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A technique to dispose waste plastics in an ecofriendly way – Application in construction of flexible pavements

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ABSTRACT

Waste plastics, littered both by domestic and industrial sectors was found to be a source of raw material for the flexible pavement. Waste plastics, mainly used for packing are made up of PE, PP and PS, their softening point varies between 110 °C and 140 °C and they do not produce any toxic gases during softening. But the softened plastics have a tendency to form a film like structure over the aggregate, when it is sprayed over the hot aggregate at 160 °C. The formed PCA is a better raw material for the construction of flexible pavement. PCA was then mixed with hot bitumen of different types and the mixes were used for road construction. PCA + bitumen mix showed improved binding property and poor wetting property. The sample showed higher Marshall Stability value in the range of 18–20 kN and the load bearing capacity of the road is increased by 100% and there is no pothole formation. The roads laid since 2002 using PCA + bitumen mixes are performing well. A detailed studies on the performances of these roads shows that the PCA bitumen mix roads are performing well. This is an eco friendly and economic process too.

1. Introduction

1.1. Plastic waste scenario

Solid waste management is the thrust area. Of the various waste materials, plastic waste and municipal solid waste are of great concern. Finding proper use of the 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 use of PCA for asphalt pavement helps for the reuse of plastics waste and for the improvement of road strength. This is a new innovative technique developed by the author. Plastics, a versatile packing material and a friend to common man, become a problem to the environment after its use. Most used materials are bags, cups, films and foams, made up of PE, PP or PS. The use of plastics in India is hoped to reach 12 million tonnes by the end of 2010. Around 55% is being used for packing. They are mostly littered after their use. The littered plastics, a non biodegradable material, get mixed with domestic waste and make the disposal of municipal solid waste difficult. The municipal solid waste is either incinerated or used for land filling. Both are not right techniques to dispose the waste and it will create both land and air pollution [1–3]. Moreover municipal solid waste, if contains PVC waste, when burnt, can give rise to toxic gases like dioxins [1]. Disposal of plastic wastes in an eco friendly way is the thrust area of today's research. The author has innovated [4] a technique to use the waste plastics for the construction of asphalt pavement. This process helps to dispose the waste by eco friendly method. This process can promote value addition to the waste plastic too.

1.2. Literature review

In the construction of asphalt pavement, hot bitumen is coated over hot stone aggregate and rolled. Bitumen acts as a binder. Yet when water is stagnated, over road it penetrates and results in pot holes, a defective spot on the pavement. Uses of anti stripping agents are having limited use only and the process also increases the cost of road laying [7]. Use of plastic as virgin as well as waste to modify the bitumen and also the use of PCA are being studied to find better results for the better performance of the pavement.

Abbreviations: PE, poly ethylene; PS, poly styrene; PP, poly propylene; PCA, polymer-coated aggregate/plastic coated aggregate; PVC, poly vinyl chloride; IRC, Indian Road Congress; ASTM, American Society for Testing and Materials; PET, poly ethylene terephthalate; DTA, differential thermal analysis; TGA, thermo gravimetric analysis; AC, asphalt concrete; EVA, ethylene vinyl acetate; SBS, styrene butadiene styrene; LAR, Los Angeles abrasion value; TCE, tri chloro ethylene; AIV, aggregate impact value; ACT, aggregate crushing test; PMB, polymer-modified bitumen; LDPE, low density PE; MSV, Marshall Stability value; FV, flow value; MQ, Marshall quotient; IS, Indian standards; BS, British standards; DRDA, Department of Rural Development Agency; SDBC, semi dense bituminous concrete; bitumen types, Pen Grade 80/100 and 60/70.

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Bituminous mixes used in the surface course of the bituminous pavements are being improved in their performance by incorporating various types of additives to bitumen such as rubber latex, crumb rubber, styrene, butadiene styrene, styrene–ethylene–butylenes, recycled PP, low density PE [5] PE [6], EVA (5%) [7] and polyolefin [8,9]. Some of the properties improved are durability, fatigue life [11,12], resistance to rutting, softening point, visco elastic property [10], etc.

The major obstacle to widespread usage of polymer modified bitumen in paving practice has been their tendency towards gross phase separation under quiescent conditions [13].

2. Present study

Polymer material is coated over stone aggregate and this PCA is used as a raw material for pavement construction. Plastics waste like PE, PP and PS is coated over stone aggregate and the PCA is mixed with bitumen and the mix is used for flexible pavement construction. Higher percentage of plastic waste (10–15%) can be used without separation. The quality of the aggregate is also improved. Detailed studies are going on this direction [14,4]. Various tests were carried out to find the characterization of the following

1. Different waste plastics used for coating over the aggregate.
2. PCA along with stone aggregate.
3. PCA mix with bitumen.
4. Polymer coated bituminous road scrap.

All the tests were carried out using standard procedures available either with AASHTO, IRC, and ASTM standards.

Central Pollution Control Board, New Delhi, India has already published two Program Objective Series [15,16] on this work.

2.1. Characterization of waste plastics

2.1.1. Thermal characteristics

The thermal behavior of the polymers namely PE, PP and PS was studied using Thermo Gravimetry Analyzer and Differential Scanning Calorimeter to find out the decomposition temperature and the softening point of the polymers. Instruments used were TGA-50 and DSC-60 (SHIMADZU MAKE) Table 1.

