PARTIAL REPLACEMENT OF BITUMEN BY WASTE PLASTIC AND POLYPROPYLENE IN ROAD CONSTRUCTION

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Abstract

Now a days, disposal of plastic waste has became issue of great concern for environmental engineers due its non-biodegradable characteristics and health hazard. Bitumen is currently one of the most widely used binding materials in road pavement. The reasons due to which bitumen is mostly used as a binding material are its excellent binding characteristics, waterproofing properties and low cost as compared to other binders. However, it is widely known to have various types of distresses and does not perform well in aggressive situations. To counter these shortcomings, bitumen is ordinarily assorted with various forms of modifiers such as polymers, crumb rubber etc. These modifiers are costly and not easily available, so research is focused on waste plastic and polypropylene instead. This study presents results of the waste plastic and polypropylene which have been used as a modifier by an amount of 1%, 3%, 5% & 7% by weight of bitumen in making bituminous mixture for pavement applications. When waste plastic is mixed with bitumen it increases its water resistivity, capacity and stability. Marshal stability test is considered to stimulate with field condition. Flow and stability of the mix increase after incorporating waste plastic. On the basis of experimental work it is concluded that the asphalt mixtures with waste plastic and polypropylene modifier can be used for flexible pavement construction in a warmer region from the standpoint of stability ad flow characteristics

Keywords: Waste Plastic, Crumbed rubber, Aggregate, Bitumen.

I INTRODUCTION

The amount of waste plastics and polypropylene are generating in day today life. Disposal of this waste plastic is the challenging problem in all over the world. They either get mixed with municipal solid waste or disposed over land area. Various attempts have been made for the recycling and reuse of waste plastic like polythene covers, plastic bags, plastic bottles, etc., the rapid increase in high traffic intensity in addition to significant variations in daily and seasonal temperature, demand qualitatively best road characteristic.

Especially in under developing countries where proper maintenance of road networks is difficult due to lack of funds, heavy control while laying and effective machinery. Better infrastructure of road is required which needs less maintenance. Many investigations have found that the strength of paving mixes can be enhanced by using various types of modifiers with bitumen such as crumb rubber, polypropylene, and organic polymers. Using these modifiers the temperature susceptibility and viscosity characteristics are improved and also helped in elevating certain problem like bleeding of binder during peak summer temperature and stripping of aggregate in moisture prone areas.

These polymers besides being costly are not easily available that is why many research have been performed for modification of bitumen by using waste polymers. The polymers used for modification of bitumen for paving purposes are generally styrene-butadiene-styrene, copolymer styrene-butadiene, rubber latex, ethylene vinyl acetate, copolymer PVC, polypropylene etc.

Various studies are being carried out to improve the quality of bitumen used in bituminous road construction. One of the results of such studies is to use polymer modified bitumen. Use of disposed plastic waste (especially plastic bags) is the need of the hour. The studies on the thermal behavior and binding property of the molten plastics promoted a study on the preparation of plastic waste – bitumen blend and its properties to find the suitability of the blend for road construction.

Energy recovery from municipal solid plastics waste can take the routes like burning the waste in stream generated incinerators, burning the refuse in heat exchangers, pyrolysis hydrogenation and anaerobic digestion. Tyre waste is also the major part of polymer and it is also necessary to dispose. It creates health and Environmental problems, if dispose by land filling and incineration. Hence, one is the way of disposing tyre waste as crumb rubber into the road for modification of bitumen. Proper addition of such waste in bitumen improves quality, life and minimizes construction cost of road. The phenomenal increase in the volume of vehicular traffic on our road, including commercial vehicle combined with perpetual overloading by transport vehicle and significant variation in daily and seasonal temperature in various parts of the country calls for the improved performance of the road pavement and consequently better quality of bitumen.

OBJECTIVE

- To utilize the waste plastic as useful binding material.
- Analysis of the properties of bituminous mix specimen.
- To increase the Stability and Life of the Road Pavement.
- To increase the Durability of Pavement.
- To increase the flow value.
- To reduce the cost of the materials (bitumen).
- It will be economical since waste material like plastic is used.

