Utilization of Waste Plastic as a Strength Modifier in Surface Course of Flexible and Rigid Pavements

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Abstract

The present study investigates the potential use of waste plastic as a modifier for asphalt concrete and cement concrete pavement. Plastic waste, consisting of carry bags, cups etc can be used as a coating over aggregate and this coated stone can be used for road construction. Different ratios of plastic such as Polypropylene (PP), Low Density Polyethylene (LDPE), and High Density Polyethylene (HDPE) by weight of asphalt were blended with 80/100 paving grade asphalt. Unmodified and modified asphalt binders were subjected to rheological test. The performance tests including, Marshall Stability, loss of stability tests were conducted using plastic coated aggregates and polymer modified bitumen on HMA mixtures. Work has been done by using plastic coated aggregates in cement concrete pavements. The results showed better values for asphalt concrete. This is an eco-friendly process.

Key Words - waste polymer, Hot Mix Asphalt (HMA), plastic coated aggregates, polymer modified bitumen, Marshall Stability, M20 plain cement concrete.

1. INTRODUCTION

One of the main components of hot mix asphalt (HMA) is asphalt cement binder. Asphalt is used primarily construction of roads and as a major component in roofing materials due to its remarkable binding and waterproofing properties. The behavior of asphalt cement in service is governed by their initial engineering properties as well as by the mechanical and environmental conditions to which they are subjected. The steady increase in high traffic intensity in terms of commercial vehicles, the increase in over loading of trucks and the significant variation in daily and seasonal temperature demand improved road characteristics. Under these situations, it is essential to modify the asphalt cement using modifiers to improve its engineering properties. On the other hand, the environmental problem such as disposal of waste plastic is major concern. To overcome the problems the modifiers (waste plastic) are used. Among various types of modifiers, polymers are probably the most promising.

Despite the large number of polymeric products, relatively few are suitable for modification of asphalt cement and are compatible with asphalt cement. Polymers used for asphalt modification can be grouped into three main categories: thermoplastic elastomers, plastomers, and reactive polymers. Thermoplastic elastomers are obviously able to confer good elastic properties on the modified binder; while plastomers and reactive polymers are added to improve rigidity and reduce deformations under load [1].The following are some of the examples of polymers.

- SBS (radial and linear) – good fatigue resistance, high creep rate, but oxidation susceptibility.
- PE – high thermal extension but low stiffness.
- SBR – very good aging and weather resistance but low tear strength, low ozone resistance, oxidation susceptibility.
- Polybutadiene (PB) – excellent wear resistance, impact resilience, but low strength.
- PP – good chemical resistance, good fatigue resistance but oxidative degradation, high mould shrinkage and thermal expansion was observed.

The vigorous tests at the laboratory level proved that the bituminous concrete mixes prepared using the treated bitumen binder fulfilled all the specified Marshall mix design criteria for surface course of road pavement. There was a substantial increase in Marshall Stability value of the BC mix, in the order of two to three times higher value in comparison with the untreated or ordinary bitumen. Polyethylene which belongs to plastomer gives rigidity to the binder and reduces the deformation under load. The affect of this is more profound when the concentration of polyethylene was kept below 1% by weight of the base bitumen.

However the present study investigates about the use of waste plastic as coating over aggregates and as a modifier in bitumen. The highlights of the study are

- To evaluate the properties of aggregates by coating plastic over it and by blending the plastic with bitumen in different ratios (LDPE, HDPE, PP) and comparing with unmodified materials.
- To evaluate the performance tests like Marshall Stability and loss of stability using polymer modified bitumen and plastic coated aggregates.
- To know the compressive strength of cubes using plastic as coated over aggregates.

2. MATERIALS & METHOD

2.1 Aggregate, Bitumen, polymer

Materials used in this study include 80/100 penetration grade. Bitumen is obtained from HPCL, Visakhapatnam. Aggregate used for the study was brought from a local Quarry near Rapaka, 10km away from Rajam (Andhra Pradesh). The physical properties of aggregate and bitumen are shown in Table 1 and 2.