2.1.2. Physical properties

Most of the packing materials used are made up of PE, PP, PS. These materials were characterized for their thickness, solubility and softening temperature (Table 1b). All these materials can be shredded and used for road construction.

2.2. Characteristics of plastic coated aggregate

For the asphalt 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 was coated with waste plastic material by the following process. The waste plastics namely films, cups and foams shredded to the required size of 2.5–4.36 mm. The aggregate is heated to 170 °C. The shredded waste plastic was sprayed over the hot aggregate. Plastics got softened and coated over the aggregate. The extent of coating was varied by using different percentage of plastics. Higher percentage of plastics was used up to 25% to evaluate the binding property, whereas lower percentage of plastics like 1–5% to evaluate the properties like moisture absorption and soundness.

2.3. Binding properties

The hot plastics coated aggregate was compacted into a block using compacting machine operated hydraulically and cooled. Then the block was subjected to a compressive test using universal testing machine (Table 1a).

2.3.1. Moisture absorption AASHTO T 96 (2001) [17–20]

A known quantity of PCA was taken. It was then immersed in water for 24 h. Then the aggregate was dried using dry clothes and the weight was determined. The water absorbed by the aggregate was determined from the weight difference. The test was repeated with plain aggregate for comparison of results (Table 2).

2.3.2. Soundness test AASHTO T 96 (2001)

Soundness is mainly to test the stability towards weathering of the aggregate and its chemical resistance. The plain aggregate when exposed to stagnation of water, the water penetrates easily inside the pores of the aggregate. Since the water contains dissolved salts, the salt gets crystallized and expands inside the pores during evaporation resulting in the breaking of the aggregate. The low soundness property directly depends upon the amount of voids and porosity of the aggregate. This is evaluated by conducting accelerated weathering test cycle. The average loss in weight of aggregate for five cycles should not exceed 12% when tested with sodium sulfate. The plain aggregate and PCA was subjected to this tests and the results are tabulated in Table 2 for comparison.

2.3.3. Aggregate impact test AASHTO T 96 (2001)

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 15 blows with a hammer of weight 14 kg and the crushed aggregate is sieved on 2.26 mm sieve. The aggregate impact value is the percentage of fine (passing through the 2.36 mm 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 values are 35% for bituminous macadam and 40% for water bound macadam. The PCA was subjected to this test and the results are tabulated in Table 2.

2.3.4. Los Angeles abrasion test AASHTO T 96 (2001)

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% for pavements. For the LA abrasion test, the portion of a PCA sample retained on the 1.70 mm (No. 12) sieve was placed in a large rotating drum that contains a shelf plate attached to the outer wall. A specified number of steel spheres were then placed in the machine and the drum was rotated for 500 revolutions at a speed of 30–33 rpm (rpm). The material was then extracted and separated into material passing the 1.70 mm (No. 12) sieve and material retained on the 1.70 mm (No. 12) sieve. The retained material (larger particles) was then weighed and compared to the original sample weight. The difference in weight was reported as a percent of the original weight and called the percentage loss. LAR value should be less than 30% for pavements. The results are tabulated in Table 2.

2.4. Characteristics of the bitumen PCA mix

The hot PCA was mixed with 80/100 bitumen which was at 160 °C. The bitumen PCA mix was subjected to tests like Stripping test, bitumen extraction test and Marshall Value determination test.

Table 1
Thermal properties of polymers.

Polymer	Solubility		Softening temperature range in °C	Products reported	Decomposition temp. range in °C	Products reported	Ignition temp. range in °C	Products reported
	Water	EPT[a]						
PE	Nil	Nil	100–120	No gas	270–350	CH_4, C_2H_6	>700	CO, CO_2
PP	Nil	Nil	140–160	No gas	270–300	C_2H_6	>700	CO, CO_2
PS	Nil	Nil	110–140	No gas	300–350	C_6H_6	>700	CO, CO_2

[a] 5% Acetic acid.

Table 1a
Type of plastics and variation in bending strength.

Type of plastic	Percentage of plastics	Bending strength in kg	Compression strength (tonnes)
PE	10	325	250
	20	340	270
	25	350	290
Poly propylene	10	350	280
	20	370	290
	25	385	310
PS	10	200	155
	20	210	165
	25	215	170
PE foam	10	310	250
	20	325	265
	25	335	290
PP foam	10	340	270
	20	360	290
	25	365	310
Laminated plastics	10	360	290
	20	385	310
	25	400	335
BOPP	10	380	300
	20	400	310
	25	410	330

2.4.1. Stripping (IS: 6241-1971)

Stripping value is the determination of binding strength of the aggregate and the bitumen. It is tested by immersing bitumen coated aggregate in water for 24 h at 40 °C. When bitumen coated aggregate was immersed in water, the water penetrates into the pore and voids of the stone resulting in the peeling of the bitumen. This in turn results in the loosening of the aggregate and forming potholes. 200 g of PCA bitumen mix was taken and cooled to room temperature and weighed. The mixture was immersed in water bath maintained at 40 °C for 24 h. After 24 h the stripping was observed and the percentage of stripping was noted and the results are tabulated in Table 2a.

2.4.2. Bitumen extraction test ASTM D2172

The extraction tests were carried out in the following order.

