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ECONOMICS AND VIABILITY OF PLASTIC ROAD : A REVIEW

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ABSTRACT

The use of plastic and related materials is increasing exponentially due to tremendous growth in population, urbanization and changed life style leads to widespread littering of plastic on the landscape. Disposal of waste plastic is a serious problem globally due to their non-biodegradability and hazardous to human health, since these are not disposed scientifically and thus, create ground and water pollution. If this curse to mankind in the form of waste plastic is used as a boon for mankind by using it as additives in road construction, it will proved to be a best solution over worst road condition. In the present paper techniques has been developed to use plastic waste for construction of bituminous roads and flexible pavements. In general bitumen is used as binder in road construction. Binding properties of this bitumen can be modified by blending it with waste plastic pieces. It can be used for construction purpose. Waste plastic coated road aggregates can improve road strength. This modified bitumen mix and aggregates show better binding property, stability, density and more resistant to water thus increasing durability of roads with increased resistance to wear and tear of road.

Key words: Plastic waste, Mechanical characteristics, Bituminous mix, Plastic roads.

INTRODUCTION

The threat of disposal of plastic will not solve until the practical steps are not initiated at the ground level. It is possible to improve the performance of bituminous mixed used in the surface course of roads. Studies reported in the use of recycled plastic, mainly polyethylene, in the manufacture of blend indicated reduced permanent deformation in the form of rutting and reduced cracking and crazing of the pavement surface. The field tests withstood the stress and proved that plastic wastes used after proper processing as an additive would enhance the life of the roads and also solve environmental problems[1].

Plastic is a very versatile material. Due to the industrial revolution, and its large scale production plastic seemed to be a cheaper and effective raw material. Today, every vital sector of the economy starting from agriculture to packaging, automobile, electronics, electrical, building construction, communication sectors has been virtually revolutionized by the applications of plastics. Plastic is a non-biodegradable material and researchers found that the material can remain on earth for 4500 years without degradation. Several studies have proven the health hazard caused by improper disposal of plastic waste. The health hazard includes reproductive problems in human and animal, genital abnormalities etc. Looking forward the scenario of present life style a complete ban on the use of plastic can't be put. Although the waste plastic taking the face of devil for the present and future generation, we can't avoid use of plastic but we can reuse it[2].

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EXPERIMENTAL

Materials

Plastic: The plastic used was the waste plastic bottles, LDPE/HDPE bags, wrappers, collected from the nearby houses and apartments and from the dump yards.

Steps involved in the plastic recycling process[3]

(i) Selection/analysis: The recyclers/reprocessors have to select and analyse the waste/scrap, which are suitable for recycling/reprocessing.

(ii) Collection/segregation: The plastics waste collected/segregated as per the **codes 1-7** mentioned in the BIS guidelines (IS:14534:1998).

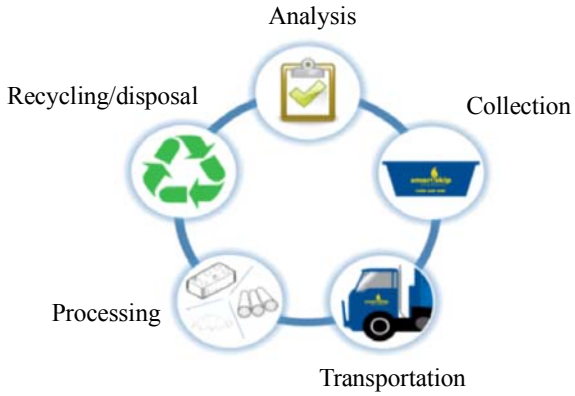

Fig. 1: Steps in recycling

(iii) Transporting/processing/recycle: After selection and segregation of the used plastic waste; it shall be washed, shredded, agglomerated, extruded and granulated.

Waste plastic was segregated, and shredded using shredding machine (particle size 2-3 mm).

Bitumen: The bitumen was 60/70 & 80/100 penetration grade obtained from H.P.C.L. Mumbai. Physical properties of the bitumen were presented in Table 1.

