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Use of Plastic Waste in Pavement Construction: An Example of Creative Waste management

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Abstract: Plastic which is toxic in nature is found to be nearly 5% in Municipal Solid Waste (MSW). A major problem nowadays is the disposal of plastic wastes. These wastes are non biodegradable in nature causing environmental pollution and hygiene problems. The experimentation at several institutes indicated that waste plastic can be utilized in Asphalting of roads. The use of these wastes in road construction is based on Economic, Technical and Ecological criteria. Taking an example of INDIA (Authors native land) several million metric tons plastic wastes are produced every year. If these wastes can be suitably utilized in road construction, the disposal and pollution problems can be minimized to a large extent. In road making process bitumen is used as binder. The bitumen can be modified with plastic waste pieces forming a mix which can be used as a top layer of flexible pavement, showing better binding property, stability, density and which is more resistant to water.

***Abbreviations*:**

1. *CPCB: Central Pollution Control Board*
2. *LDPE: low density polyethylene*
3. *MSV: Marshall Stability*
4. *PCA: Polymer-Coated Aggregate/ Plastic Coated Aggregate*
5. *PE: Poly Ethylene*
6. *PMB: Polymer modified Bitumen*
7. *PP: Poly Propylene*
8. *PS: Poly Styrene*

Keywords: *Asphalting, Bitumen, Non biodegradable, Plastic waste*

I. INTRODUCTION

Plastic is everywhere in today s lifestyle. The main problem is what to do with the plastic waste. Use of plastic waste which is non biodegradable is rapidly growing and researchers have found that the material can remain on earth for 4500 years unchanged and without degradation. This threat of disposal of plastic will not solve itself and certain practical steps have to be initiated at the ground level. On the other hand the road traffic is increasing with time hence there arises a need to increase the load bearing capacities of roads.

In construction of Asphalt pavement, hot bitumen is coated over stone aggregates mixed, laid and rolled. But when the stagnation of water takes place over roads, it penetrates forming depressions called Potholes. Certain anti stripping agents are used but these have limited use and the cost of construction increases. The use of plastic waste for coating aggregates of the bituminous mix found to improve the performance of the pavement improving abrasion, slip resistance and increased the durability and fatigue life. Bituminous mix with recycled plastics mainly LDPE replacing 30% of 2.36 - 5mm aggregates showed 250% increase in Marshall stability and the mix density reduced to 16% and in addition to it the Indirect Tensile Strength (ITS) was also improved. On heating at 100-160'C polythene, polypropylene and polystyrene soften and exhibit good binding properties, blending it with bitumen results in a mix which is suitable for road laying. In Maharashtra 1,500 km of road have been laid by the above mix and other states including Tamil Nadu, Andhra Pradesh, Karnataka, Pondicherry, Kerala have also laid test roads which have successfully withstood loads due to heavy traffic, rain and temperature variation.

II. CONSUMPTION, GENERATION & CLASSIFICATION OF PLASTIC WASTE IN INDIA

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

2.1 GENERATION

India generates 5.6 million metric tons of plastic waste annually, with Delhi generating the most of at municipality at 689.5 metric tons every day, according to a report from the Central Pollution Control Board (CPCB). CPCB submitted the report to the Indian Supreme Court, which said, **"We are sitting on a plastic time bomb."**