1. Bitumen coated aggregate was treated with TCE and the bitumen was extracted. Here the extraction was almost complete.
2. PCA bitumen mix was first treated with TCE and the bitumen extracted was separated and estimated. Complete removal of bitumen was not taking place.
3. So further extraction was carried out using another solvent, namely decaline, which can act as a solvent to extract plastics also.

Table 1b
Physical properties of waste plastics.

Commercial plastic material	Nature of plastics	Thickness (μ)	Softening point (°C)
Cup	PE	150	100–120
Carry bag	PE	10	100–120
Water bottle	PET	210	170–180
Cool drinks bottle	PET	210	170–180
Chocolate covers	Poly ester + PE + metalised polyester	20	155
Parcel cover	PE	50	100–120
Supari cover	Polyester + PE	60	120–135
Milk pouch	LDPE	60	100–120
Biscuit covers	Polyester + PE	40	170
Decoration papers	BOPP	100	110
Film	PE	50	120–130
Foam	PE	NA	100–110
Foam	PS	NA	110

Table 2
Aggregate technical properties.

Stone aggregate	Plastic content	Moisture absorption	Soundness	AIV	ACT (%)	LAR (%)	Voids (%)
Without plastic coating	0	4%	5 ± 1%	25.4	26	37	4
With plastic coating	1%	2%	Nil	21.20	21	32	2.2
With plastic coating	2%	1.1%	Nil	18.50	20	29	1
With plastic coating	3%	Traces	Nil	17.00	18	26	Nil

Table 2a
Stripping value of PCA bitumen mix (percentage of plastic – 10%).

PCA + bitumen mix	Stripping value	Plain aggregate				PCA			
		2 h	24 h	72 h	96 h	2 h	24 h	72 h	96 h
		0	0	2	5	0	0	0	0

Table 3
Results of the bitumen extraction test for the bitumen mix containing the PCA.

Plastic content (% by weight)	Bitumen extracted after 5 min (%)	Bitumen extracted after 10 min (%)	Bitumen extracted after 15 min (%)
0	96.0	98.0	99.0
0.5	63.5	88.7	92.3
0.75	63.2	86.7	90.7
1.0	61.3	76.7	83.6

4. The PCA bitumen mix obtained from step 2 is then treated with decaline for another 30 min and separated bitumen was estimated.
5. The extraction was again repeated after refluxing the mix for 5 min. Further separation took place.

The process was repeated using aggregate, coated with different percentage of plastics. The results are tabulated (Table 3).

2.4.3. Marshall Stability ASTM: D 1559-1979

Marshall Stability value is the basic study on the stability of the mix with application of load. The standard mixture was prepared as per the IRC specification. The aggregate mix was coated with plastics waste as described earlier. This PCA mix was then mixed with a known quantity of 80/100 bitumen. The mixture then transferred to the mold. It was compacted with 75 blows on either side. The specimens (64 mm height and 10.2 mm diameter) were prepared by (1) varying the percentage of plastics waste and (2) by varying bitumen quantity. These specimens were tested. The voids present in the mix also play an important role in deciding the performance of the mix as pavement. The Marshall Mix block was subjected to different types of tests to find out the following properties, Voids filled with Mineral Aggregate, Air Voids, Voids filled with bitumen, Bulk Density, Specific Gravity and Voids in Mix. The results are reported in Table 5.

Marshal Stability Value is indicative of load withstanding property of the flexible pavement. The minimum value is fixed as 4 kN by IRC with 5% of bitumen and 95% of stone aggregate (Tables 4 and 5).

3. Discussion of results

3.1. Waste plastics characterization

3.1.1. Thermal analysis

The results obtained from the thermal analysis using DSC and TGA (Table 1) show that polymers namely PE, PP and PS get softened easily around 130–140 °C without any evolution of gas and around 270 °C they get decomposed, releasing gases like methane, ethane, etc. and above 700 °C they undergo combustion, producing gases like CO and CO_2. Hence it is safe to use molten waste plastics below 100–150 °C. This is supported by TGA and DSC graphs (Fig 1).

3.1.2. Binding property

The aggregate coated with higher percentage of plastics was compacted into a block and compacted blocks showed a compressive strength not less than 130 tonnes. This shows that the molten plastics have a good adhesion property. The increase in the values of the compression strength and bending strength show that the plastics can be used as a binder. Moreover the strength increases with the increase in the percentage of plastics used for coating. It is also depended on the types of plastics used like PE, PP and PS. The following is the increasing order of strength of block produced PS < PE < PP < Laminated films < BOPP. This order is in agreement of the chemical nature of the above polymers[1] (Table 1a).

3.1.3. Aggregate characterization

It was found that there is significant improvement in the strength properties of the plain aggregate with coating of polymers. This is due to the fact that when the polymer was coated over the aggregate, the aggregate surface is covered with the thin film of polymer. This coating is non wetting thus preventing the wetting of aggregate when exposed to water and moisture. The film of polymer also fills the pores at the surface and there is no water absorption. Hence there is significant improvement in the general properties of the aggregate like soundness, abrasion resistance, etc., Moreover, the PCA mixed with bitumen shows better stripping property.

