

Utilization of Waste Polymers for Flexible Pavement and Easy Disposal of Waste Polymers

R. Vasudevan¹⁺, R. Velkennedy², A. Ramalinga Chandra Sekar³, and B.Sundarakannan⁴

Abstract: Solid waste management is the thrust area. Of this various waste materials, plastic waste, and municipal solid waste are of great concern. Use of disposed plastics waste is the need of the hour. On the other side, the road traffic is increasing. The traffic intensity is increasing. The load bearing capacities of the road are to be increased. The studies on the improvement of road strength using polymer modified bitumen (PMB) for flexible pavement are being carried out by different schools. Virgin and recycled polymers are being used for these studies. But when higher percentage of plastics waste was used, the polymer got separated from the blend. Hence a new innovative technique was developed by the author and the heated stone aggregate was first coated with plastics generated from wastes like carry bags, films, foams, and multi layers and the plastics waste coated aggregate (PCA) was used as the raw material for flexible pavement. PCA is then mixed with 60/70 or 80/100 bitumen and the mix is used for road construction. PCA + Bitumen mix showed better binding property. It had less wetting property. Its voids were much less. The sample showed higher Marshall Stability value. By this process a road of 1km length and 3.75m width of single lane can consumes 10,00,000 carry bags and the road strength is increased by 100% and there is no pothole formation. The roads laid using PCA + Bitumen mixes are performing well. Performance studies were carried out for plastic road of different ages and reported in this paper.

Key words: Bitumen; Monitoring; Municipal solid waste; Plastic coated aggregate; Plastic tar road; Roads; Waste plastics.

Introduction

Plastic Waste Scenario

Plastics, a versatile material and a friend to common man, become a problem to the environment after its use. Most used materials are bags, films, cups, and foams, made up of polyethylene, polypropylene, or polystyrene. In addition to this, there are other molded plastics made out of poly ethylene terephthalate (PET) and poly vinyl chloride (PVC). Today, in India nearly 4 million tons of plastics are used and it is hoped to reach 12 million tons by 2010. Around 55% is used for packing. They are then mostly littered. They get mixed with municipal solid waste and make the disposal of municipal solid waste difficult. Hence the municipal solid waste is either incinerated or land filled. Both are not right techniques to dispose the waste and it will create both land and air pollution [1-3]. If the municipal solid waste contains PVC waste, when it burnt, can give rise to toxic gases like Dioxin [1]. Environmental consciousnesses and legislative restrictions have to stimulate various efforts for finding segregation (separation) of waste plastics and its use. Disposal of plastic wastes in an eco friendly way is the

thrust area of today's research. The authors' innovation [4] techniques to use the waste plastics for the construction of flexible pavement, for making pathway blocks, and for making laminated roofing sheets form a good solution for the waste disposal problem of both plastic waste and municipal solid waste. The authors have patented the process.

Waste Plastics in Road Construction

In the construction of flexible pavement, bitumen plays the role of binding the aggregate together by coating over the aggregate. It also helps to improve the strength of the road. But its resistance towards water is poor. Anti stripping agents are being used. Use of the anti stripping agent depends on the type of bitumen and the environment conditions. The cost factors also play an important role. Also traffic conditions such as heavier loads, high traffic volume and higher tire pressure demand higher performance pavements.

Methods to improve the quality of bitumen are by modifying the rheological properties of bitumen by blending with organic synthetic polymers like rubber and plastics. Polymer modified bitumen is emerging as one of the important construction materials for flexible pavement. Choice of polymers varies from virgin polymers to waste polymer. Studies are going both at national and international level and a review of about these works is presented below.

Literature Review

International Scenario

Bituminous mixes used in the surface course of the bituminous pavements are being improved in their performance by incorporating various types of additions to bitumen such as rubber latex, crumb rubber, polymers, recycled plastics etc. Additions of

¹ Dean and Professor, Department of Chemistry, Thiagarajar College of Engineering, Madurai-625015, Tamil Nadu, India.

² Assistant Professor, Department of Civil Engineering, Thiagarajar College of Engineering, Madurai-625015, Tamil Nadu, India.

³ Senior Research Fellow, Department of Chemistry, Thiagarajar College of Engineering, Madurai-625015, Tamil Nadu, India.

⁴ Project Associate, Department of Chemistry, Thiagarajar College of Engineering, Madurai- 625015, Tamil Nadu, India.

⁺ Corresponding Author: E-mail deaneca@tce.edu

Note: Submitted April 6, 2009; Revised June 22, 2009; Accepted August 12, 2009

Table 1. Thermal Behavior of Polymers.