Table 1: Specifications of bitumen 60/70 and specifications of bitumen 80/100[4]

Characteristic	Test result		Test method	
	60/70 Grade	80/100 Grade	ASTM	IS
Specific gravity @ 25/25°C	1.01/1.06	1.01/1.05	D-70	IS : 1202-1978
Penetration @ 25°C	60/70	80/100	D-5	IS : 1203-1978
Softening point (°C)	49/56	45/52	D-36	IS : 1205-1978
Ductility@25°C, cm	100	100	D-113	IS : 1208-1978
Flash & fire point (°C)	>250	>225	D-92	IS : 1209-1978
Loss on heating (wt. %)	<0.2	<0.2	D-6	IS : 1212-1978

Aggregates: Aggregate was obtained from a local Quarry. The physical properties of aggregates are given in Table 2. Recommended gradation limits for BT works are shown in Table 3.

Table 2: Physical properties of aggregates[4]

Test description	Specification	Values
Combined flakiness and elongation index (%)	IS 2386 (Pt I – 1963)	18
Water absorption (%)	IS 2386 (Pt III – 1963)	0.5
Specific gravity	IS 2386 (Pt IV – 1963)	2.65
Impact value (%)	IS 2386 (Pt IV – 1963)	16

Table 3: Gradation of aggregates for pavement purpose[4]

Percentage of passing of stone aggregates								
Sieve size (mm)	19	12.5	9.5	4.75	2.36	0.60	0.30	0.18
Permissible Limits (%)	100	85-95	75 max	20-28	16-24	12-16	10-14	06-08

Methods[5]

There are two different processes, namely wet and dry process, to incorporate waste plastic bags into the bituminous mixes. Field trials have been carried out using wet process and dry process.

Wet process

It is the blending of shredded plastic bags and bitumen prior to the production of modified bituminous mixes. Figure 2 shows process flow in wet process of bitumen modification in wet process, the chemical processes that produces binders, are considered to be swelling of the plastic particles from absorbing some of the more volatile compounds from the bitumen, followed by degradation of the plastic from devulcanising and polymerization.

The rate of reaction is affected by the following:

- Temperature of the binder (higher temperatures provide a quicker reaction),
- The surface characteristics of the plastic used (rougher surface reacts quicker),
- The size of the waste plastic particles (smaller particles swell quicker but lesser)
- The period, blend is kept at the reaction temperature (longer time, greater reaction).

The main and important process in bitumen modification using wet process is blending of polymers and bitumen. It requires proper blending technique to ensure a required quality of blend. This can be achieved by using blending assembly as shown below in Fig. 2.[6]

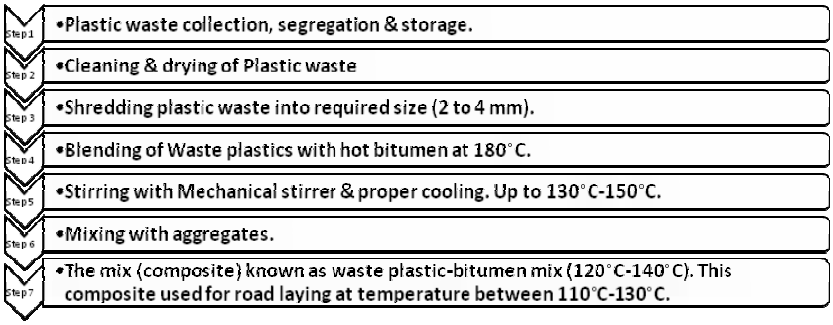

Fig. 2: Schematic flow diagram wet processes

Dry process

Mixing the appropriate quantity of dry shredded waste plastic with hot aggregate prior to production of bituminous mixes at hot mix plant by varying percentage of plastic by weight of mix.

(i) Various types of waste plastic are collected, analysed as per their type and sent for storage.

(ii) These segregated wastes are then cleaned and dried to remove impurities from them. Then cut into a size of 1.18-4.36 mm using shredding machine, (PVC waste should be eliminated).