- *Soundness* PCA showed nil value for soundness. This can be explained as follows. The coating of plastics fills the pores and voids present at the surface of the aggregate. There is no penetration of water and there is no salt deposition. Hence the disintegration is nil (Table 2).
- In *Los Angeles abrasion*, the hardness of aggregate is measured. PCA show better resistance to higher wear and tear load (Table 2). The resistance increase with the increase of coating thickness of the plastics coated. This is due to the reason that coating of polymers over aggregate gives better adhesion over the surface particles. It reduces the roughness of the aggregate and thus resulting in the reduction of abrasion over the surface of aggregate.
- *Impact value* The brittleness of the aggregate is measured as Impact value. Coating of waste polymers over the aggregate reduces the voids and the air cavities present in the aggregate (Table 2). The film formed helps in preventing the cracking on load. The toughness of the stones is also increased. Hence, the impact value of the PCA is lower when compared with the plain aggregate.
- *Crushing test* is the indirect measurement of the crushing strength of the road aggregate. The crushing strength of the PCA is also low (Table 2) due to the formation of the film which helps for voids filling and pores filling. The increase in the pores and voids will result in the crushing of the aggregate due to load. This was totally avoided in case of PCA.

3.2. Plastic coated aggregate bitumen mix characterization

3.2.1. Extraction characteristics

The experimental results of extraction of bitumen (Table 3) from the PCA bitumen mix clearly explain the bonding nature of the bitumen with the PCA. It is observed that the TCE could remove bitumen almost from the plain bitumen coated aggregate, whereas in the PCA bitumen mix the removal of the bitumen by TCE is a slow process and it is also partial only. The TCE cannot remove completely all the bitumen from PCA bitumen mix. Decaline, an organic solvent could remove both bitumen and plastic on further treatment. Complete removal is possible only by refluxing the PCA bitumen mix with decaline for more than 30 min.

Following observations is made from the results of extraction test. In the case of PCA bitumen mix, TCE removes only loosely bonded bitumen. It could not remove the bitumen bonded with the aggregate through the plastics. Decaline being a solvent to plastic could remove the bonded bitumen further. Only after refluxing complete removal of bitumen and plastic was possible. Moreover, when the percentage of coating of plastics was more, the extent by bitumen removal was correspondingly less. This observation helps to conclude the bonding of bitumen over PCA is strong.

3.2.2. Stripping value

In the case of PCAs (Table 2), the surface is covered by the polymer film and there are no pores. The molten polymer not only fills the voids of the aggregate and binds the aggregate together but also strongly binds with bitumen forming an organic bonding. Water cannot penetrate over PCA, hence peeling out of bitumen from the PCA is nil even after 96 h (Table 2a), thus have better stripping value.

3.2.3. Marshall Stability value

Marshall Stability value (kN), flow value (mm) and Marshall quotient (kN/mm) were obtained for plain aggregate bituminous mixes and PCA bituminous mixes of varied compositions (Tables 4 and 5).

For an effective asphalt pavement, the flow values should be in the range 2–5 and the ratio of MSV and FV (referred to as Marshall Quotient) should be not more than 500. The results obtained for the PCA are within this range. Voids filled with bitumen (VFB) are expected around 65%. The observed value is around 58%. The reduction is attributed to the reduction in the use of percentage of bitumen (90%) and the reduction in voids. 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 by 0.5% of the total weight. This accounts for 10% reduction in the quantity of bitumen needed to be used. It is a good saving of natural resource.

The following observations are made

- The use of PCA increases the MSV of the mix.
- As the percentage of the waste plastics coated increases the MSV is also increased.
- Higher percentage of plastics (more than 15%) results in lesser compatibility with bitumen and lesser bonding resulting in lower MSV.
- The use of PP gives higher MSV value than PE.
- The foams of PP and PE also gives better MSV results.
- The waste plastics available as foams or films can also be used.
- The use of optimum percentage of plastics was arrived using mathematical modeling and it is found to be 10% of bitumen used.
- The flow value and the voids filled with bitumen are within the tolerance value.
- The MSV of PCA bitumen mix is compared with PMB mix. It is observed that the values of the PCA bitumen mix are 50–60% higher than that of the PMB mix, showing that the binding strength is higher in the case of PCA bitumen mix.

3.2.4. Theoretical explanation

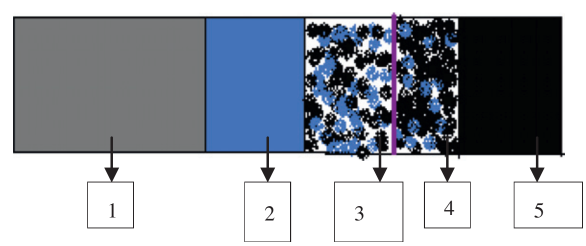
The shredded plastics on spraying over the hot aggregate get melted and spread over the aggregate giving a thin coating at the surface. When the aggregate temperature is around 140–160 °C the coated plastics remains in the softened state. Over this, hot bitumen (160 °C) is added. The added bitumen spreads over the aggregate. At this temperature both the coated plastics and bitumen are in the liquid state, capable of easy diffusion at the inter phase. This process is further helped by the increase in the contact area (increased surface area).

These observations may be explained as follows. Waste polymers namely PE, PP and PS are hydrocarbons with long chains. The bitumen is a complex mixture of asphaltenes and maltenes which are also long chain hydro carbon. When bitumen was mixed with PCA a portion of bitumen diffuse through the plastic layer and binds with aggregate. The plastic layer has already bonded strongly with aggregate.