Polymer	Solubility		Softening Temperature Range (°C)	Products Reported	Decomposition Temperature Range (°C)	Products Reported	Ignition Temperature Range (°C)	Products Reported
	Water	EPT*						
PE**	Nil	Nil	100-120	No Gas	270-350	CH ₄ , C ₂ H ₆	>700	CO, CO ₂
PP**	Nil	Nil	140-160	No Gas	270-300	C ₂ H ₆	>700	CO, CO ₂
PS**	Nil	Nil	110-140	No Gas	300-350	C ₆ H ₆	>700	CO, CO ₂

* EPT: 5% Acetic Acid.

**PE: Poly Ethylene; PP: Poly Propylene; PS: Poly Styrene.

polymers like styrene butadiene styrene, styrene –ethylene – butylenes styrene were found to increase the quality of bitumen. Shuler et al. [5] carried out investigations on indirect tensile test using AC-5 and styrene butadiene styrene (SBS) polymer system as one of the modifiers SBS modified AC-5 exhibited superior fatigue properties. Use of recycled polypropylene and low density polyethylene as modifiers for plain bitumen resulted in increased durability and improved fatigue life [6]. Denning and Carswell [7] reported that asphalt concrete with polyethylene modifier is more resistant to rutting during elevated temperature. The use of ethylene vinyl acetate (EVA) as a binder additive produced highest fatigue life improvement [8]. The resistance to deformation of asphalt concrete modified with 5% low density polyethylene is significantly better than that of unmodified mix [9]. There is improvement in the temperature susceptibility of the mixes by adding 5% recycled polyolefin [10]. The use of styrene–butadiene elastomers decreased the penetration value. Polyethylene increased softening point and viscosity [11].

Indian Scenario

Similar works are in progress at India too. Uses of low density polyethylene (LDPE), EVA copolymer, and SBS as bitumen modifier have been studied [12]. Use of 2% poly ethylene (PE) to asphalt resulted in increasing the fatigue life by 10 times [13]. It is also reported that reclaimed PE material can be easily blended with bitumen by stirring the mix using a 1/8HP high speed stirrer rotating at 300rpm jar for about 20mins [14]. By increasing the bitumen temperature the concentration of polymer in bitumen was increased. Recent work [15] on the use of waste plastics by blending with bitumen has also been reported. The major obstacle to widespread usage of polymer modified bitumen in paving practice has been their tendency towards gross phase separation under quiescent conditions [16].

A new innovative method referred as Dry Process, has been developed by the authors by coating plastics over the stone aggregate and subsequently mixing with bitumen and this mix is being used for road construction. Various plastics and their uses as coating materials for this process are being examined. This polymer coated aggregate bitumen mix shows better properties. The authors of this paper have presented a paper at 169th Indian Road Congress Meeting [17] and also published this work [4].

Central Pollution Control Board, New Delhi, India has already published two Program Objective Series; the first, on the indicative operational guidelines on construction of polymer bitumen road [18] and the second, on the performance evaluation of polymer coated bitumen built roads [19].

This paper will represent the authors' innovative work with all experimental details, results, and discussion.

Characterization of Waste Plastics

Thermal Study

A study of the thermal behavior of the polymers namely polyethylene, polypropylene, and polystyrene shows that these polymers get softened easily without any evolution of gas around 130-140°C. This has been verified by carrying all experiments using differential thermal analysis (DTA) and thermo gravimetric analysis (TGA). This is also in agreement with the observation made by others [1]. Around 350°C they get decomposed releasing gases like methane, ethane etc. and above 700°C the undergo combustion, producing gases like CO and CO₂ (Table 1).

Binding Property

Experimental Test

The stone aggregate used for road construction was heated to around 170°C. The waste plastics is shredded using shredding machine and collected, and the shredded waste plastic (passing 4.35mm sieve and retaining 2.36mm sieve) was sprayed over the hot aggregate. Plastics got softened and coated over the aggregate. The aggregate-plastics mix was compacted and cooled. The block showed compression strength not less than 130kN/m² and binding strength of 500kg (using universal testing machine). This shows that the binding strength of the polymer is good. Similar observation was made with respect to other raw materials like ceramics, slag waste, etc., The increase in the values of the compression strength and bending strength show that the plastics can be used as a binder.

Characteristics of Plastic Coated Aggregate (Used for Flexible Pavement)

For the flexible pavement, stone aggregate with specific characteristics is used for road laying. The aggregate is chosen on the basis of its strength, porosity, and moisture absorption capacity. The aggregate, when coated with plastics improved its quality with respect to voids, moisture absorption, soundness, and other properties [4].