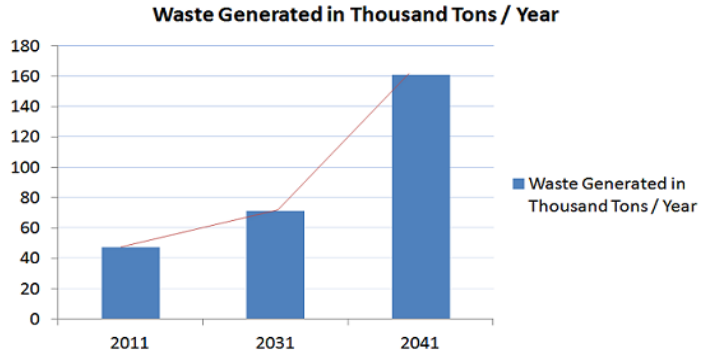


FIG. 1

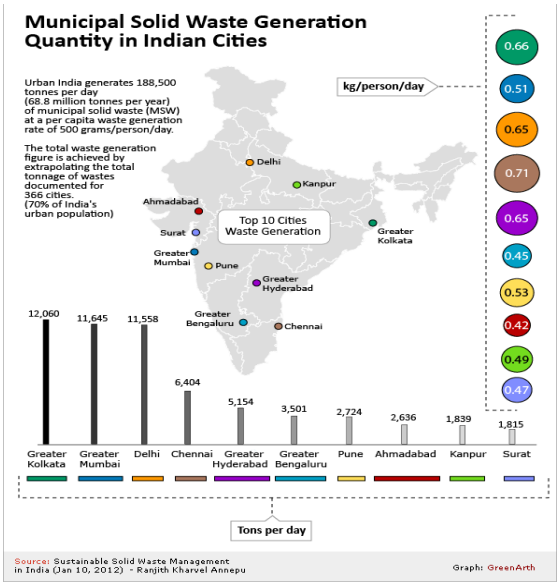


FIG.2

FIG. 3

FIG.1 SHOWS GRAPHICALLY WASTE GENERATED IN THOUSAND TONS/YEAR.

FIG.2 SHOWS THE TOP 10 CITIES WASTE GENERATION IN INDIA

FIG.3 SHOWS THE WASTE PLASTIC SOURCES

2.2 DATA ON PLASTIC CONSUMPTION AND GENERATION OF PLASTIC WASTE

TABLE – 1
CONSUMPTION OF PLASTIC WASTE

Sr. No.	Year	Consumption(Tones)
1	1996	61000
2	2001	400000
3	2006	700000
4	2011	1350000
5	2013	1740000

TABLE-1 SHOWS PLASTIC WASTE CONSUMPTION IN INDIA

TABLE -2 MUNICIPAL SOLID WASTES IN INDIAN CITIES [1,2]

Population Range (Millions)	Average Per Capita Value
0.1-0.5	0.21
0.5-1.0	0.25
1.0-2.0	0.27
2.0-5.0	0.35
> 5	0.50

TABLE-3 PLASTIC CONSUMPTION IN INDIA [3,4]

S. No.	Year	Consumption (Tones)
1	1996	61,000
2	2001	4,00,000
3	2006	7,00,000
4	2011	13500000

TABLE-4 POLYMER DEMAND IN INDIA (MILLION TONES)[5]

Type of polymer	1995-96	2001-02	2006-07	2010-11
PE	0.83	1.83	3.27	7.12
PP	0.34	0.88	1.79	3.88
PVC	0.49	0.87	1.29	2.87
PET	0.03	0.14	0.29	0.75
TOTAL	1.69	3.72	6.64	14.62

Due to the change in scenario of life style, the polymer demand is increasing everyday across the globe.

TABLE-5 PLASTIC WASTE CONSUMPTION [6]

S. No.	Description	World	India
1	Per capita per year consumption of plastic (Kg)	24-28	12-16
2	Recycling (%)	25	60
3	Plastic in solid waste (%)	7	9

2.3 PLASTIC WASTE CLASSIFICATION

On the basis of physical properties, plastic can be classified as thermoplastic and thermosetting materials.

Thermoplastic materials can be remoulded and thermosetting materials once shaped cannot be softened / remoulded by application of heat. Thermoplastics constitute 80% of total post consumer plastic waste generated while Thermoset plastics constitute 20% of total post consumer plastic waste generated. Some examples of thermoplastic and thermosetting materials are tabulated below.