TABLE 1
Physical Properties of Coarse Aggregates

Property	Test	Result	Specification Requirement
Specific Gravity	Specific Gravity	2.83	-
Water absorption	Water absorption	0.02	Max 2 %
Strength	Aggregate Impact value	23.7	Max 27 %
Strength	Crushing strength value	24.5	Max 30 %

TABLE 2
Physical Properties of Bitumen

Characteristics	Method of Test	Test Results	Requirements
Specific Gravity	IS 1202:1978	1.021	0.99 Min
Softening Point	IS 1205:1978	52	40 to 60
Penetration	IS 1203:1978	93	80 to 100
Ductility	IS 1208:1978	77	75 Min

The polymer used for modification supplied by Shyama Plastics (Vishakhapatnam), were low density polyethylene (LDPE), High density polyethylene (HDPE) and Polypropylene (PP). LDPE, PP and HDPE were in shredded form of size 2-3mm. The specifications of the polymer used were tabulated in Table 3.

TABLE 3
Specifications for Properties of Plastics

Type of plastic	Polypropylene	Low density polyethylene	High density polyethylene
Chemical unit	CH_2=$CHCH_3$	(–CH2–CH2–)n	(CH2=CH2) n
Density (g/cc)	0.910 - 0.928	0.91-0.94	0.945-0.962
Softening point	140-160	100-120	120-130
Solubility	Nil	Nil	Nil

2.2 Cement, Fine Aggregate, Water

Cement is the core material in concrete, which acts as a binding agent and imparts strength to the concrete. The cement used for this study is of grade 43 and the properties of cement used are given in Table 4.

TABLE 4
Properties of Cement

Property	Results
Specific gravity	3.15
Initial setting time	60min
Final setting time	450min

For plain and reinforced cement concrete (PCC and RCC) or prestressed concrete (PSC) works, fine aggregate shall consist of clean, hard, strong and durable pieces of crushed stone, or natural sand or a suitable combination of natural sand, crushed stone. All fine aggregates shall conform to IS: 383 and tests for conformity shall be carried out as per 1S: 2386, (Parts I to VIII). The properties of fine aggregates are presented in the Table 5.

TABLE 5
Properties of Sand

Property	Results
Zone	III
Bulking of sand	5%
Fineness modulus of sand	2.9

IS: 456-2000 covers requirement for water used for mixing and curing of concrete. Portable water is generally considered satisfactory for mixing concrete. Mixing and curing with salty water shall not be permitted.

2.3 Polymer-Aggregate Formulation (plastic coated aggregates)

First the waste polymer is selected and is shredded into pieces which passes through 4.75 and 2.36 mm and mixed with hot stone with uniform mixing. When heated to around 150°C to 170°C, they melt and in their molten state they spread over the stone as a thin liquid, which acts as a binder. Tests were conducted by using these plastic coated aggregates and results showed improved values
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2.4 Polymer-Asphalt Formulation (polymer modified bitumen)

The bitumen about 400 gm was heated in oven till fluid condition and polymer was slowly added, while the speed of the mixer was maintained at 120 rpm and temperature was kept between 160°C and

170°C. The concentration of PP, LDPE and HDPE used, were 0.5, 1.0, 1.5, 2.0, 2.5, 3 and 5% by weight of blend. Mixing was continued for 30 min to produce homogenous mixtures. Empirical test such as penetration, softening point and ductility were then conducted on the prepared samples.

2.5 Preparation Of Concrete Cubes

Coarse aggregates are heated to a temperature of 100-150^{o}C. The waste plastics obtained in the shredded form are added throughout the heated aggregates and mixed thoroughly. It is then cooled for two to three hours and it is mixed with cement, sand and water to prepare concrete mix as per IS 10262-2009. Now concrete cubes are casted which of dimension of 10x10x10cm.The specimens are kept for curing and tested for its compressive strength for different days(3,7,28 days) .

2.6 Optimization of the mixtures

Marshall Mix design procedure is normally used to optimize the HMA mixtures. In HMA mix design, usually the Marshall method of mix design is used to verify satisfactory voids in HMA mixtures. Laboratory specimens were prepared using seventy five blows of the Marshall hammer per side. The optimum asphalt content for HMA mixtures is usually selected to produce 3–5% air voids. The specimens were then removed from the mold and left to cure in air for 24 hrs.