Moisture Absorption and Void Measurement

A known quantity of aggregate was taken, dried at 110°C and cooled.

Table 2. Aggregate Qualities.

Stone Aggregate	% of Plastic with Respect to Total Weight	Moisture Absorption, %	Soundness	AIV*	ACT*	LAR*	Voids %
Without Plastic Coating	0	4	5+/- 1 %	25.40	26	37	4.0
With Plastic Coating	1	2	Nil	21.20	21	32	2.2
With Plastic Coating	2	1.1	Nil	18.50	20	29	1.0
With Plastic Coating	3	Traces	Nil	17.00	18	26	Nil

* AIV: Aggregate Impact Value; ACT: Aggregate Crushing Test; LAR: Los Angle's Abrasion Value.

Table 3. Extraction Characteristics of Polymer Coated Aggregate Bitumen Mix.

Percentage of Plastics Added with Respect to Total Weight	Bitumen Removed (%)		
	after 5mins	after 10mins	after 15mins
0	96.0	98.0	99.0
0.50	63.5	88.7	92.3
0.75	63.2	86.7	90.7
1.00	61.3	76.7	83.6

The weight of the aggregate was determined. It was then immersed in water for 24hrs. Then the aggregate was dried using dry clothes and the weight was determined. The water observed by the aggregate was determined from the weight difference.

The coating of plastics fills the voids [6] and decreases the porosity. With less voids, the absorption of moisture is also reduced this helps to improve the quality of the aggregate and its performance in the flexible pavement, as shown in Table 2.

Durability Property Using Soundness Test: Indian Standards (IS) 2386-part V 1963

Soundness test is intended to study the resistance of aggregates to the action of weather; this is evaluated by conducting accelerated weathering test cycle. The resistance to disintegration of aggregate is determined by immersing known quantity of aggregate in saturated solution of sodium sulphate or magnesium sulphate for a known period.

The average loss in weight of aggregate for 5 cycles should not exceed 12% when tested with sodium sulphate, and 18% when tested with magnesium sulphate respectively.

The weight loss is attributed to the poor quality of the aggregate. The plastic coated aggregate, did not show any weight loss, thus conforming the improvement in the quality of the aggregate (Table 2).

Porosity: IS 2386 (Part 3)-1963

The porosity of the aggregate should be less than 2%. If pores are present, the air accumulated in the pores, oxidizes the bitumen and the bitumen loses its viscoelastic property. The material becomes hard. By coating plastics, the pores are very much reduced. This is evidenced by the reduction in the moisture absorption with the increase in plastic percentage coated (Table 2).

Toughness Property Using Aggregate Impact Test: IS 2386 Part 4

It is used to evaluate the toughness of stone or the resistance of the

aggregate to fracture under repeated impacts. The aggregate is subjected to 15blows with a hammer of weight 14kg and the crushed aggregate are sieved on 2.26mm sieve. The material collected is referred as fine. The aggregate impact value is the percentage of fine (passing through 2.36mm sieve size) to the total weight of the sample. The aggregate impact value should not exceed 30% for use in wearing course of pavements. Maximum permissible value is 35% for bituminous macadam and 40% water bound macadam. It is observed that the coating of plastics decreases the AIV, thus improves AIV (Table 2), and also improving the quality of the aggregate. Increase in the thickness of polymer layer improves the quality further. Moreover a poor quality of aggregate can be made useful by coating with polymers. This, in turn helps to improve the quality of flexible pavement. The polymer layer formed over the aggregate improves the toughness of the aggregate.

Hardness Property Using Los Angeles Abrasion Test: IS 2386 Part 4

The principle of Los Angeles abrasion (LAR) test is to find the percentage wear due to relative rubbing action between the aggregate and the steel balls used as abrasive

LAR value should be less than 30 percent for pavements. From the results (Table 2),obtained it is inferred that the abrasion resistance increases linearly with addition of polymers. The linear increase for addition of 2% of polymer is about 20%. The coating of polymers over the aggregate forms a protective coating over the aggregate, there by preventing the aggregate from the abrasive action from the wheels.

Characteristics of Polymer Coated Aggregate Bitumen Mix

The plastic coated aggregate is mixed with bitumen of 80/100 kept at 160°C. The bitumen polymer coated aggregate mix was subjected to testing like Stripping test, Bitumen extraction test, and Marshall Value determination test.

Stripping Test: IS 6241-1971

The waste plastic coated aggregate is mixed with bitumen and the mix was immersed in water. Even after 96hrs. There was no stripping. This shows that the waste plastic coated aggregate - bitumen mix has good resistance towards water. Moreover, during water stagnation, the pores accelerate the stripping of bitumen resulting in pothole formation. By coating the plastics, the pores are reduced. Hence, the quality of the aggregate is improved and there was no stripping of bitumen.