During this process three dimensional internal cross linked net work structure results between polymer molecules and bitumen constitutes. Therefore the bonding becomes stronger and the removal of bonded bitumen becomes difficult as explained earlier in Section 3.2.1.

The results of the studies on the extraction of bitumen (Table 3) from Dry process showed that the bonding between stone aggregate and bitumen is improved due to the presence of polymers. This may be explained by the following structural models. Using these models the extraction pattern is explained.

A plastic aggregate bitumen interaction model for the Plastics waste coated aggregate bitumen mix (Not to Scale)



Key: Black- Bitumen; Blue- Polymer; Grey - Aggregate

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.
5. Area of Plain bitumen layer.

This will also add its suitability as a blend for asphalt pavement. This is supported by the high Marshall Stability values.

On the whole, the coating of plastics over the stone aggregate helps bitumen to have a strong bonding at the surface.

Basing on the above observations, the increased value of MSV, nil stripping and improved strength of road is explained.

3.2.5. Reduction of carbon dioxide emission

Littered waste plastics are otherwise burnt along with domestic waste resulting in the production of green house gases thus helping global warming.

In the dry process, waste plastics are used as a coating material by softening the plastic and not by burning. Hence there is no evolution of gases like carbon dioxide. For a distance of 1 km single lane plastic bitumen road, a minimum of one ton of waste plastics is used. This accounts for a reduction of Carbon Dioxide to a tune of

Table 4
Marshall Stability value for PCA.

Percentage of bitumen	Percentage of polymer w.r.t wt of bitumen	Type of polymer	PCA	Marshall value (kN)	Flow value (×0.25 mm)	Void percentage	Marshall quotient (kN/mm)
4.5	5	PP	PCA	16	4	53	4
4.5	10	PP	PCA	20	5	55	4
4.5	5	LDPE	PCA	16	4	55	4
4.5	10	LDPE	PCA	17.5	4	55	4.38
4.5	10	PE foam	PCA	20	4	58	5
4.5	15	PE foam	PCA	22.5	4	56	5.63
4.5	20	PE foam	PCA	26.5	4	56	6.62

Table 5
Marshall Stability value for polymer modified bitumen.

Percentage of bitumen	Percentage of Polymer w.r.t wt of bitumen	Type of polymer	PMB	Marshall value (kN)	Flow value (×0.25 mm)	Void percentage	Marshall quotient (kN/mm)
4.5	**5**	PP	PMB	14.50	3	56	4.83
4.5	**10**	PP	PMB	17.00	3.3	62	5.15
4.5	**10**	PE FOAM	PMB	18.00	3.4	66	5.29
4.5	**5**	LDPE	PMB	15.00	3.3	62	4.55
4.5	**10**	LDPE	PMB	17.00	3.5	62	4.86

Table 6
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	2700	41	0.63	2.55	0.85
Veerabadhra Street	2003	3785	45	0.70	2.62	0.60
Vandiyur road	2004	3005	41	0.66	2.75	0.84
Vilachery Road, Mai	2005	3891	45	0.50	2.89	0.86
Canteen Road, TCE	2006	3100	45	0.65	2.33	0.86
Plain Bitumen Road[a]	2002	5200	76	0.83	2.86	1.55
Tolerance value[b]	–	4000	<65	0.6–0.8		0.5–1

[a] Reference road constructed with plain bitumen.
[b] Theoretical value for the effective performance of a good road.

3 tonnes. Using this technology we have laid more than 2500 km of plastic bitumen road at various places in India. This amounts to a prevention of burning of waste plastics to an extent of 2500 tonnes. This means that the process prevented the formation of Carbon Dioxide to an extent of 7500 tonnes. (If this waste plastic is burnt along with MSW, nearly 250,000 tonnes of Carbon Dioxide would have been produced.)

4. Field study

More than 2500 km of Plastic tar road were laid in India at different States like Tamil Nadu, Kerala, Andhra Pradesh, Maharashtra, Pondicherry and Himachal Pradesh from 2002 to till date by various authorities like DRDA, Tamil Nadu; High Ways; Tamil Nadu; National Transport Planning and Research Centre, Kerala; Public works Department of Pondicherry, Private sectors, etc., These roads are functioning well without pothole, raveling and rutting. The performance studies of these plastic tar roads had been conducted by the following methods.

4.1. Site selection and studies

Six sites were chosen (Table 7). Sites 1–5 are referring the performance of plastic road and the site 6 is referring the performance of reference plain bitumen road. The following tests are conducted to evaluate the performance of these sites.

4.1.1. Deflection studies using Benkelman Beam Test

The Benkelman beam method is one of the methods for measuring surface deflections in field. A pavement is regarded as having insufficient strength if the deflection measured under a test load exceeds a pre-determined value related to the traffic expected. In case where the structure has to be strengthened, the observed deflection serves as the basis for determining the thickness of the overlay to be applied. The measurement is done by following the IRC: 81-1997 procedure. The results are tabulated in Table 6.