II MATERIALS USED & EXPERIMENTAL INVESTIGATION

WASTE PLASTIC

A material that contains one or more organic polymers of large molecular weight, solid in its finished state and at some state while manufacturing or processing into finished articles, can be shaped by its flow.

The properties of plastic are defined chiefly by the organic chemistry of the polymer such as hardness, density, and resistance to heat, organic solvents, oxidation, and ionizing radiation. In particular, most plastics will melt upon heating to a few hundred degrees Celsius.

Table 1 Plastic Waste and its source

WASTE PLASTIC	ORIGIN
Low Density Polyethylene	Carry bags, sacks, milk pouches, bin lining, cosmetic and Detergent bottles.
High Density Polyethylene	Carry bags, bottle caps, house hold articles etc.
Polyethylene Teryphthalate	Drinking Water bottles etc.
Polypropylene	Bottle caps and closures, wrappers of detergent, biscuit, vapors packets, microwave trays for readymade meal etc.
Polystyrene	Yoghurt post, clear egg packs, bottle caps. Foamed polystyrene: food trays, eg boxes, disposable cups, protective packaging etc.
Polyvinyl Chloride	Mineral water bottles, credit cards, toys, pipes and gutters, electrical fittings, furniture, folders and pens, medical disposables etc.

POLYPROPYLENE

Polypropylene (PP), also known as polypropene, is a thermoplastic polymer used in a wide variety of applications including packaging and labeling, textiles (e.g., ropes, thermal underwear and carpets), stationery, plastic parts and reusable containers of various types, laboratory equipment, loudspeakers, automotive components, and polymer banknotes. An addition polymer made from the monomer propylene, it is rugged and unusually resistant to many chemical solvents, bases and acids.

The properties of plastic are Low density (weight saving), High stiffness, Heat resistance, Chemical inertness, Steam barrier properties (food protection), Good transparency, Good impact / rigidity balance, Stretch ability (film and fibre applications)

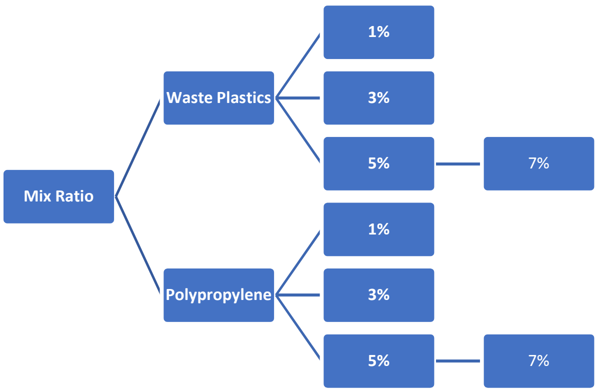

Fig. 1 Mix Ratio of Waste Plastic and Polypropylene

EXPERIMENTAL INVESTIGATION

a) Aggregate impact value test
b) Los Angeles abrasion test
c) Water absorption test on Course aggregate
d) Aggregate crushing test
e) Penetration test on bitumen
f) Ductility test on Bitumen
g) Flash & fire point test on Bitumen
h) Softening point of Bitumen
i) Marshall Stability test of Bitumen

III. MARSHALL STABILITY TEST ON BITUMEN

This test is done to determine the Marshall stability of bituminous mixture as per ASTM D 1559. The principle of this test is that Marshall Stability is the resistance to plastic flow of cylindrical specimens of a bituminous mixture loaded on the lateral surface. It is the load carrying capacity of the mix at 60^{o} C and is measured in kg.

The total weight of the mix should be 1200g.