Table 4. Effect of Variation of Bitumen/Plastic Content on Marshall Stability Value.

Percentage of Bitumen	Percentage of Plastic with Respect to Total Weight	Type of Plastic	PCA*	MV (Kg)	FV* ($\times 0.25mm$)	Void Percentage (VFB)	MQ* (Kg/mm)
4.5	0.25	PP	PCA	1,600	4	53	400
4.5	0.50	PP	PCA	2,000	5	55	400
4.5	0.25	LDPE	PCA	1,600	4	55	400
4.5	0.50	LDPE	PCA	1,750	4	55	438
4.5	0.50	PE Foam	PCA	2,000	4	58	500
4.5	0.75	PE Foam	PCA	2,250	4	56	563
4.5	1.00	PE Foam	PCA	2,650	4	56	662

*PCA: Polymer Coated Aggregate; FV: Flow Value; MQ: Marshall Quotient.

Table 5. Comparative Study on MV for PCA and Polymer Modified Bitumen (PMB).

Percentage of Bitumen	Percentage of Plastic with Respect to Total Weight	Type of Plastic	PCA/PMB	MV (Kg)	FV ($\times 0.25mm$)	Void Percentage	MQ Kg/mm
4.5	0.5	PP	PCA	2,000	5	55	400
4.5	0.5	PE Foam	PCA	2,000	4	58	500
4.5	0.5	LDPE	PCA	1,750	4	55	438
4.5	0.5	PP	PMB	1,700	3.3	62	515
4.5	0.5	PE Foam	PMB	1,800	3.4	66	529
4.5	0.5	LDPE	PMB	1,700	3.5	62	486

This may be due to

- (1) polymer coated over aggregate prevents wetting of the aggregate, and
- (2) bitumen also binds well with aggregate through the plastics layer.

Bitumen Extraction Test: American Society for testing and Materials (ASTM) D2172 and British Standards (BS)-598-Part 102-1989

The polymer coated aggregate bitumen mix was also submitted to bitumen extraction using benzene. The results are tabulated (Table 3). The results show that the removal of bitumen is slow in the case of plastics waste-coated aggregate compared to plain bitumen coated aggregate. This may help to conclude that a portion of the bitumen was held by the polymer whose release was difficult. When the residue was treated with decaline, an organic solvent, both polymer and bitumen were removed. This shows that there is an inter mixing surface layer of polymer and bitumen at the surface which gives strength and improvement in the bonding. The bonding strength of bitumen with the polymer coated aggregate has increased due to polymer bitumen interaction at the surface.

Marshall Stability Value Determination: ASTM D 1559 – 1979 and Indian Road Congress (IRC):SP:53

Marshall stability value (MV) is a measure of strength of the road. Marshall stability values for different mixes having different percentage of plastics and having different types of plastics were determined, as per IS coding, as shown in Tables 4 and 5.

The results show that plastic coated aggregate bitumen mix has high load withstanding strength.

Marshall stability values were calculated with different percentage of polymer and by varying the polymer nature. This shows that stability value increases with increase in the percentage

of plastics and a maximum of 15% by weight of bitumen can be used. Moreover the percentage of bitumen needed is reduced to the extent of amount of plastic added, thus helping lesser consumption of bitumen.

It is also observed that the polymer modified bitumen mix has a lower Marshall Stability value when compared to Polymer coated aggregate bitumen mix (Table 4). It is also inferred that the increasing in Marshall stability value is in the order of LDPE < PP < PE foams.

Dry Process

The authors' innovative process is named as Dry process and this name is used wherever our process is referred.

Plastic tar road can be laid either by Mini hot mix plant or by Central mix plant (Continuous Process). The processes are being discussed below.

Mini Hot Mix Plant

Mini hot mix plant is a small scale mix plant used for laying roads of small distance. The process of plastic tar road laying using a mini hot mix plant is discussed below.

● Step I:

Plastics waste (bags, cups , thermocole) made out of PE, PP, and PS cut into a size between 2.36 and 4.75mm using shredding machine, (PVC waste should be eliminated) and used for road construction.

● Step II a:

The stone aggregate mix is heated to 170°C (as per the IRC specification) and transferred to mixing chamber.

● Step II b:

Simultaneously, the bitumen is heated to 160°C and kept ready for mixing (Highways Research Station (HRS) Specification/to have good binding and to prevent weak bonding/ Monitoring the

temperature is very important.)