The optimum asphalt content for the control HMA mixture was found to be 4% at 4% air voids.

The following steps were performed for the formulation of compacted specimens:

- The mixture of aggregates (unmodified and modified) and filler was heated to 160^{o}C in an electrically controlled oven.
- The binder (modified and unmodified) was heated up to 160^{o}C in an electrically controlled oven.
- The combination of aggregate (modified and unmodified), filler and binder (modified and unmodified) was mixed mechanically at a temperature of 165^{o}C for 1.5 min.
- The specimens formulated were then compacted at 145^{o}C using Marshall Apparatus.

3. LABORATORY EVALUATION

A series of tests were carried out on unmodified and modified materials that is aggregates and bitumen for different percentages of waste plastic (pp, LDPE, HDPE) as additive. The tests that were conducted include the following:

- Aggregate Tests such as aggregate impact, aggregate crushing, Los Angeles abrasion test, water absorption.
- Rheological tests, such as penetration, ductility and softening point.
- Performance tests such as Marshall Stability and loss of stability for different types of plastic by varying % of plastic.
- Compressive strength of concrete cubes by using plastic coated aggregates in cement concrete cubes.

4. RESULTS AND DISCUSSION

4.1 Engineering Properties Of Aggregate

The engineering properties of aggregates have been increased by the addition of plastic as a coating over aggregates by increasing the percentage of plastic and results were tabulated in Table 6. The results show that there is an increase in the properties of aggregates. There is an improvement in impact value, abrasion value and Los Angeles value. Fig 1, 2 and 3 shows the comparative graph between % of plastic and aggregate properties.

TABLE 6
Natural and Plastic Coated Aggregates (unmodified and modified)

Stone aggregates	% of plastic	Aggregate impact value (IS 2386 (part IV) - 1963) %			Los Angeles Abrasion Test (IS 2386 (part IV) - 1963) %			Aggregate Crushing Value (IS 2386 (part IV) - 1963)%		
Without plastic	0	23.7			22.24			24.5		
With plastic		PP	LDPE	HDPE	PP	LDPE	HDPE	PP	LDPE	HDPE
	1	19.5	17.9	18.2	18.56	16.68	20.44	23.4	20.19	21.56
	2	15.3	14.1	12.42	17.48	14	16.3	18.5	13.55	17.4
	3	10.2	9.7	8.45	16.4	12.2	11.42	15.6	11.74	13.28

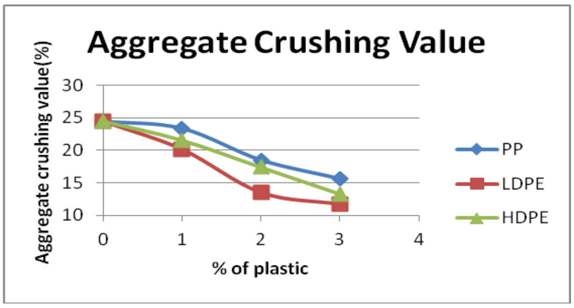

Figure 1 variation of crushing value with different % of plastic.