TABLE-6 TYPICAL THERMOPLASTIC AND THERMOSETTING RESINS [4]

S. No.	Thermoplastic	Thermosetting
1	Polyethylene Teryphthalate (PET)	Bakelite
2	Polypropylene (PP)	Epoxy
3	Polyvinyl Acetate (PVA)	Melamine
4	Polyvinyl Chloride (PVC)	Polyester
5	Polystyrene (PS)	Polyurethane
6	Low Density Polyethylene (LDPE)	Urea – Formaldehyde
7	High Density Polyethylene (HDPE)	Alkyd

TABLE-7 WASTE PLASTIC AND ITS SOURCES

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

III. BASIC PROCESS

Waste plastic is ground and made into powder; 3 to 4 % plastics mixed with the bitumen. Plastic increases the melting point of the bitumen and makes the road retain its flexibility during winters resulting in its long life. Shredded plastic waste acts as a strong "binding agent" for tar making the asphalt last long. By mixing plastic with bitumen, the ability of the bitumen to withstand high temperature increases. The plastic waste is melted and mixed with bitumen in a particular ratio. Normally, blending takes place when temperature reaches 45.5°C but when plastic is mixed, it remains stable even at 55°C. 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, of the order of two to three times higher value in comparison with the untreated or ordinary bitumen. Another important observation was that the bituminous mixes prepared using the treated binder could withstand adverse soaking conditions under water for longer duration [7].

IV. PLASTIC AGGREGATE BITUMEN INTERACTION MODEL

The shredded plastics on spraying over the hot aggregate melted and spread over the aggregate giving a thin coating at the surface. When the aggregate temperature is around 1400° C to 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 plastic sand 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 plastic coated aggregate a portion of bitumen diffuses 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 bond becomes stronger and the removal of bonded bitumen becomes difficult [8].

FIG.4 shows plastic aggregate bitumen interaction model for the Plastics waste coated aggregate bitumen mix.

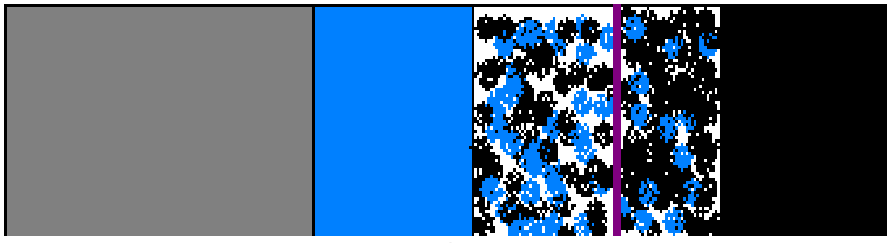


FIG.4

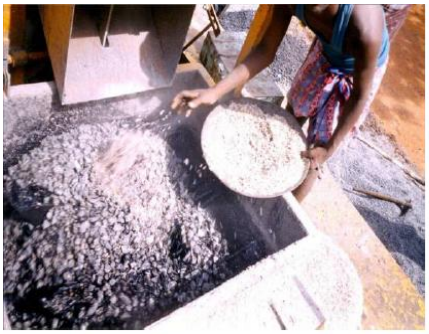
V. MIXING PROCEDURE AT HOT MIX PLANT

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


2(a). The aggregate mix is heated to 165°C (as per the HRS specification) and transferred to mixing chamber.

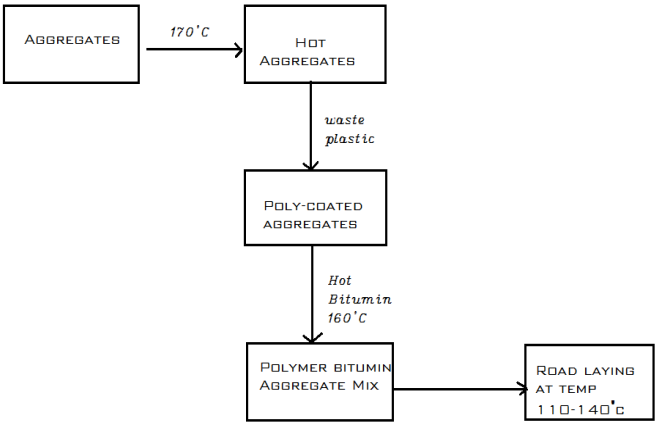
2(b). Similarly the bitumen is to be heated upto a maximum of 160°C (HRS Specification) to have good binding and to prevent weak bonding. (Monitoring the temperature is very important).