● Step III:

At the mixing chamber, the shredded plastics waste is to be sprayed to the hot aggregate. It gets melted and coated uniformly over the aggregate surface within 30 seconds, giving an oily look. Plastics coated aggregate is obtained.

● Step IV:

Hot bitumen is then added over the plastic coated aggregate and the resulting mix is used for road construction. The road laying temperature is between 110 and 120°C. The roller used is 8-ton capacity

Central Mixing Plant (CMP)

The plastic road laying process can also be carried out using central mixing plant. This process is a continuous process for laying long distance roads in a less time span.

The aggregate are transferred from the hopper through a conveyer belt with the cylinder where it is heated and mixed with bitumen.

The shredded plastics are sprayed over the cold aggregate uniformly while it is transferred through the conveyor belt. The addition is done quantitatively. This is transferred into the hot cylinder. Inside the cylinder, the stone is heated along with the plastic, which is melted around 160°C. The stone is first coated with plastics and PCA moves further to get mixed with the bitumen. The mixer, so prepared, is then loaded in the dipper lorry and transported for road laying. CMP helps to have better control of temperature and better mixing of this material thus helping to have a uniform coating.

Discussion of Results

The coating of molten plastics over the surface of the aggregate reduced water absorption as seen in Table 2. This shows that the voids at the surface were reduced. Generally voids should be less than 2%. Lesser the voids better the quality of the aggregate. Otherwise, the air entrapped in the voids would cause oxidation of bitumen resulting in stripping, pothole formation, etc. Moreover, the presence of water in the voids is detrimental to adhesion between aggregate and the binder namely bitumen. Hence the aggregate with lesser voids is considered to be good for better road construction. The coating improves soundness; the coating of plastics also improves the quality of aggregate (1) by decreasing aggregate impact value, (2) by decreasing aggregate crushing value and (3) abrasion value. These observations help to conclude that plastics waste coated aggregate can be considered as more suitable material for flexible pavement construction.

In our process the aggregate is coated with plastics and then blended with bitumen. The PCA is not only easy to prepare but also helps to use higher percentage of plastics waste for coating without much of difficulty. The results, as seen in Tables 4 and 5, also show that the Marshall Stability values are higher and there is no stripping. This shows that the mix is much better for flexible pavement. Here the mixing of bitumen with plastics waste was taking place at the surface of the aggregate and at a temperature around 160°C. At this temperature both the plastics and bitumen are in the liquid state,

capable of easy diffusion. This process is further helped by the increase in the contact area (increased surface area). Both polymer and bitumen are similar in chemical nature. These factors would help to have better adhesion and better binding. Moreover the polymer molecule interact with the constituents of bitumen namely asphaltene and other similar compounds and results in a three dimensional internal cross-linked net work. The cross-linking results in strong and elastic structure. This will also add its suitability as a blend for flexible pavement. The Marshall Stability values are fairly high. The Marshall Quotient is around 500. Flow value is in the expected range. Voids filled with bitumen (VFB) percentage are expected around 65. But because of (1) The reduction in the percentage of bitumen used (90%) and (2) The reduction in voids by coating of plastics at the surface, there observed a decrease in the VFB values (Table 4).

The data (Tables 4 and 5) also suggest that with the use of plastics waste coated aggregate, the quantity of bitumen needed for a good mix can be reduced to the extent of 0.5% of the total weight which accounts for 10% reduction in the use of bitumen. This saving goes to extent of several hundred cores and it is a great national savings.

The results of the studies on the extraction of bitumen (Table 3) from Dry process showed that the bonding in Dry process is stronger. This may be explained by the following structural models. Using these models the extraction pattern is explained.

A structural model for the Plastics waste coated aggregate bitumen mix is shown in Fig. 1.

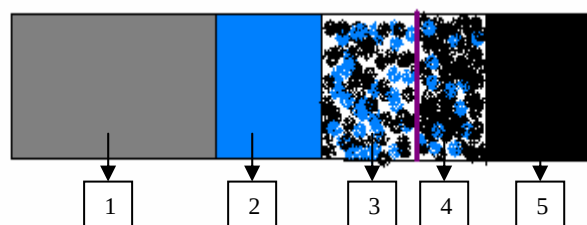


Fig. 1. Structural Model for the Plastics Waste Coated Aggregate Bitumen Mix.

where

1. Aggregate,
2. Area of Plastics bonded with aggregate (polymer coating),
3. Area of Bitumen-plastics blend (due to diffusion between molten plastics and hot bitumen),
4. Area of Loosely bonded bitumen with dispersed plastics, and
5. Area of Plain bitumen layer.

