30
9%	0	46.9	0	47.30
11%	0	40.2	0	40.7
13%	0	32.1	0	31.8

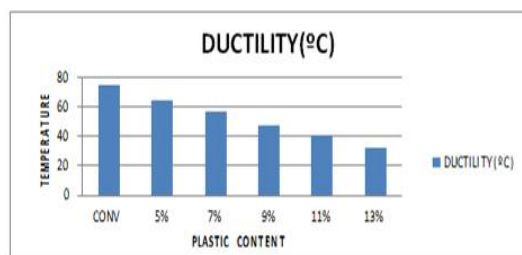


Fig. Plastic Content Vs Length

### TEST RESULTS FOR MARSHALL SPECIMEN

The stability and flow of the specimen can be determined by marshall test. All the samples, both conventional mix and 5%, 7%, 9%, 11% and 13% plastic containing mix are tested in marshall test apparatus and the values are recorded.

It is possible that while making the specimen, the thickness slightly vary from the standard specification of 63.5mm. Therefore, measured stability values need to be corrected to those which would have been exactly 63.5 mm. This

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is done by multiplying each measured stability value by an appropriated correction factors as given in the table below.

Volume of specimen (cm <sup>3</sup> )	Thickness of specimen (mm)	Correction factor
457 - 470	57.1	1.19
471- 482	68.7	1.14
483 - 495	60.3	1.09
496 - 508	61.9	1.04
509 - 522	63.5	1.00
523 - 535	65.1	0.96
536 - 546	66.7	0.93
547 – 559	68.3	0.89
560 – 573	69.9	0.86

**Table. Correction Factor**

### AIR VOIDS, BULK DENSITY & VFB

Air voids are small airspaces or pockets of air that occur between the coated aggregate particles in the final compacted mix. A certain percentage of air voids is necessary in all dense-graded highway mixes to allow for some additional pavement compaction under traffic and to provide spaces into which small amounts of asphalt can flow during this subsequent compaction. The allowable percentage of air voids is between 2.0 percent and 4.0 percent for most surface course mixes or as required by the owner. The VFA is the percentage of voids in the compacted aggregate mass that are filled with asphalt cement. It is synonymous with the asphalt-void ratio. The VFA property is important not only as a measure of relative durability, but also because there is an excellent correlation between it and percent density. If the VFA is too low, there is not enough asphalt to provide durability and to over - densify under traffic and bleed. Thus, the VFA is a very important design property. Most dot specifications require 70-80 during the design phase; this requirement is intended for the mix during the design phase only and is typically not a production requirement.

**Table: Results For Bulk Density, Vma And Vfb**

PERCENT OF PLASTIC		WEIGHT	WEIGHT	WEIGHT
		IN AIR $W_a$	IN WATER $W_w$	IN SSD $W_s$
5%	1.	1245	741	1247
	2.	1234	735	1237
	1.	1211	724	1213

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7%	2.	1222	731	1225
9%	1.	1263	757	1264
	2.	1260	753	1264
11%	1.	1259	753	1262
	2.	1255	752	1258
13%	1.	1244	742	1246
	2.	1236	738	1238

PERCENT OF PLASTIC		BULK VOLUME Vb	SPECIFIC GRAVITY BULK	VV	VMA	VFB
5%	1.	506	2.460	2.24	71.53	7.87
	2.	502	2.458	2.16	72.27	7.79
7%	1.	489	2.476	2.90	65.92	8.54
	2.	494	2.473	2.78	66.94	8.41
9%	1.	5107	2.491	3.53	61.46	9.16
	2.	508	2.480	3.07	64.71	8.7
11%	1.	509	2.473	2.78	66.94	8.41
	2.	506	2.480	3.07	64.71	8.7
13%	1.	504	2.468	2.57	68.65	8.2
	2.	500	2.472	2.74	67.26	8.37

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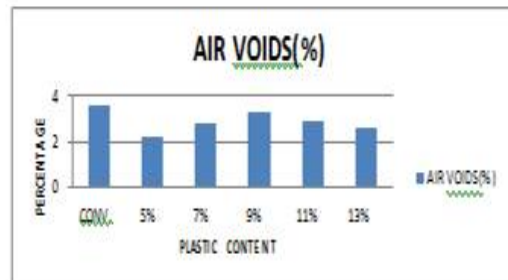


Fig 4.6 Plastic Content Vs Flow

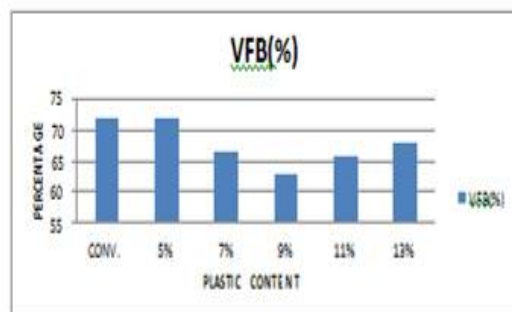


Fig 4.5 Plastic Content Vs VFB

#### IV. STABILITY AND FLOW

In marshal stability test, the deformation of specimen of bituminous mixture is measured when the same load is applied. This test procedure is used in designing and evaluating bituminous paving mixes. The marshal stability of mix is defined as a maximum load carried by a compacted specimen. The following results of Marshal Stability test are shown in Table below.