3. Shredded plastic is added to the hot mix. The plastic gets softened and coated over the surface of the aggregate giving an oily look in 30 - 60 sec




4. The plastics waste coated aggregate is mixed with got bitumen and the resulted mix is used for road construction. The road laying temperature is between 110°C to 140°C. The roller used is 8-ton capacity.

5.1 FLOW DIAGRAM OF PLASTIC COATED BITUMIN MIX ROAD



VI. CHARACTERISTICS OF PCA – BITUMEN MIX

1. Marshall stability test: It is observed that the Marshall stability values obtained for were generally higher than the value obtained for pure bitumen.

OBSERVATIONS

1. Use of PCA increases MSV of the mix.
2. As the percentage of waste plastics coated increases the MSV is also increased.
3. Use of PP gives higher MSV value than PE.

TABLE-8 MARSHALL STABILITY VALUE FOR PCA [9]

% of Bitumen	% of Polymer w.r.t wt of bitumen	Type of Polymer	PCA	Marshall Value (kN)	Flow Value (X 0.25mm)	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-9 MARSHALL STABILITY VALUE FOR PMB [9]

% of Bitumen	% of Polymer w.r.t wt of bitumen	Type of Polymer	PMB	Marshall Value (kN)	Flow Value (x 0.25mm)	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

2. Stripping test: (IS 6241-1971) In case of PCA the surface is covered by a polymer film and there are no pores. The PCA bitumen mix prepared was immersed in water for. Even after 96 hours there was no stripping showing that the plastic waste coated aggregate bitumen mix has highly improved resistance towards water.

TABLE- 10 STRIPPING VALUE OF PCA BITUMIN MIX (10% PLASTIC) [9]

		Plain aggregate				Plastic coated Aggregate			
PCA+ Bitumen Mix	Stripping Value	2 hrs	24 hrs	72 hrs	96 hrs	2 hrs	24 hrs	72 hrs	96 hrs
		0	0	2	5	0	0	0	0

3. WATER ABSORPTION TEST: It is observed that absorption of water increases with the increase in the percentage coating of the plastic over the aggregate showing that the coating of plastic reduces the voids thereby improving the quality of aggregates.

4. FIELD STUDY: Road length of more than 1200 km were laid in Tamil Nadu at different places using the dry process technique. The roads are exposed to heavy rain, heavy traffic but are functioning well without potholes and rutting.

VII. PROCESSES FOR MANUFACTURING BITUMIN MIX ROAD USING PLASTIC WASTE

There are two main processes namely:

1. DRY PROCESS
2. WET PROCESS

1. DRY PROCESS: In Dry process waste plastics are used as coating materials by softening the plastic and not by burning. For a flexible pavement hot stone aggregate (170**'**C) is mixed with hot bitumen (160'C) and the mix is used for road laying. The aggregate when coated with plastics improved its quality with respect to voids, soundness and moisture absorption and decreases porosity and thus the performance of the pavement is increased.

ADVANTAGES

1. As the plastic is coated over the aggregates thus surface property of aggregates gets improved.
2. Binding property of aggregates gets doubled and aggregates show increased strength.
3. No degradation of roads even after years of construction.
4. It reduces need of bitumen by around 10%.
5. Use of waste plastic more than 15% is possible.

2. WET PROCESS: Plastic waste is ground and made into powder 6 to 8%. Plastic is added to the bitumen at 160'C. The process did not yield a homogenous mix with prominent separated solid deposits of mix therefore wet process was not adopted and another waste material (crumb rubber) has been adopted to add to it.