(iii) The aggregate mix is heated to 165^{o}C (as per the HRS specification) and transferred to mixing chamber. Similarly the bitumen is to be heated up to a maximum of 160^{o}C (HRS Specification) to have good binding and to prevent weak bonding. (Monitoring the temperature is very important).

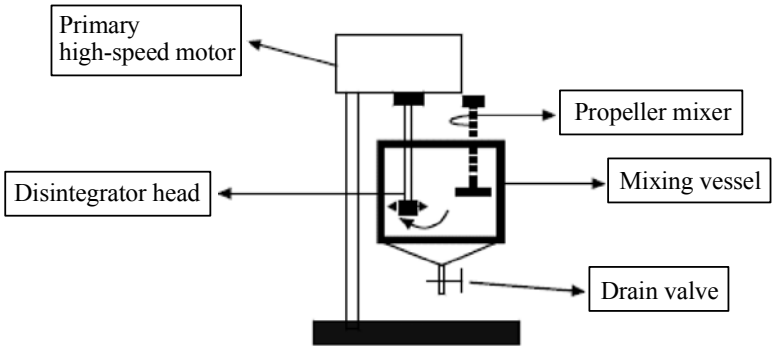

Fig. 3: Polymer-bitumen mixing assembly

(iv) At the mixing chamber, the shredded plastics waste is to be added over the hot aggregate. It gets coated uniformly over the aggregate within 30 to 45 secs, giving an look of oily coated aggregate.

(v) The plastics waste coated aggregate is mixed with hot bitumen at the temperature range between 150^{o}C-165^{o}C. The resulted mix of temperature range 130^{o}C-140^{o}C is used for road construction. The road laying temperature is between 110^{o}C-120^{o}C. Using the roller of 8 ton (min.) capacity.

EXPERIMENTAL

Wet process

Development of initial blends

Selection of appropriate polymers: Through literature survey for Indian plastic companies and contact with several plastic recyclers in nearby districts (Amravati, Akola); it was established that there are seven main polymers recycled in India. These include low and high density polyethylene (LDPE, HDPE) widely used in packaging and plastic bottles; polypropylene (PP) often used in straws and sweet wrappings; polyvinyl chloride (PVC), used in plumbing pipes and fittings; polyethylene terephthalate (PET), widely used in water and soft-drink bottles and acrylonitrile butadiene styrene (ABS), used in electronic devices such as laptops and mobile phones. It was suspected that some of these materials would be unsuitable for use in manufacturing recycled polymer modified bitumen. So samples were taken from main three components of waste viz. HDPE, LDPE, PP and also crumb rubber from rubber waste with a view to

incorporating them into the bitumen. Although the above polymers are available in sufficient quantities so as to be commercially feasible, not all are suitable for the proposed use. Factors influencing suitability for use with bitumen includes melting point and density.

Initial evaluation process

The initial evaluation process involved attempting to incorporate the recycled polymers into a straight run bitumen. The selected bitumen was 60/70 grade bitumen with a softening point of avg. 52.5^{o}C and a penetration value of avg. 65 dmm. And 80/100 grade bitumen with a softening point of avg.48.5^{o}C and penetration value of avg. 90 dmm. Of the 7 common recycled polymers available, representative samples were selected for testing, including: HDPE, LDPE, PP and Crumb rubber.

Preparation of blend

Waste plastic bags of various polymers cited above, were cut into pieces using a shredding machine. It was sieved and the plastics pieces passing through 4.75 mm sieve and retaining at 2.36 mm sieve were collected. These samples prepared, were added slowly to hot molten bitumen of temp. around 170-180^{o}C. All samples were first mixed at low polymer concentrations as follows,

- For mixing with 60/70 grade bitumen: Beginning with 2% by weight of the bitumen, further in the concentrations of 4%, 6%, 8%, 10% and 12%.
- For mixing with 80/100 grade bitumen: Beginning with 1% by weight of the bitumen further in the concentrations of 1%, 2%, 3%, 4%, and 5%.

The mixture was stirred well using stirrer for about 20-30 minutes. Blends of different compositions were prepared.