From the experiment results it may be concluded that the order of extraction of bitumen from the plastics waste coated aggregate (Dry process) is as follows.

Loosely bonded bitumen (5) < Bitumen bonded with plastics (4) < Bitumen Plastics blend (3) < Plastics bonded with aggregate (2)

Benzene first extracted the loosely bonded bitumen. Then bitumen bonded/blended with plastics was removed. After a prolonged refluxing with decaline, the bitumen diffused with plastics got extracted. The polymer, bonded with aggregate was not extracted by benzene.

Coating of plastics waste over aggregate gives better strength than blending of the plastics waste with bitumen.

Table 6. Surface Condition Survey.

Site Name	Surface Condition Survey	Photo
Jumbulingam road, Chennai (2002) Photo Date: 21-02-2008	1. No Pothole 2. No Cracking 3. No Deformation 4. No Edge Flaw	
Veerabadhra Street, Erode(2003) Photo Date: 04-01-2008	1. No Pothole 2. No Cracking 3. No Deformation 4. No Edge Flaw	
Vandiyur Main road (2004) Photo Date: 10-02-2008	1. No Pothole 2. No Cracking 3. No Deformation 4. No Edge Flaw	
Vilachery Main road (2005) Photo Date: 11-02-2008	1. No Pothole 2. No Cracking 3. No Deformation 4. No Edge Flaw	
Canteen road (2006) Photo Date: 01-03-2008	1. No Pothole 2. No Cracking 3. No Deformation 4. No Edge Flaw	

Table 7. Summary of Results.

Road	Year laid	Unevenness (mm/km)	Skid number	Texture Depth (mm)	Field Density (kg/m^3)	Rebound Deflection (mm)
Jambulingam Street	2002	2,700	41	0.63	2.55	0.85
Veerabadhra Street	2003	3,785	45	0.70	2.62	0.60
Vandiyur Road	2004	3,005	41	0.66	2.75	0.84
Vilachery Road, Mai	2005	3,891	45	0.50	2.89	0.86
Canteen Road, TCE	2006	3,100	45	0.65	2.86	0.86
Plain Bitumen Road*	2002	5,200	76	0.83	2.33	1.55
Tolerance Value**	-----	4,000	<65	0.6-0.8	2.86	0.5-1

*Reference road constructed with plain bitumen

**Theoretical value for the effective performance of a good road.

Table 8. Materials Used in the Comparative Study.

Material	Plain Bitumen Process	Plastic-Tar Road
60/70 Bitumen	30kg	27kg
Plastic Waste	-	3kg

Note that Dry process is definitely a better process due to the following added test results. In addition to that, leaching test was also carried out

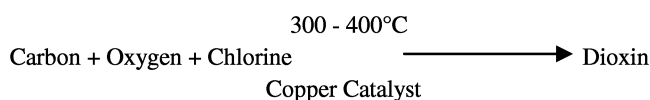
● Leaching test

Polymers are not soluble in water or acids and even in most of the organic solvents. The polymer waste is tested with 5% acetic acid solution and it is observed that there is no dissolution of polymer. Therefore it may be concluded that polymer will not leach out after laying the road using plastics waste coated aggregate bitumen mix.

● Dioxin formation

The fear about the formation of Dioxin, the toxic compound, during the heating of polymers is always in the mind of the people.

Dioxin may be formed under the following condition.



Presence of chlorine, copper, and appropriate temperature are needed to form the Dioxin.

In the process of the preparation of plastics waste coated aggregate bitumen mix, the maximum temperature used is only approximately 170°C and no chlorine or copper is present in the system, as the polymer materials used are polyethylene, polypropylene, and polystyrene only. Polyvinyl chloride is not used. Hence, there is no possibility of presence of chlorine in the system. Hence Dioxin does not form during the use of plastics waste for road construction. So it is a safe disposal of plastics waste.

Field Study

More than 2,000km length of Plastic tar road was laid in India at different States like Tamil Nadu, Kerela, Andhra Pradesh, Maharashtra, and Pondicherry from 2002 to till date by various authorities like Department of Rural Development Agency (DRDA), Tamil Nadu, High Ways, Tamil Nadu, National Transport Planning and Research Centre, Kerela, Public works Department of Pondicherry, Private sectors, etc., These roads are functioning well without pothole, raveling, and rutting. The process requires only 30 seconds extra for mixing 10% of plastics. The waste plastic available in the nearby area can be used. (In Situ Process)

Testing of Roads

As per our discussion above, the load withstanding capacity of the plastic tar road is increased by a large amount. This is proved by conducting various tests on the built plastic tar roads at different places at different times. This test has been carried out with the guidance of National Transport Planning and Research Centre, Trivandrum, Kerela, India. The tests show very good results. The tests carried out are to measure.