ADVANTAGES

1. Process can be utilized for recycling of any type, size, shape of waste material.

VIII. COST COMPARISON

Reusing plastic waste to pave roads is an experiment that has been successfully conducted in many places, such as Kalamassery in Kerala and in Kolkata and Bangalore. The first technology approach, developed by Bangalore-based K K Plastic Waste Management Limited, entails using plastic waste along with bitumen – the ingredient conventionally used to make roads [11]Bangalore city generates nearly 15 tones of waste plastic bags every day. The mixing up of these waste plastic bags with other degradable organic waste Materials in the garbage of the urban areas have been the main cause of the problem in handling wastes that are collected in the city. The Bangalore Municipal Corporation has experimented using a compound made of waste plastic bags in the construction of roads in 2002. So far, 35kms stretch of road has been laid using this compound. After 2 years, the roads have not developed cracks, and provide smooth riding surface displaying much better durability (now extended to 800 Km in Bangaluru city).

i) The cost difference for the roads laid with compound as against without it is Rs. 500 / Cubic Meter.
ii) Saving of 8% by weight of bitumen
iii) Increase in compressive strength
iv) Indirect tensile strength values increased by 3 times
v) Provide smooth riding surface displaying much better durability
vi) This initiative demonstrates scalability of the project and a win - win situation for both constructions of roads and handling of waste plastic bags

FIG. 5 A portion of J P. Nagar Ring Road withstanding prolong pooling of water

FIG. 5

FIG.6 The same stretch of road unaffected by prolong pooling of water

FIG. 6

IX. SUSTAINABILITY & ROAD FEATURES

About 40 tones of compound can be generated from 100-120 tones of waste plastic bag. If the entire length of roads in Bangalore city is overlaid with the poly-blend compound it will require about 9022 tones of compound. The maintenance cost of the road will come down, as the road life is increased by 2 to 3 times .The **durability** of the roads laid out with shredded plastic waste is much more compared with roads with asphalt with the ordinary mix. Roads laid with plastic waste mix are found to be better than the conventional ones. The binding property of plastic makes the road last longer besides giving added strength to withstand more loads. Plastic roads would be a boon for India's hot and extremely humid climate, where temperatures frequently cross 50°C and torrential rains create havoc, leaving most of the roads with big potholes. The cost of plastic road construction may be slightly higher compared to the conventional method. However, this should not deter the adoption of the technology as the benefits are much higher than the cost. As road pavement life is doubled when we use this novel technique for road construction, we have to pay only Rs.25000/- more, instead of spending Rs. 10,80,000/- for its up gradation in just 2-3 years, thus saving Rs.10,50,000/- per Km.

9.1 SALIENT FEATURES OF THE ROAD

- Road strength is twice stronger than normal roads;
- Resistance towards water stagnation i.e. no potholes are formed;
- Less bleeding during summer;
- Burning of plastics waste could be avoided
- It doesn't involve any extra machinery;
- It doesn't increase cost of road construction; and
- It helps to reduce the consumption of bituminous mix vis-à-vis reduce cost.

FIG.7

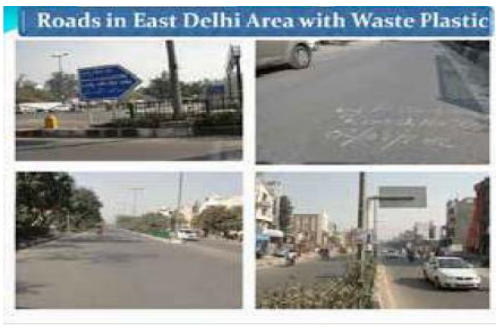


FIG.8

FIG.7: Polymer-Aggregate-Bitumen Mix Road Undamaged By Heavy Rain.

FIG.8: Roads made with plastic waste.

X. CONCLUSION

The issues highlighted above indicate the urgency for re-examining and formulating new guidelines/specification with regard to design and construction of concrete roads in India. This review intended to find the effective ways to reutilize the hard plastic waste particles as bitumen modifier for flexible pavements. The use of recycled waste plastic in pavement asphalt represents a valuable outlet for such materials. Plastics will increase the melting point of the bitumen. The use of the innovative technology not only strengthened the road construction but also increased the road life as well road quality... 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 process is eco friendly and socially highly relevant and hence one of the best methods for easy disposal of Waste plastics.

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