Material balance

According to Law of conservation of mass Energy can neither be created nor be destroyed, only one form of energy can be converted to other. In its general form it can be written as –

(Mass flow in the system) = (Mass leaving the system) + (Mass accumulated in the system)

As there is no specific reaction taking place, during blending, between bitumen and polymer, there is no specific change in terms of mass takes place. Material balance for samples, various types of plastic waste added to virgin bitumen is given as in Table 4.

Table 4: Material balance of samples with 60/70 grade bitumen for various polymers

S. No.	Base material		Additive			Blend Gms
	Bitumen	weight (g)	Polymer	%	weight (g)	
1	Grade 60/70	500	----	0	----	500
2	Grade 60/70	490	HDPE	2	10	500
3	Grade 60/70	480	HDPE	4	20	500
4	Grade 60/70	470	HDPE	6	30	500
5	Grade 60/70	460	HDPE	8	40	500

Cont…

S. No.	Base material		Additive			Blend Gms
	Bitumen	weight (g)	Polymer	%	weight (g)	
6	Grade 60/70	450	HDPE	10	50	500
7	Grade 60/70	440	HDPE	12	60	500
8	Grade 60/70	490	LDPE	2	10	500
9	Grade 60/70	480	LDPE	4	20	500
10	Grade 60/70	470	LDPE	6	30	500
11	Grade 60/70	460	LDPE	8	40	500
12	Grade 60/70	450	LDPE	10	50	500
13	Grade 60/70	440	LDPE	12	60	500
14	Grade 60/70	490	PP	2	10	500
15	Grade 60/70	480	PP	4	20	500
16	Grade 60/70	470	PP	6	30	500
17	Grade 60/70	460	PP	8	40	500
18	Grade 60/70	450	PP	10	50	500
19	Grade 60/70	440	PP	12	60	500
20	Grade 60/70	490	CR	2	10	500
21	Grade 60/70	480	CR	4	20	500
22	Grade 60/70	470	CR	6	30	500
23	Grade 60/70	460	CR	8	40	500
24	Grade 60/70	450	CR	10	50	500
25	Grade 60/70	440	CR	12	60	500

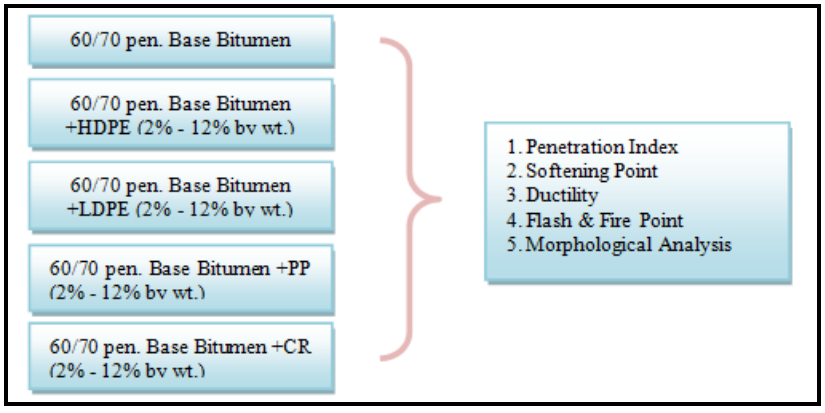

Fig. 4: Methodology adopted for modification of 60/70 pen. Bitumen

Dry process

As stated earlier, dry process used in asphalting technique of roads is nothing but the coating of plastic over aggregates which in turn increases the binding property of the aggregates improving the strength of the Pavement.