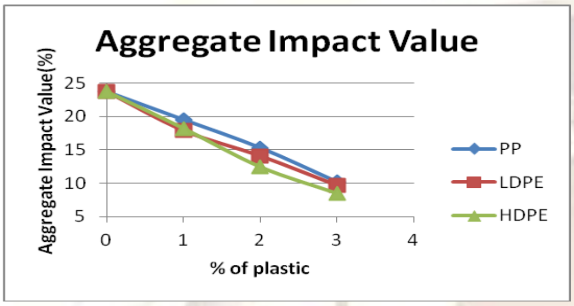

Figure 2 variation of impact value with different % of plastic

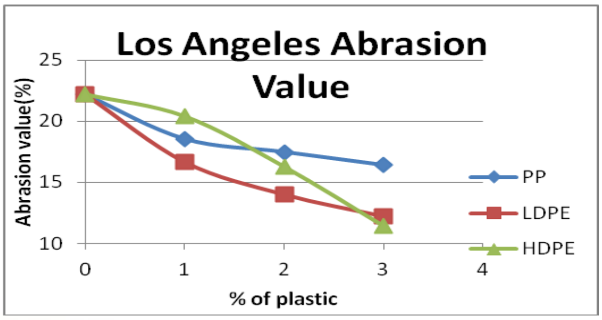

Figure 3 variation of abrasion value with different % of plastic

4.2 Rheological Tests

The rheological properties of waste plastic–asphalt binders were evaluated such as softening point, ductility, penetration test and the results are presented in Table 7. The results indicate that waste plastic is effective in improving the rheological properties of asphalt cement. Examining Table 7, it can be seen that there is an increase in softening point and decrease in penetration and ductility values. Figure 4, 5 shows the comparative graph between % of plastic and properties of bitumen.

TABLE 7
Tests Conducted on Natural and Modified Bitumen

% of plastic	Softening point(^{o}C) (IS: 1205 – 1978)			Penetration value (mm) (IS: 1203 - 1978)			Ductility (cm) (IS: 1208 – 1978)		
	PP	***LDPE***	***HDPE***	***PP***	***LDPE***	***HDPE***	***PP***	***LDPE***	***HDPE***
0	52.25	52.5	52.28	9.3	9.7	8.9	77	80	83
0.5	52.75	52.8	53	7.91	9.1	8.64	61	70.55	75.3
1	58.75	53.5	53	6.68	7.7	8.4	37	63.2	67.28
1.5	60.2	57.25	54.5	6.25	6.84	6.9	25	55.78	58
2	61.75	62.3	58	5.45	6.3	5.4	14.66	50.3	49.6
3	63.25	65	67.4	4.86	4.26	4.3	12	42.6	33
4	65.25	72.5	73	4.43	4.0	3.9	11.33	40	26.45
5	74.25	74	79	3.36	3.6	2.3	9.83	32.5	19

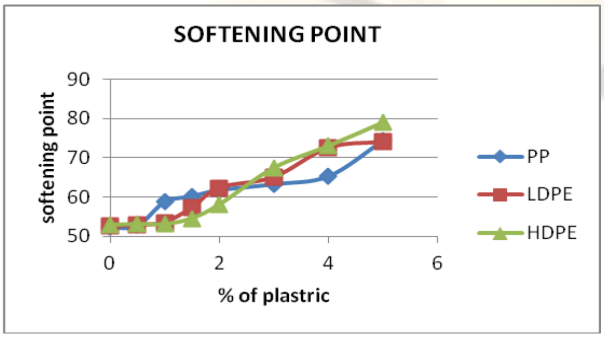

Figure 4 variation of softening point with different % of plastic

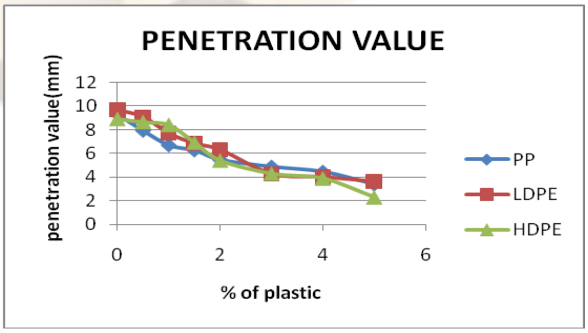

Figure 5 Variation of penetration value with different % of plastic

4.3 Engineering properties of HMA mixtures

4.3.1 Marshall Properties

The aggregate gradation used for preparing Marshall Mix design is shown in Table 8. Specimens of unmodified and modified mixtures were prepared for different percentages of plastic (PP, LDPE) and bitumen to determine the Marshall properties by using both plastic coated aggregates (PCA) and polymer modified bitumen (PMB). Specimens were placed in water bath at 60°C for 30 min and then loaded at a ratio of 50.8 mm/min and the stability and flow values were recorded. Marshall Stability test is conducted on both plastic coated aggregates and polymer modified bitumen. Marshall Test results were summarized in Table 9. From Fig. 6, it can be seen that the addition of waste plastic raises the Marshall Stability values. It can be said that these bituminous binders provide better resistance against permanent deformations due to their high stability. Based on stability values, it can also be seen that for plastic coated aggregates the optimum percentage of plastic is 8% and for polymer modified bitumen is 6% for PP type of plastic and from Fig. 7 it can be seen that 8% is optimum for LDPE type of plastic.