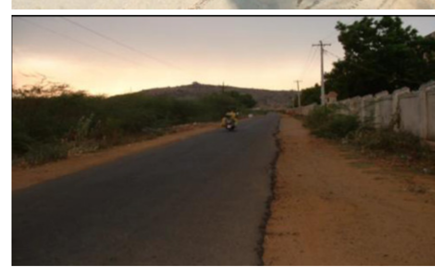
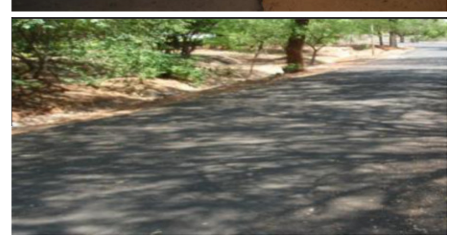
4.1.2. Studies on unevenness

It is the measure of the irregularity of the road after its performance over a period. The road unevenness is measured by the nature of the road i.e. whether it is rough or smooth in condition. The measurement of the surface unevenness is done by using MERLIN (Machine for Evaluating Roughness using Low-cost Instrumentation). *IRC*: SP16-2004. The results are tabulated in Table 6.

4.1.3. Field density by sand replacement method

The studies on field density are normally carried out before laying and after laying to ensure the correct process of laying. The field density here is calculated using the sand replacement method. The field density measurement gives an clear detail about the compaction of the road and its performance after usage. The results are tabulated in Table 6.

Table 7
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	
Veerbadhra 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	

4.1.4. Skid resistance

This method provides a measure of frictional property, micro texture of surfaces, either in the field or in the laboratory. The quantity measured with the portable tester has been termed "Skid-resistance" and this correlates with the performance of a vehicle with patterned types braking with locked wheels on a wet road at 50 km/h. Test is done on basis of Road Note 27 and ASTM E 303-83. The results are tabulated in Table 6.

4.1.5. Texture depth by sand patch method

The ability of bituminous surfacing to provide the required skid resistance is governed by its micro texture and macro texture. The macro texture of the surfacing, as measured by its texture depth, contributes particularly to wet skidding resistance at high speeds by providing drainage routes for water between tire and road surfaces. The sand patch test is described in detail in BS 598 Part 105 (1990). The results are tabulated in Table 6.

4.1.6. Surface condition survey

Detailed surface condition survey (procedure adopted by Central Road Research Institute, New Delhi) was carried out on the study stretches based on the nature, extend, severity and position of the defects namely, surfacing defects like bleeding, fretting, stripping, etc., cracking, deformation, patching, potholes and edge failures. The photos of these roads taken recently are also attached for having a visual exhibition (Table 7).

5. Discussion of performance studies

The above tests were conducted as per the specification and the values were compared with standard values which are given in Table 6 as tolerance value. The tests were conducted periodically from May 2007 to May 2008. The average values are tabulated (Table 6).

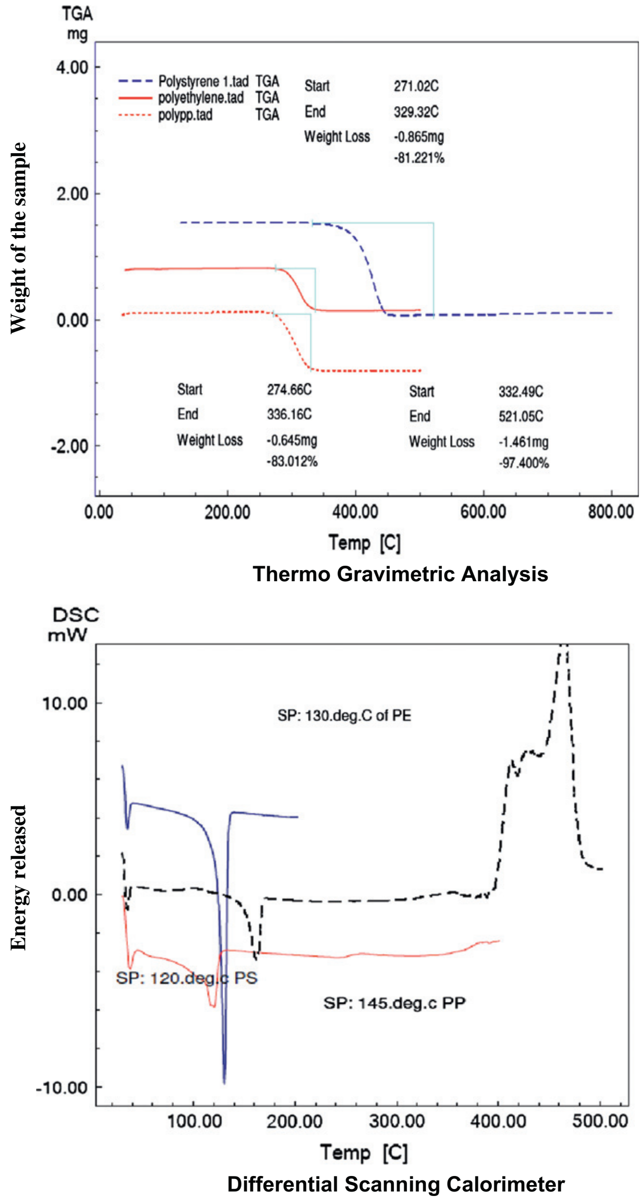


Fig. 1. Thermal analysis graph.