Table 5: Material balance of samples with 80/100 grade bitumen for various polymers

S. No.	Base material		Additive			Blend
	Bitumen	weight (g)	Polymer	%	by weight (g)	
1	Grade 80/100	500	----	0	----	500
2	Grade 80/100	495	HDPE	1	5	500
3	Grade 80/100	490	HDPE	2	10	500
4	Grade 80/100	485	HDPE	3	15	500
5	Grade 80/100	480	HDPE	4	20	500
6	Grade 80/100	475	HDPE	5	25	500
7	Grade 80/100	495	LDPE	1	5	500
8	Grade 80/100	490	LDPE	2	10	500
9	Grade 80/100	485	LDPE	3	15	500
10	Grade 80/100	480	LDPE	4	20	500
11	Grade 80/100	475	LDPE	5	25	500
12	Grade 80/100	495	PP	1	5	500
13	Grade 80/100	490	PP	2	10	500
14	Grade 80/100	485	PP	3	15	500
15	Grade 80/100	480	PP	4	20	500
16	Grade 80/100	475	PP	5	25	500

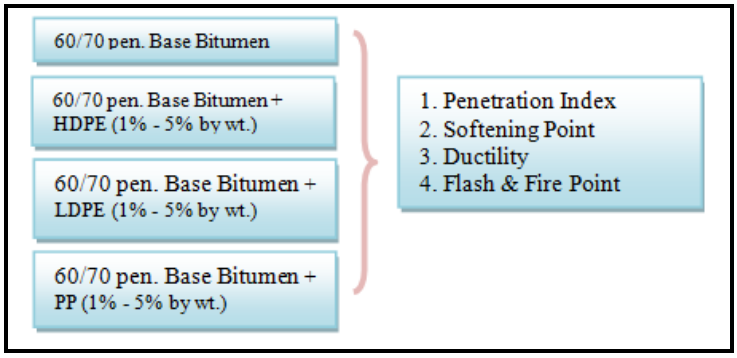

Fig. 5: Methodology adopted for modification of 80/100 pen. Bitumen

Preparation of process

Various types of waste plastics collected, segregated, cleaned and shredded in the required size of 2-4 mm. Aggregates, which are to be used, are taken and graded according to grading limits using sieve analysis.

Table 6: Sieve analysis of the aggregates

Cumulative % of passing of aggregates								
Metal size	**6 mm metal**				**10 – 12 mm metal**			
Sieve size (mm)	9.5	5.75	2.36	0.18	22.4	13.2	11.2	5.6
Specified limits (%)	100	33.5-100	0-33.5	0	100	33.5-100	0-33.5	0

Actual process

At first sheared plastic is taken in the quantity of 10% and 15% (by wt of aggregate) then graded aggregates are heated to 160-170^{o}C. Bitumen is also heated upto a maximum of 160^{o}C.

(HRS Specification) to have good binding and to prevent weak bonding.

At the mixing chamber, the shredded plastics waste is to be added over the hot aggregate. It gets coated uniformly over the aggregate within 30 to 45 secs, giving an look of oily coated aggregate. The plastics waste coated aggregate is mixed with hot bitumen at the temperature range between 150^{o}C-165^{o}C. Total three samples were to be prepared according to plastic used as follows –

(i) Aggregates coated with base bitumen only.

(ii) Aggregates coated with 10% plastics (% by weight of aggregates)

(iii) Aggregates coated with 15 % plastics (% by weight of aggregates)

The above samples made using dry process are subjected for various tests as: Marshal Stability, flow value, Sieve analysis, Impact value, water absorption & abrasion value.

Table 7: Layer wise requirement of bitumen for road construction[7]

Pavement layer of road	Thickness	Bitumen required (Kg./Sq. M of road)
BBM on WBM surface	50 mm	1.75 Kg. / Sqm.
	75 mm	2.00 Kg. / Sqm.
BBM on existing BT Surface	50 mm	2.25 Kg. / Sqm.
	75 mm	2.50 Kg. / Sqm.
Carpet	20 mm	2.06 Kg. / Sqm.
Sealcoat	06 mm	1.12 Kg. / Sqm.
Total bitumen consumption	**50 mm**	**5.43 Kg. / Sqm.**
	75 mm	**5.68 Kg. / Sqm.**

Cost estimation and economy incorporated

Cost estimation

In wet process, we use waste plastic for modification of bitumen, whereas in dry process, waste plastic is used for coating over aggregates. Waste plastic collection in India is typically a huge network of man power, engaged at various stages. Thus a separate economy is running there.