Procedure to determine Marshall Stability of bituminous mixture

- Heat the weighed aggregates and the bitumen separately up to 170°C and 163°C respectively.
- Mix them thoroughly, transfer the mixed material to the compaction mould arranged on the compaction pedestal.
- Give 75 blows on the top side of the specimen mix with a standard hammer (45cm, 4.86kg). Reverse the specimen and give 75 blows again. Take the mould with the specimen and cool it for a few minutes.
- Remove the specimen from the mould by gentle pushing. Mark the specimen and cure it at room temperature, overnight.
- A series of specimens are prepared by a similar method with varying quantities of bitumen content, with an increment of 0.5% (3 specimens) or 1 % bitumen content.
- Before testing of the mould, keeps the mould in the water bath having a temperature of 60°C for half an hour
- Check the stability of the mould on the Marshall Stability apparatus

Theoretical Maximum Specific Gravity of the mix (G_{mm})

$$G_{mm} = \frac{Wmix}{Vol\ of\ the\ (mix - air\ voids)}$$

Where, W_{mix} is the weight of the bituminous mix, G_{mm} is calculated as per ASTM D 2041 – 95.

Bulk specific gravity of mix (G_{mb})

The bulk specific gravity or the actual specific gravity of the mix G_{mb} is the specific gravity considering air voids and is found out by

$$G_{mb} = \frac{Wmix}{Bulk\ volume\ of\ the\ mix}$$

Air voids percent (VA)

The following equation represents the percentage of air voids in the specimen.

$$VA = \frac{(Gmm - G\ mb)}{Gmm}\ X\ 100$$

Voids filled with bitumen (VFB)

The following equation represents the percentage of voids filled with bitumen in the specimen.

$$VFB = \frac{(VMA - VA)}{VMA}\ X100$$

Where, VA is air voids in the mix and VMA is the voids in the mineral aggregate.

Voids in mineral aggregate (VMA)

The following equation represents the percentage of voids in mineral aggregate in the specimen.

$$VMA = 1 - \frac{Gnb\ X\ Ps}{Gsb} X100$$

Where, P is the fraction of aggregates present, by total weight of the mix and G_{sb} is the bulk specific gravity of the mixed aggregates.

IV. RESULTS AND DISCUSSIONS

a) Aggregate impact value test

Total weight of the aggregate sample (W1) = 470g

Weight of the aggregate passed through 2.36 mm sieve (W2) = 90g

Aggregate impact value = (W2/W1) X100

= (90/470)X 100

= 19.14%

b) Los Angeles abrasion test

Initial weight of the aggregate (A) = 5000g

Weight of the aggregate after sieving in 1.7mm sieve (B)= 3270g

Abrasion test value = ((A – B) / A) X 100

= ((5000-3270) / 5000) X100

= (1730 / 5000) X 100

= 34.6 %

c) Water absorption test on Course aggregate

Weight of oven dried specimen (W1) = 200g

Weight of the specimen at fully saturated (W_2) = 201g

Weight of aggregate after heated in oven and dried (W_3) = 199g

Percentage of water absorption = ((W_2-W_3) /W1)X100= ((201-199)/ 200)X 100

Water absorption = 1%

d) Aggregate crushing test

Aggregate crushing value = (W_2 /W_1) X 100

Total weight of dry sample (W_1) = 3500g

weight of the portion of crushed material passing 2.36mm IS sieve. (W_2) = 690g

Aggregate crushing value = (690 / 3500) X 100

= 19.1 %

e) Penetration test on bitumen

This test done to determine the penetration of bitumen as per IS: 1203 – 1978. The principle is that the penetration of bituminous material is the distance in mm that a standard needle would penetrate vertically, into a sample of the material under standard conditions of temperature, load and time.

Table 2 Penetration test result on Bitumen

(a) Conventional

S.NO	Weight (g)	Reading(mm)	Mean value
1	0	16.3	18
2	50	17.5	
3	100	20.2	

(b) Addition of Waste Plastic

S.NO	Mix ratio	Weight(g)	Reading (mm)	Mean Value
1	1%	0	16	17.4
		50	16.8	
		100	19.6	
2	3%	0	15.8	17.2
		50	16.5	
		100	19.3	
3	5%	0	15.4	16.6
		50	16.2	
		100	18.2	
4	7%	0	15	16.1
		50	15.8	
		100	17.6	