TABLE 8
Aggregate Gradation for Marshall Mix Design

Size of the aggregate	Cumulative % of passing, by weight of aggregates (by fuller and Thomson equation)
20	100
12.5	80.93
10	73.2
4.75	53
2.36	38.2
600	20.63
300	15.2
150	11.1
0.075	8.096

TABLE 9
Stability Values for % of Plastic

% of plastic	Plastic coated aggregate sample(PCA)		Polymer modified bitumen sample(PMB)	
	PP	LDPE	PP	LDPE
0	12	12	12	12
4	12.13	17.42	11.8	13.38
6	12.45	18.51	13.15	15.61
8	13.38	20.04	12.43	18.648
10	13.34	19.17	12.52	17.08

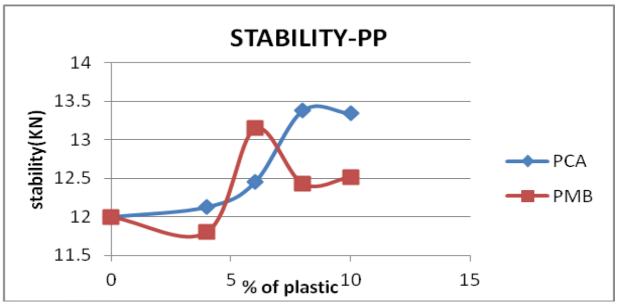

Figure 6 variation of stability with % of plastic (PP) for PCA and PMB

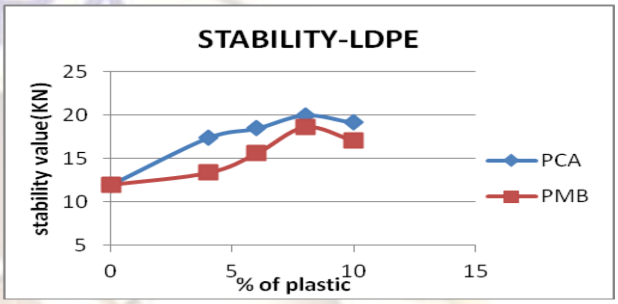

Figure 7 variation of stability with % of plastic (LDPE) for PCA and PMB

4.3.2 Loss of stability

This test is intended to measure the loss of Marshall Stability resulting from the action of water on compacted bituminous mixtures and is done according to ASTM D 1075-88. The result is a numerical index of reduced stability obtained by comparing the Marshall stability with the stability of specimens that have been immersed in water for a prescribed period. Marshall Specimen tests were prepared by using the optimum binder content for each test. Separate the set of specimens into two groups. One set of samples were tested using the Marshall method at a period of 30min (at 60°C). Immerse the other set in water (at 60°C) for 24 hours and then it is tested for retained strength. The results are computed as a ratio of soaked stability to unsoaked stability, and expressed it as a percentage as given in (1)

$$\text{Index or reduced stability} = (S_2/S_1) \times 100 \qquad (1)$$

Where,
$S1$ = average stability of unsoaked specimens
S2 = average stability of soaked specimens
Mixes with an index of less than 75 percent are rejected or an approved method of processing aggregate and treating asphalt is required to increase the index to a minimum of 75 percent. From fig 8, 9 it is observed that the retained stability index has been increased for both type of plastic used. Hence by using waste plastic retained stability has also increased.