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**Table. Results for Stability and Flow**

Dial Gauge Reading		Load (Reading $\times 5.953$ )		Correction factor	Dial reading
5%	1.	180	10.71	1.04	270
	2.	170	10.12	1.04	250
7%	1.	200	11.90	1.09	360
	2.	185	11.01	1.09	350
9%	1.	220	13.09	1.04	330
	2.	200	11.90	1.04	320
11 %	1.	195	11.60	1.00	320
	2.	190	11.31	1.04	340
13 %	1.	165	9.82	1.04	380
	2.	160	9.52	1.04	370

**Table. Results for Stability and Flow**

Dial Gauge Reading		Corrected load		Mm
5%	1.	180	11.13	2.7
	2.	170	10.52	2.5
7%	1.	200	12.97	3.6
	2.	185	12.00	3.5
	1.	220	13.61	3.3

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9%	2.	200	12.37	3.2
11%	1.	195	11.60	3.2
	2.	190	11.76	3.4
13%	1.	165	10.21	3.8
	2.	160	9.9	3.7

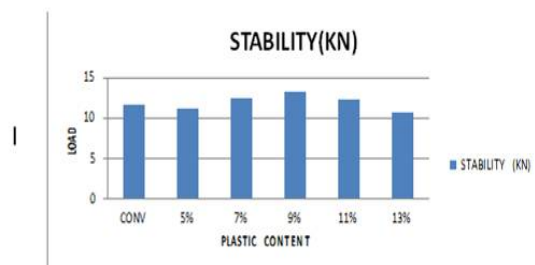


Fig. Plastic Content Vs Load

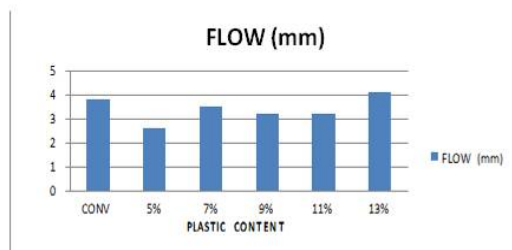


Fig. Plastic Content Vs Flow

## V. CONCLUSION

In the present study, the importance was to add the shredded waste plastic bottles to bituminous concrete mix and to evaluate the various mix properties like Marshall Stability, flow, bulk density, voids in the mix and VFB.

The properties of bitumen can be enhanced by adding small amounts of the modifier. Therefore modified bituminous materials can bring real benefits to highway construction, maintenance, in terms of better and longer lasting roads, and savings in total road life costing.

The modified mix has better stability with 9% plastic blended bitumen. The polymer blend also reduces the voids. This prevents the moisture absorption and oxidation of bitumen by entrapped air. This has resulted in reducing rutting, ravelling and there is no pothole formation. The roads can withstand heavy traffic and show better durability.

The increase in softening and ductility values indicate reduce bleeding and cracking. The decrease in penetration value shows better hardness.

It is hoped that in near future we will have strong durable and eco-friendly roads which will relieve the earth from all types of plastic-waste.



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## SUMMARY

From the Marshall Test results, the optimum binder content for conventional mix was found to be 5.8% and optimum plastic replacement content for bitumen was found out to be 9%. The plastic modified mix showed better results for penetration, softening and ductility compared to that of conventional mix. The 9% plastic blend showed better results as compared to the other blends and conventional mix as shown in the table. 9% plastic modified bitumen has better penetration, ductility and softening values as compared to the conventional bitumen as well as other plastic modified blends. Indirect tensile strength was investigated for OBC and 9% plastic coated on aggregates which had yielded the higher Tensile strength ratio 83.84 compared to conventional blend which yielded 74.41%. Hence there is an increase in stability with the addition of PET plastic in asphalt mix by incorporating wet process this can be used in highway construction for better stability for the appropriate traffic.

**Table: Comparison Of Test Results**

Tests	For 9% Blend	For Conventional Mix
Penetration	48.83mm	82.66 mm
Softening Point	56.5° C	40.25° C
Ductility	47.1 cm	74.55 cm

## V. FUTURE SCOPE OF STUDY

As the above results were found to be satisfactory, it is further suggested that the Polyethylene terephthalate can be either substituted or mixed along with different type of plastics such as polysterene, LDPE, HDPE etc.,

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