(c) Addition of Polypropylene

S.NO	Mix ratio	Weight(g)	Reading (mm)	Mean Value
1	1%	0	15.5	16.8
		50	16.4	
		100	18.6	
2	3%	0	15	16.2
		50	15.9	
		100	17.8	
3	5%	0	14.7	15.7
		50	15.2	
		100	17.2	
4	7%	0	14	15.1
		50	14.8	
		100	16.5	

Discussion:

The penetration values are decreasing significantly when bitumen is mixed with the modifier. There is a significant decrease in penetration values for modified blends, indication the improvement in their temperature susceptibility resistant characteristics.

f) Ductility test on Bitumen

This test is done to determine the ductility of distillation residue of cutback bitumen, the blown type bitumen and other bituminous products as per IS: 1208 – 1978. The principle is that the ductility of a bituminous material is measured by the distance in cm to which elongate before breaking when a standard briquette specimen of the material is pulled apart at a specified speed and a specified temperature.

Table 3 Ductility Value on Bitumen

Fibres	Addictive Percentage	Ductility Result
Normal Bitumen	0	61
Waste Plastic	1	58
	3	55
	5	53
	7	51
Polypropylene	1	57
	3	54
	5	52
	7	50

Discussion:

It may be seen that the ductility values for bitumen modified with 1%, 3%, 5%&7% modifiers are very low compared to original binders. The ductility values decrease with increase in percentage of modifier, the ductility value less than 50cm should not be used in road construction, but may be used as crack and joint filler materials.

g) Flash & fire point test on Bitumen

Table 4 Flash and Fire Point test

Fibres	Addictive percentage	Flash point Temperature In °C	Fire point Temperature In °C
Normal bitumen	0	168	175
Waste plastic	1	169	178
	3	172	182
	5	175	184
	7	177	187
Polypropylene	1	170	177
	3	173	180
	5	177	184
	7	180	187

h) Determining Softening Point of Bitumen

This test is done to determine the softening point of asphaltic bitumen and fluxed native asphalt, road tar, coal tar pitch and blown type bitumen as per IS: 1205 – 1978. The principle behind this test is that softening point is the temperature at which the substance attains a particular degree of softening under specified condition of the test.

Table 4.5 Softening point result

Fibres	Addictive percentage	Softening point
Normal bitumen	0	46
Waste plastic	1	48
	3	49
	5	51
	7	52
Polypropylene	1	48
	3	51
	5	53
	7	55

DISCUSSION:

The softening point increase in percentage of modifiers, the results show that bitumen modified with lower percentage of modifier can be used in road construction, but may be used as a roofing material.

i) Marshall Stability test on Bitumen

This test is done to determine the Marshall stability of bituminous mixture as per ASTM D 1559. The principle of this test is that Marshall Stability is the resistance to plastic flow of cylindrical specimens of a bituminous mixture loaded on the lateral surface. It is the load carrying capacity of the mix at 60^{o} C and is measured in kg.

Table 6 weight of aggregate used in Marshall Stability Test

Aggregate size	Weight of aggregate
25mm	20%-240g
20mm	15%-180g
12mm	18%-216g

6mm	45%-540g
Fines	2%-24g
Total Weight	4.5%-1200g

Table 7 Marshall Stability Properties for the Conventional specimen

S.No	Specification	Readings
1	Stability (KN)	7.416
2	Flow (mm)	3.18
3	Marshall Quotient	2.332
4	Air Void (%)	4
5	Bulk specific gravity	2.32
6	VMA (%)	18.865
7	VFB (%)	78.796

Table 8 Marshall Stability of Waste Plastic

S.No	Specifications	1%	3%	5%	7%
1.	Stability (KN)	8.717	11.18	13.12	13.7
2.	Flow (mm)	3.025	2.916	2.818	2.794
3.	Marshall Quotient	2.882	3.834	4.656	4.903
4.	Air Voids (%)	3.95	3.91	3.82	3.66
5.	Specific Gravity	2.326	2.33	2.336	2.346
6.	VMA (%)	18.65	18.51	18.30	17.95
7.	VFB (%)	78.826	78.882	79.132	79.616