1. the roughness (unevenness) of the pavement surface, IRC: SP: 16: 2004,
2. the resistance offered by the pavement surface against skidding (Skid Number) of vehicles, BS: 812 – 1967,
3. the pavement macro texture (texture depth), BS: 598 - Part 105 - 1990 for the geometrical deposition,
4. the structural evaluation of flexible pavement (rebound deflection), IRC 81 – 1997 for the strength of the pavement, and
5. the field density of the road and
6. to physical examine the condition of the road like cracks, raveling, potholes, rutting, and corrugation edge break (Table 6).

Six sites were chosen (Table 6). Sites 1 to 5 are referring the performance of plastic road and the site 6 is referring the performance of reference plain bitumen road. The above tests were conducted as per the specification and the values were compared with standard values which are given in the Table 7 as tolerance value. The tests were conducted periodically from May 2007 to May 2008. The average results are tabulated (Table 7).

It is observed from the results that the plastic roads laid since 2002 to 2006 are showing results which are the characteristics of a good road. For example roads laid in 2002 and 2003 are showing better results compared to the plain bitumen road which shows higher value than the tolerance value. Hence it can be concluded that the plastic tar road are performing much better than the plain bitumen road.

In addition to this the physical surface condition survey of the plastic tar road (procedure adopted by Central Road Research Institute, New Delhi) shows that there is no pothole formation, cracking, deformation, rutting, raveling, and edge flaw. The photos of these roads taken recently are also attached for having a visual exhibition. Hence it can be concluded that the plastic tar roads are having good skid resistance values, good texture values, good surface evenness, reasonably good strength, and field density with least change.

Economy of the Process and the Plastic Waste Available

Comparative Study for 25mm Thickness SDBC-10m²

Three kilogram of bitumen is saved and three kilogram of waste plastics is used, as indicated in Table 8. The cost of bitumen is much higher than that of plastics and this process also helps to save the natural resources. There is no maintenance cost for a minimum period of five years. Hence the process is cheap and eco friendly. A comparative study for 25mm thickness SDBC-10mm² is shown below:

- Cost reduction for 1km × 3.75mm = Approximate Rupees (Rs) 30,000,
- Savings of bitumen = 1ton,
- Use of plastics waste - (1,000,000) carry bags (1ton),
- Bitumen needed - 10,125kg, and
- Plastics waste - 1,125kg.

Conclusions

As per our process (Dry process) plastics waste is coated over aggregate. This helps to have better binding of bitumen with the plastics waste-coated aggregate due to increased bonding and increased area of contact between polymer and bitumen. The polymer coating also reduces the voids; this prevents the moisture absorption and oxidation of bitumen by entrapped air. This has resulted in reduced rutting and raveling and there is no pothole formation. The roads can withstand heavy traffic and show better durability. In a net shell the Dry Process thus helps to

1. use higher percentage of plastics waste,
2. reduce the need of bitumen by around 10%,
3. increase the strength and performance of the road,
4. avoid the use of anti stripping agents,
5. reduce the cost to around Rs. 20000/km of single lane road as on date,
6. carry the process in situ,
7. avoid industrial involvement,
8. avoid disposal of plastics waste by incineration and land filling,
9. generate jobs for rag pickers,
10. add value to plastics waste, and
11. develop a technology, which is eco-friendly.

Our studies on the performance of plastic tar road conclusively proves that it is good for heavy traffic due to better binding, increased strength, and better surface condition for a prolonged period of exposure to variation in climatic changes.