It is observed from the results that the plastic roads laid since 2002–2006 are showing results which are the characteristics of a good road. They are showing better results and maintain good quality compared to the plain bitumen roads laid in 2002. Hence it can be concluded that the plastic tar roads are performing much better than the plain bitumen road. Detailed discussions of the results are given here.

Monitoring of test roads of study area were carried out using structural evaluation and functional evaluation studies as mentioned above. The results obtained for polymer coated aggregate bituminous roads show that these roads are performing very well in spite of their age. These roads have not developed even small cracking or pothole. The roads were distributed over different localities of Tamil Nadu exposed to various environmental conditions like temperature, rainfall, etc., yet the roads are performing well. Under similar conditions, most of the bituminous roads are not performing well.

The reason for the performance of the plastic tar road is detailed below with the explanations for every tests made.

The overall comparison of the properties of the selected area shows that the values are within the allowable limit in spite of aging, traffic load and environmental variation. Hence it is concluded that the performance of the plastic tar road is really good.

5.1. Benkelman Beam Test

The BBT test studies were carried out for the above given six sites and the results were discussed here (Table 6). For a good bitumen road the tolerance value of the BBT deflection should be between 0.5 and 1 mm. The BBT value mainly depends upon on the visco elastic property of the bituminous layer over a period of performance. In our studies the value of the plain bitumen road is 1.55 mm which is in the higher side; this shows that the bituminous layer lost its visco elastic property due to its prolonged exposure to the atmosphere. But in the case of the plastic tar road the rebound deflection value of the five sites are inside the tolerance value, say for example the BBT value for the site Jambulingam Street is 0.85 mm which is well inside the tolerance value. This is supported by the higher Marshall Stability value of the road and also the flow value is pretty good, which are mainly depends upon the visco elasticity property of the bituminous mix. The reason is upon coating the polymers over the aggregate and mixing it with bitumen the polymer will help in maintaining the visco elastic property of the mix due to its strong bonding and a small modification in the structure of bitumen. Hence the plastic tar road, on prolonged exposure to the atmosphere and in different environmental conditions does not show any change in the visco elastic nature. Thus the observed values of the plastic tar road shows that even after a performance of more than 5 years the road layer is not in a position to be relayed.

5.2. Studies on unevenness

The studies on irregularity of all the six sites chosen were carried out using the MERLIN instrument and the results were discussed here (Table 6). For a standard bitumen road, the international roughness index value should be less than 4000 mm/km. If a road posses an IRI value more than 4000 mm/km, then the road is said to be uneven and it contains more up and downs. The unevenness of a road is mainly due to the poor binding of the mix. This would results in raveling and loosening of the road materials. In our studies the plain bitumen road shows a roughness index of 5200 mm/km which is higher value than the tolerance value. This shows that the surface of the plain bitumen road deteriorates and tends to form raveling and loosening of the surface material due to the oxidation or the aging of bitumen. But under similar conditions plastic tar road even after a prolonged performance, the IRI value for all the roads fall below the IRI index. This shows that there is uniformity in the road and also the road does not form ups and downs due to raveling and loosening of the road. This is explained as follows, coating the polymers over the aggregate and mixing it with bitumen the polymer will help in maintaining the visco elastic property of the mix due to (1) Its strong bonding and (2) Small modification in the structure of bitumen. This would help in increasing the stability of the mix, reduces the stripping of bitumen which results in raveling and loosening of the surface layers. The aging or the oxidation level of the bitumen present in the plastic coated aggregate bitumen mix is also very low due to the dual binding of bitumen to the aggregate with the plastic and also the slight modification of bitumen properties due to its mixing with polymers. Thus the results obtained for the plastic tar road laid shows that the roads are performing well without formation of any ups and downs and also there is no raveling and loosening of aggregated due to heavy load movement.

5.3. Field density

A loss in the packing of the bituminous material, speaks about the poor binding, improper compaction, stripping, loosening, movement at edges and difference in the surface of the road. The field density results will clearly explain all the factors. The field density of a road which was measured before and after the performance of the road will be around 2.86 kg/m^3. This value normally decreases over a period of usage due to very many factors affecting the road. But the rate of degradation of field density should be noted. In our studies (Table 6) the field density value for a normal bitumen road which has a performance of 7 years shows a value of 2.33 which is a 19% reduction from the standard value (IRC), but in the case of the plastic tar road laid on the same period, the average decrease in the field density value is around 9–10% which shows that the road is performing well without any defects as mentioned earlier. This is due to the improvement in all the basic properties like binding, stripping, MSV, FV, as discussed in the both properties of bitumen as well as in the properties of PCA. Due to this reasons the rate of decrease in the value of plastic tar road is less when compared with the plain bitumen roads.

5.4. Skid resistance

The skidding nature of a road, particularly in wet condition mainly depends upon the surface texture of the road layer. The skid resistance is measured as a skid number and it is then compared with reference value. Lesser the skid number more is the resistance. For a well performing road, the prescribed skid number should be less than 65. Keeping this as standard the skid resistance for all the chosen sites was determined (Table 6). From our findings the skid number of the plain bitumen road is around 76 which is a higher value. For a plain bitumen road the water absorption capacity is high which turn makes the road more slippery. Other important reason for road slippery is the excessive bleeding of bitumen during summer, in case of plain bitumen the softening point is reduced as the performance of the road prolongs which in turn results in over bleeding and smoothening of the road surface, resulting in increased value of skid number. But in the case of plastic tar road, it absorbs less moisture and reduces slippery, and there is small modification in the basic properties of bitumen which increases and hence there is no bleeding. The skid number for the plastic tar road is low due to the above explained conditions.