Table 9 Marshall Stability of Polypropylene

S. No	Specifications	1%	3%	5%	7%
1.	Stability (KN)	8.252	10.213	12.843	11.25
2.	Flow (mm)	3.085	2.923	2.828	2.83
3.	Marshall Quotient	2.675	3.494	4.541	3.975
4.	Air Voids (%)	3.94	3.86	3.75	3.59
5.	Bulk Specific Gravity	2.328	2.338	2.346	2.355
6.	VMA (%)	18.585	18.235	17.955	17.641
7.	VFB (%)	78.800	78.832	79.115	79.646

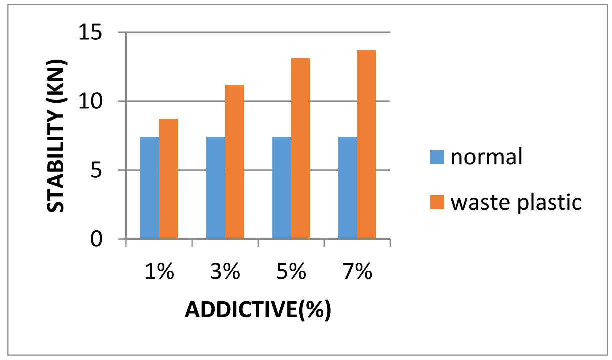

Fig. 2 Comparison between Conventional and Waste plastic in terms of stability

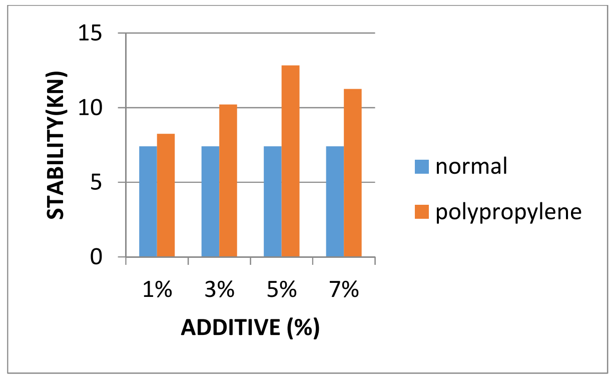

Fig. 3 Comparison between Conventional and Polypropylene in terms of stability

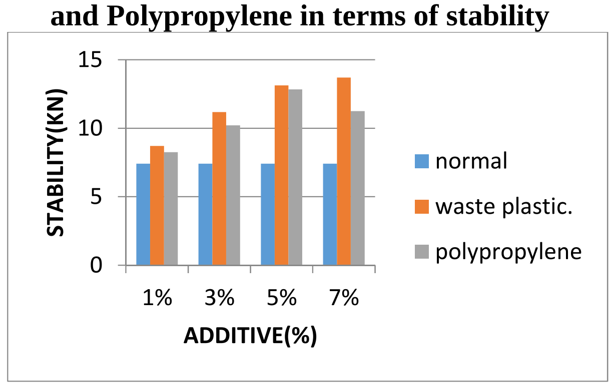

Fig. 4 Comparison between Conventional, Waste plastic and Polypropylene in terms of stability