References

1. Mustafa, N., (1993). *Plastics Waste Management*, Canadian Plastics Institute, Toronto, Ontario, Canada, Marcel Dekker, Inc.
2. Central Pollution Control Board, (2003). *A Support Manual for Municipal Solid Wastes*, Central Pollution Control Board, New Delhi, India.
3. Garg, S.K., (1999). *Environmental Engineering*, Vol. II, Khanna Publishers, New Delhi, India.
4. Vasudevan, R. and Rajasekaran, S., and Saravanavel, S., (2006). Reuse of Waste plastics for Road Laying, *Indian Highways, Indian Roads Congress*, 34(7), pp. 5-20.
5. Shuler, T.S., Collins, J.H., and Kirkpatrick, J.P., (1987). Polymer Modified Asphalt Properties Related to Asphalt Concrete Performance, Asphalt Rheology Relationship to Mixture, *ASTM STP:941*, ASTM, Philadelphia, PA, USA.
6. Zoorab, S.E. and Suparna, L.B., (2000). Laboratory Design and Performance of Improved Bituminous Composites Utilizing Recycled Plastics Packaging Waste. Presented at *Technology Watch and Innovation in the Construction Industry*, pp. 203-209, Palais Descongres, Brussels, Belgium.
7. Denning, J.H. and Carswell, J., (1981). Improvements in Rolled Asphalt Surfacing by the Addition of Organic Polymers, Department of the Environment and Department of Transport, *Report LR 989*, Transportation Road Research Laboratory (TRRL), Crow Throne, United Kingdom.
8. Salter, R.J. and Rafati-Afshar, F., (1987). Effect of Additives on Bituminous Highway Pavement Materials Evaluated by the Indirect Tensile Test, *Transportation Research Record* No, 1115, pp. 183-195.
9. Dallas, N.L., (1986). AN Additive of Asphalt Additives to Reduce Permanent Deformation and Cracking in Asphalt Pavements: A Brief Synopsis of on Going Research, *Proceedings of the Association of Asphalt Paving Technologists(AAPT)*, Vol. 55, pp. 314-320.
10. Tappeinier, W.J., (1999). *Performance and Economical Advantage of Polymer Modified Asphalt*, Richard Felisinger, Vienna, Austria.
11. King, G.N., Muncy, H.W., and Prudhome, J.B., (1986). Polymer Modification: Binder's Effect on Mix Properties, *Proceedings of the Association of Asphalt Paving Technologists(AAPT)*, Vol. 55, 1986 pp 519-540.
12. Bose, S. and Jain, P.K., (1989). Laboratory Studies on the Use of Organic Polymers in Improvement of Bituminous Road Surfacing, *Highway Research Bulletin 38, Indian Road Congress*, New Delhi, India.
13. Bose, S., Jain, P.K., Sangita and Arya, I.R., (1992). Characterization of Polymer Modified Asphalt Binders for Roads and Air Field Surfacing, *Polymer Modified Asphalt Binders, ASTM STP:1108*, pp. 331-335, ASTM, Philadelphia, PA, USA.
14. Panda, M. and Muzumdar, M., (1997). Development and Evaluation of a Bituminous Paving Binder Containing Reclaimed Polyethylene, *Indian Highways, Indian Roads Congress*, Vol. 25(5).
15. Punith, V.S. and Veeraragavan, A., (2004). Fatigue Characteristics of Recycled Plastics Modified Bituminous Concrete Mixes, *Highways Research Bulletin 70, Indian Road Congress*, New Delhi, India.
16. Oscar González Uranga, (2000). *Rheological Properties of Bitumen Modified with Polyethylene and Polyethylene Based Blends*, Department de cynical Technologic de Polymers. Faulted de Química, Universidad del País Vasco. Spain.
17. Vasudevan, R., Rajasekaran, S., and Saravanavel, S., (2003). Utilization of Plastics Waste in Construction of Flexible Pavement, *Proceeding of the National Seminar on "Integrated Development of Rural & Arterial Road Network for Socio-Economic Growth"*, P-II. 243, Mumbai, India.
18. Central Pollution Control Board, (2006). Indicative Operational Guidelines on the Construction of Polymer - Bitumen Roads, *Probes/101/ 2005-2006*, Central Pollution Control Board, New Delhi, India.
19. Central Pollution Control Board, (2009). Performance Evaluation of Polymer Coated Bitumen Built Roads, *Probes/121/2008-2009*, Central Pollution Control Board, New Delhi, India.

Abbreviations:

PMB - Polymer Modified Bitumen.
 PCA - Polymer Coated Aggregate.
 PE - Poly Ethylene.
 PS - Poly Styrene.

PP - Poly Propylene.

PVC - Poly Vinyl Chloride.

PET - Poly ethylene Terephthalate.

DTA - Differential Thermal Analysis.

TGA - Thermo Gravimetric Analysis.

AC - Asphalt Concrete.

EVA - Ethylene Vinyl Acetate.

SBS - Styrene Butadiene Styrene.

AIV - Aggregate Impact Value.

LAR - Los Angle's Abrasion Value.

ACT - Aggregate Crushing Test.

LDPE - Low Density Polyethylene .

MV - Marshall Stability Value.

FV - Flow Value.

MQ - Marshall Quotient.

IS - Indian Standards.

ASTM - American Society for testing and Materials.

BS - British Standards.

IRC - Indian Road Congress.

DRDA - Department of Rural Development Agency.

SDBC - Semi Dense Bituminous Concrete.