On the other hand, we travel a lot by roads than any other means of travelling such as railways, airways or waterways, as roadways are the most convenient & economical ways of travelling. But the condition of the roads is decreasing day by day. The cost for up gradation is increasing as the availability of natural recourses are minimizing. Therefore any techniques for improving quality of roads parallely saving some of natural resources such as bitumen and aggregates are needed. Use of this novel technique for up gradation of roads proved to be useful and economical, saving thousand Crores of rupees. There are tremendous possibilities of road up gradation in terms of quality and cost effectiveness, as condition and quality of roads are declining with next day.

Some of basic information is given below –

- ❖ Cost of waste plastics Rs. 7/- per Kg.
- ❖ Cost of processing: Rs. 5/- per Kg.
- ❖ Total cost of waste plastics: Rs. 12/- per Kg.[8]
  - Optimum percentage of plastic in the blend as per the test results is around 8% (% wt. of bitumen)
  - Generally roads in India are constructed in basic width of 3.0 m, 3.75 m. and 4.0 m.
  - Consider 1 Km length road of width 3.75 m. it uses bitumen approx. 21300 Kg. (For new work) and 11925 Kg. (For Up gradation).
- ❖ Cost of Bitumen per drum (200 Kg):- 8400/- [9]
- ❖ Cost of Bitumen Per Kg.:- 42.00/-
  - Cost of Road (New)/Km including BBM, Carpet and Seal Coat: Rs. 18,95,000/-10

    → Bitumen required for work (approx.): 21,300 Kg. per Km

    → Cost of bitumen in new work per Km.: Rs. 8,95,000/-

    → Waste plastic, co processed with bitumen for PMB (8% by wt.): 1,704 Kg

    → Cost of waste plastic used: Rs. 20,450/-

    → Cost of Bitumen saved (1704Kg. equivalent to plastic used): Rs. 71550/-

    → Total savings per Km.: Rs. 51,100/-
  - Cost of Road (Up gradation)/km including Carpet and Seal Coat: Rs. 10, 80,000/-[10]

    → Bitumen Required for work (approx.): 11925 Kg. per KM.

    → Cost of bitumen in repairs (Up gradation) per Km.: Rs. 5,01,000/-

    → Waste plastic, co processed with bitumen for PMB (8% by wt.): 954 Kg.

    → Cost of waste plastic used: Rs. 11450/-

    → Cost of Bitumen saved (954Kg. equivalent to plastic used): Rs.40,050/-

    → Total savings per Km.: Rs.28, 600/-
  - Optimum amount of waste plastic used in dry process: 10% (by wt. of aggregates)
  - Amount of aggregates used in road construction (1 Km length x 3.75 m width):

    3750 sqm x 12.5 Kg per sqm (avg.) = 46875 Kg.

    → Therefore Amount of waste plastic used in road (10% by wt.): 4687.5 Kg.
  - Total amount of waste plastic used in road construction using both the processes together (i.e. Combination of wet process & dry process):1704 + 4687.5 =6391.5 Kg
  - Total cost of waste plastic used in road using mix process: Rs.76,700/-
  - Extra cost for construction of road (Cost of waste plastic used in road construction – Total savings using modified bitumen): 76,700 – 51,100 = Rs.25,600/- per Km

Economy incorporated

- A best use of plastic carry bags and scrap bottles, which are really most problematic face of plastic to common man.
- Expenditure of Government of Maharashtra State only for Repairs of roads under P.W.D. and Z. P. W. D. reaches over more than Rs. 3500 Crores annually. Out of which Rs. 1700 Crores approximately are for bitumen only.
- Bruhan Mumbai Municipal Corporation has its biannual budget for bituminous road repairs more than Rs. 750 Crores.
- The Central Government's annual allocation of funds towards roads and highways is approx. 55,000 Crores.
- There is huge part of budget, spent on municipal waste management by Central Govt., State Governments and local authorities from all over India.
- Use of waste plastics in roads give the best results of which today's world is in need of.