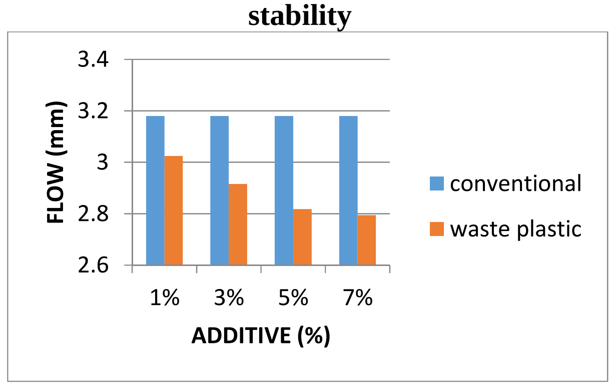

Fig. 5 Comparison between Conventional and Waste plastic in terms of flow

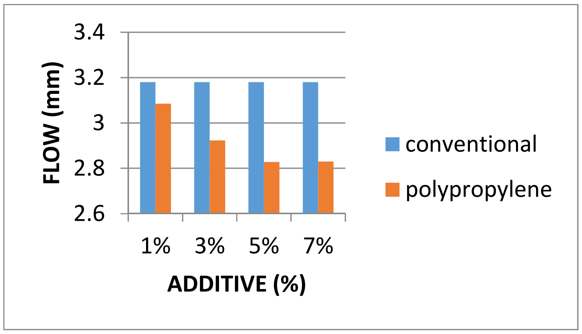

Fig. 6 Comparison between Conventional and Polypropylene in terms of Flow

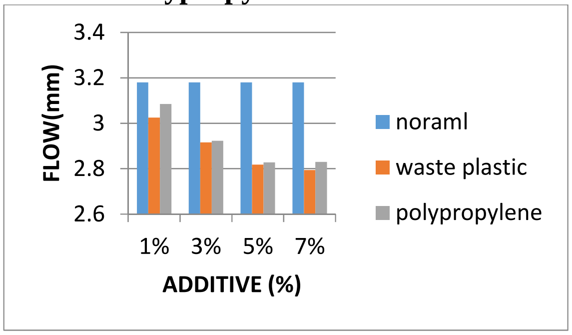

Fig. 7 Comparison between Conventional, Waste plastic and Polypropylene in terms of Flow

DISCUSSION

The figure indicates that as the additive content increases, the stability value increases initially, reaches a maximum and then decreases. The addition of 5% Polypropylene raises the Marshall stability of control mix by 73% and the percentage increase for 7% Waste plastic is 85%. This was attributed to the specific gravity of additive (less than 1) which is less than that of bitumen. This serves to penetrate between particles and enhanced the interlock of aggregates, which increases the stability and decreases the flow value. Beyond this percentage of additive content the stability value decreases. This is related to the decrease in interlocking offered by bitumen binder and additive coated aggregate particles while excess additive occupy the space to be occupied by the bitumen. Test results indicate that the mixtures with waste plastics have the higher stability (13.7 KN) than mixtures with polypropylene, indicating their higher rutting resistance.

Failure in bituminous mixtures can occur within the binder (cohesive failure) or at the aggregate-binder interface (adhesive failure). It can be considered that adhesive bond strength controls the failure mechanism in the Marshall Stability test. The presence of additives in the bituminous mixtures resulted in, increased adhesive bond strength which leads to increased stability values of the mixtures.

Flow value of Stone Matrix Asphalt mixtures decreases initially (up to 7% WP and 5% PP) and after that there is an increase as shown in Fig. 5.3. This may be due to the decrease in the stone to stone contact of Stone Matrix Asphalt mixtures at higher additive contents. However, flow values are located within the required specification range of 2 to 4mm (AASHTO T 245).

V. CONCLUSION

Plastics will increase the melting point of the bitumen. The use of the innovative technology not only strengthened the road construction but also increased the road life as well as will help to improve the environment and also creating a source of income. In this modification process plastics-waste is coated over aggregate In comparison with conventional mixture, the stability has been increased by adding 7% of Waste Plastic and 5% of polypropylene. The flow of mix got decreased by adding 7% of Waste Plastic and 5% of Polypropylene when compared to conventional mix. It is found that the Marshall Quotient almost doubled with respect to the control mixture at 5% Polypropylene content and 7% Waste Plastic content and is found that it is slightly higher with waste plastics additive. It can be inferred that these stabilized SMA provide better resistance against permanent deformations than the control mixture. The density of WP and PP is much less than that of aggregates and they will penetrate into the aggregates and a proper coating is formed over it. Owing to the filling property offered by these additives resulting in a less air void in the stabilized mixture as compared to the control mixture. It is hoped that in near future we will have strong, the process is eco-friendly.

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