TABLE 10
Loss of Stability Values for Different % of Plastic @ 60°c

Loss of stability(KN)								
	Plastic Coated Aggregates				Polymer Modified Bitumen			
	PP		LDPE		PP		LDPE	
% of plastic	30 min (s_1)	24hr (s_2)	30 min	24hr	30 min	24hr	30 min	24hr
0	16.3	12.8	16.3	12.8	16.3	12.8	16.3	12.8
4	16.8	13.6	17.5	13.7	15.4	12.3	15.7	12.7
6	18.05	14.9	18.9	14.5	16	13.2	16.9	14.0
8	19.8	16.4	21.0	16.3	14.5	11.7	18.4	15.4
10	17	13.9	20	16.6	13.4	10.5	16.5	13.4

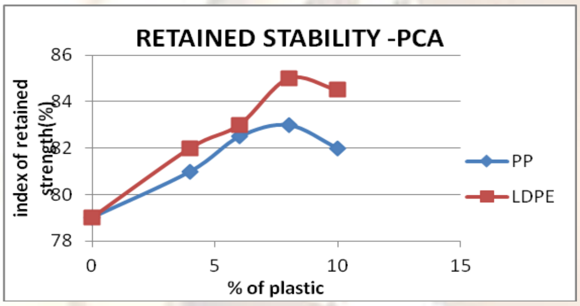

Figure 8 variation of index of retained strength with % of plastic for plastic coated aggregates

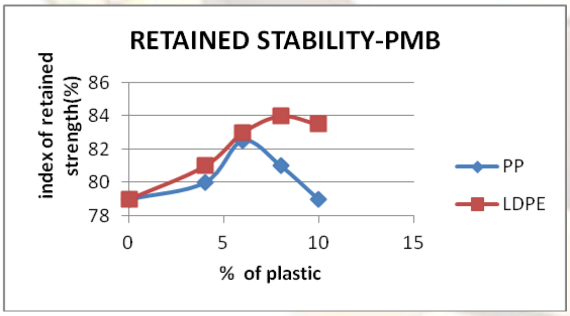

Figure 9 variation of index of retained strength with % of plastic for polymer modified bitumen samples.

4.4 Study On Concrete Cubes

The mix design is done according to 10262-2009.The plastic coated aggregates were mixed with the cement, sand and water. Cubes were casted and tested for compressive strength. The results are shown in figure 10.

From the figure 10, it is observed that there is a drastical change in the compressive strength when compared with plastic coated aggregates to plain cement concrete.This may happens due to weak bonding between the constituents of concrete.

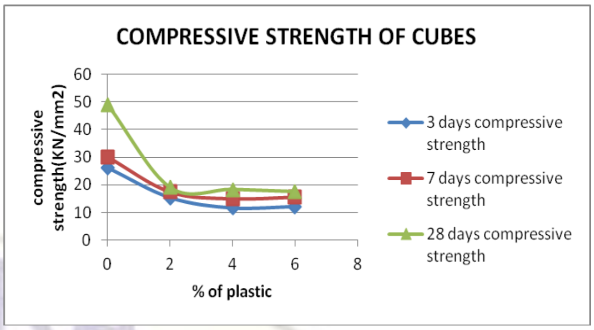

Figure 10 compressive strength of cubes for 3, 7, 28 days

5. CONCLUSIONS

From the preliminary studies of aggregates and bitumen, the following conclusions are drawn

1. By using plastic as a coating over aggregates, the properties of aggregates are improved. This shows hat weak aggregates can be used in construction by using plastic as a binder material.
2. By adding plastic to the unmodified bitumen, the rheological properties have been improved. There is an increase in the softening point and decrease in penetration and ductility values. The decrease in penetration value which indicates the hardness of the bitumen.

By conducting Marshall Stability the following conclusions can be drawn.

1. By increasing the percentage of plastic, the stability values are increased and required quantities of binder contents are decreased.
2. Based on the stability values, the optimum percentage of plastic is 8%, 6% for plastic coated aggregate samples and polymer modified bitumen samples respectively for PP type of plastic, and 8% is optimum for LDPE type of plastic for both plastic coated aggregate and polymer modified samples.
3. Based on stability values the plastic coated aggregate samples are more stable than polymer modified bitumen and can use be used in higher percentages of plastic.
4. The low density polythene type of plastic shows better performance values than polypropylene.
5. The performance values showed that there is better improvement in flexible pavement rather than rigid pavements. By conducting the loss of stability test, the results obtained is greater than 75% and this shows that these mixes can perform well in adverse situations.

By conducting compressive strength of cubes using plastic coated aggregates, there is no significant increase in the strength of cubes.

By using these plastic wastes for road construction, there is a possibility of reducing disposal of waste plastic which is harmful to the environment.

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