Environmental benefits

Today, plastic waste treatment is largely hazardous to the environment as most of the plastic is burnt resulting in toxic gases, being released in the environment. By effectively managing the collection, separation and processing of plastic waste, the environmental damages can be limited by eliminating the waste from our streets. We can have international standard roads and pavements, which are litter free.

Municipal solid waste management (MSWM)

Households and other units wrap all garbage into plastic bags and dispose them. The non-biodegradable plastic bags acts like a covering on the garbage preventing it from being converted into compost. At present only 20% of the MSW is converted into compost. This can be considerably increased to 80-85% and more by systematically managing the plastic waste.

Farming community

One of the foremost areas that would directly benefit is agriculture. At present only 20% of MSW is converted into compost. This can be converted to 80-85% once the plastic from the MSW is segregated. Farmers can directly purchase from MSWM if plastic separated and used it instead of costly fertilizers.

National economy

When life of a road is doubled, then the savings that accrue to the national exchequer are in thousands of crores. In addition to the savings accrued at the central level, every state Municipal Solid Waste Management would save crores of rupees by eliminating the plastic segregation process at its yards along with huge amount spending on road repairs yearly.

CONCLUSION

Wet process

Polymer Modified Bitumen is used due to its better performance. But in the case of higher percentage of polymer bitumen blend, the blend is a more polymer dispersion in bitumen, which get separated on cooling. This may affect the properties and quality of the blend and also the road laid using such blend.

(i) Waste plastic-bitumen blend shows decrease in penetration point and ductility whereas increase in softening point and flash point of bitumen.

(ii) Blending requires a special type of mixing assembly for proper and effective blending.

(iii) Increase and decrease in specific values of bitumen shows improved performance of bitumen which in turn helps to improve quality and durability of road.

(iv) When modified bitumen is to be used at site of construction; there should be provision of maintaining proper service temperature and blending to prevent phase separation.

Dry process

In the modified process (dry process) plastics-waste is coated over aggregate. This helps to have better binding of bitumen with the plastic-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, raveling, and there is not pothole formation. The road can withstand heavy traffic and show better durability.

(i) Coating is easy and the temperature needed is the same as the road laying temperature.

(ii) Bitumen is bonded with the aggregate by means of plastic which acts as a binder.

(iii) Bitumen bonding is strong as evidenced from higher Marshall value.

(iv) Coated plastics acts as binder and the added bitumen binds strongly.

(v) Waste plastic is collected, shredded and can be used in the hot mix plant to lay the roads.

(vi) No new technology is involved. The existing Mini hot mix plant or Central Mix plant can be used without any modification.

(vii) The coated aggregate shows increased strength

(viii) Dry process can be practiced in all type of climatic conditions. Process can be modified by varying the percentage of plastic with respect to the environmental conditions namely, Temperature, Rain, Snow, load, etc.,

(ix) No evolution of any toxic gases like dioxin as the max. temp. is only 170^{o}C.

Salient features of the road

(i) Stronger road with increased marshall stability value.

(ii) Better resistance towards rain water and water stagnation so no stripping and no potholes.

(iii) Increase binding and better bonding of the mix thus reduction in pores in aggregate and hence less rutting a raveling.

(iv) No leaching of plastics. No effect of radiation like UV.

(v) The load withstanding property increases. It helps to satisfy today's need of increased road transport.

(vi) Value addition to the waste plastics (cost per kg. increases from Rs. 4 to Rs. 12).

(vii) The cost of road construction is also decreased and the maintenance cost is almost nil.

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.

In India more than 4.25 million Km of road is available. If only some of them are constructed or repaired using this technique, there will be less waste plastic littered on the road. The process is eco friendly. Segregating plastic from the MSW at municipal yard involves application of resources, the cost of which runs into crores of rupees. A substantial amount of this can be saved. Lab tests and real time tests have revealed that the life expectancy of a plastic road, compared to a normal road is at least 100% more. This technique adds a cumulative benefit to National Economy also gives contribution to environmental benefits, employment generation and agricultural efficiency.

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