5.5. Texture depth

The surface texture depth plays an important role in deciding the following parameter of the road, unevenness, skid resistance, failures like rutting, raveling and cracking. A change in the surface texture depth will show effects in all the parameters discussed above. The effect may be a positive or a negative value. The performance study shows that the plastic tar road is performing well (Table 6). A normal road should have a texture depth between in 0.6–0.8 mm, in the case of plain bitumen road. Due to the reasons like poor binding, loosening of surface layer and also the poor stability shows that there is a margin increase in the texture depth value in turn affects all the above said properties. But in the case of plastic tar road, the texture depth value is within the allowable limit, this is due to the better binding of the PCA and the bitumen, and the road surface shows no deformation even after prolonged performance.

5.6. Surface condition survey

In addition to this, the physical surface condition survey of the plastic tar road (procedure adopted by Central Road Research Institute, New Delhi) (Table 7) shows that there is no pot hole formation, cracking, deformation, rutting, raveling and edge flaw. All these properties depend on the characteristics of the PCA and PCA bitumen mix. As discussed in Section 3 the basic properties of the PCA and the PCA bitumen mix is drastically improved when compared with plain aggregate bitumen mix. The defects like rutting, raveling, pothole formation, cracking and edge flaw is mainly due to the poor binding of aggregates and bitumen, but in case of the PCA bitumen mix the binding of the PCA and bitumen is very well which is evident from the results of stripping value test, MSV, FV, Moisture absorption values.

On the whole the performances of the plastic tar road are very good when compared with the plain bituminous roads due to better bonding and binding. Another important factor is that the performance of asphalt concrete pavement depends on the bitumen properties, asphalt concrete mixtures volumetric properties and external factors such as traffic volume and environment. On having this in discussion, the above test results shows that the performance of the plastic tar road is improved drastically due to the fact that there is a big positive change in the bitumen properties, asphalt concrete mixtures.

6. Economy of the process

The economic viability of the process was verified and the details of the economic savings are given below. Based on the experimental evidences and the amount of raw materials used for 25 mm SDBC-3750 m^2 (1 km $*$ 3.75 m road) the following calculation has been arrived.

Material needed	Plain bitumen process	Plastic-tar road
80/100 Bitumen	11250 kg	10125 kg
Plastic waste	–	1125 kg
Cost	Rs. 393750	(BIT) Rs. 354375 + (plastic) Rs. 13500 = Rs. 367875
Cost reduced	NIL	Rs. 25875.00
Carbon credit achieved on avoiding burning of plastics		3.5 tonnes

- Cost Bitumen Approx: 35,000/ton and Waste Plastic: Rs. 12000/tonnes.
- Savings of bitumen = 1 ton.
- Use of Plastics waste – (1,125,000) carry bags (1.125 ton).
- Bitumen needed – 10,125 kg.
- Plastics waste needed – 1125 kg.

As per the above findings/calculation. It was found that for laying one km road with 3.75 m width, we can save approximately an amount of 1 ton of bitumen which is equal to Rs. 35,000.00. Also as per our findings, the road can with stand more than 7 years without any maintenance, which reduces the maintenance cost also. The process also saves a large amount of carbon dioxide emission into the atmosphere which is due to the incineration of waste plastics. Hence the process is cheap and eco friendly.

7. Further research

7.1. Utilization of road scrap

Flexible pavement road scrap generally is not used for road construction. It is used for road filling mainly.

The road scrap from the highway roads was collected and analyzed and its composition was determined. The scrap was heated to 150 °C and coated with waste plastics (as described earlier). The mix, so obtained was tested for MSV and stripping. The MSV was higher with favorable flow values. The scrap polymer bitumen mix was used for pot hole filling. The performance is very good. Works on the characterization of the material is in progress.

Use of scrap with waste plastics coating reduces the cost of road laying by not less than 50% in terms of requirement of aggregate, bitumen and use of waste plastics. Further work is in progress.

8. Conclusion

In Dry process, the aggregate is modified by coating with polymers and producing a new modified raw material for flexible pavement. Patent has been obtained for this process. Coating of polymers on the surface of the aggregate has resulted in many advantages and ultimately helps to improve the quality of flexible pavement. The coating of plastics over aggregate also improves the quality of the aggregate.

In addition to the improvement of the quality of the road, this technology has helped to use the waste plastics obtained from domestic and industrial packing materials. This has added more value to the dry process as this process helps to dispose 80% of the waste polymers usefully by an eco-friendly method. This has already been accepted by the Central Pollution Control Board, New Delhi. They have already released a guideline on the technique of the road laying by dry process and its advantage.

By this technique, which is in situ, waste polymer like carry bags, foam, laminated sheets, cups are all used for road laying.

Moreover, the use of polymers helps to reduce equivalent quantity of bitumen, thus reducing the cost of the road laying.

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. 30,000/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.
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 Above all, the process helps to dispose waste plastics usefully and easily.

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