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Use of Plastic in Bituminous Concrete Mixes

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ABSTRACT

The quantum of plastic waste in municipal solid waste (MSW) is increasing due to increase in population, urbanization, development activities and changes in life style which leading widespread littering on the landscape. Thus disposal of waste plastic is a menace and become a serious problem globally due to their non-biodegradability and unaesthetic view. Since these are not disposed scientifically & possibility to create ground and water pollution. This waste plastic partially replaced the conventional material to improve desired mechanical characteristics for particular road mix. In the present paper developed techniques to use plastic waste for construction purpose of roads and flexible pavements has reviewed. In conventional road making process bitumen is used as binder. Such bitumen can be modified with waste plastic pieces and bitumen mix is made which can be used as a top layer coat of flexible pavement. This waste plastic modified bitumen mix show better binding property, stability, density and more resistant to water.

Keywords :

1. 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 surfacing course of roads. Studies reported in the used of re-cycled plastic, mainly polyethylene, in the manufacture of blended indicated reduced permanent deformation in the form of rutting and reduced low – temperature cracking of the pavement surfacing. 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 are 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 cannot be put, although the waste plastic taking the face of devil for the present and future generation. We cannot ban use of plastic but we can reuse the plastic waste. [2]

2. LITERATURE REVIEW

The concept of utilization of waste plastic in construction of flexible road pavement has been done since 2000 in India. In the construction of flexible pavements, bitumen plays the role of binding the aggregate together by coating over the aggregate. It also helps to improve the strength and life of road pavement. But its resistance towards water is poor. A common method to improve the quality of bitumen is by modifying the rheological properties of bitumen by blending with synthetic polymers like rubber and plastics. Use of plastic waste in the bitumen is similar to polymer modified bitumen. The blending of recycled LDPE to asphalt mixtures required no modification to existing plant facilities or technology.[3] Polymer modified bitumen has better resistance to temperature, water etc. This modified bitumen is one of the important construction materials for flexible Road pavement. [4] Since 90's, considerable research has been carried out to determine the suitability of plastic waste modifier in construction of bituminous mixes.[5,6] Zoorab & Suparma [7] reported the use of recycled plastics composed predominantly of polypropylene and low density polyethylene in plain bituminous concrete mixtures with increased durability and improved fatigue life. Dense bituminous macadam with recycled plastics, mainly low density polyethylene (LDPE) replacing 30% of 2.36–5mm aggregates, reduced the mix density by 16% and showed a 250% increase in Marshall Stability; the indirect tensile strength (ITS) was also improved in the 'Plastiphalt' mixtures D.N. Little worked on the same theme and he found that resistance to deformation of asphaltic concrete modified with low density polythene was improved in comparison with unmodified mixes.[8] It is found that the recycled polyethylene bags may be useful in bituminous pavements resulting in reduced permanent deformation in the form of rutting and reduced low temperature cracking of pavement surfacing[9]

Bindu et al. investigates the benefits of stabilizing the stone mastic asphalt (SMA) mixture in flexible pavement with shredded waste plastic. Conventional (without plastic) and the stabilized SMA mixtures were subjected to performance tests including Marshall Stability, tensile strength and compressive strength tests. Triaxial tests were also conducted with varying percentage bitumen by weight of mineral aggregate (6% to 8%) and by varying percentage plastic by weight of mix (6% to 12% with an increment of 1%). Plastic content of 10% by weight of bitumen is recommended for the improvement of the performance of Stone Mastic Asphalt mixtures.

10% plastic content gives an increase in the stability, split tensile strength and compressive strength of about 64%, 18%

and 75% respectively compared to the conventional SMA Mix. Triaxial test results show a 44% increase in cohesion and 3% decrease in angle of shearing resistance showing an increase in the shear strength. The drain down value decreases with an increase in plastic content and the value is only 0.09 % at 10% plastic content and proves to be an effective stabilizing additive in SMA mixtures.[11] Stone Mastic Asphalt is a gap graded bituminous mixture containing a high proportion of coarse aggregate and filler. It has low air voids with high levels of macro texture when laid, resulting in a waterproof layer with good surface drainage. Stabilizing additives are needed in the mastic which is rich in binder content to prevent the binder from draining down from the mix. Polymers and fibers are the commonly used stabilizing additives in SMA. Based on many research reports and engineering case studies [12] has been shown that the use of stone mastic asphalt (SMA) on road surfaces can achieve better rut-resistance and durability. Recycled LDPE of a size between 0.30 and 0.92mm replacing 15% aggregates in asphalt surfacing nearly doubled the Marshall quotient, and increased the stability retained (SR) by 15%, implying improved rutting and water resistance. A 20% increase of binder content was required in this case. [13]

3. DATA ON PLASTIC CONSUMPTION & GENERATION OF PLASTIC WASTE

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. The plastic constitutes two major category of plastics; (i) Thermoplastics and (ii) Thermoset plastics. The thermoplastics, constitutes 80% and thermoset constitutes approximately 20% of total postconsumer plastics waste generated. The following table describes the average municipal solid waste production from 0.21 to 0.50 Kg per capita per day in India.

Table 1 Municipal Solid Waste in Indian Cities[14,15]

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 2 provides the data on total plastics waste consumption in India during last decade. [17]

Table 2. Plastic Consumption in India [17]

Year	Consumption (Tones)
1996	61,000
2001	4,00,000
2006	7,00,000
2011	13500000

Due to the change in scenario of life style, the polymer demand is increasing everyday across the globe. Following table gives the polymer demand in India from 1995 to 2011.

Table 3 Polymer Demands in India (Million Tones)[18]

S. No	Type of Polymer	1995-96	2001-02	2006-07	2010-11
1	PE	0.83	1.83	3.27	7.12
2	PP	0.34	0.88	1.79	3.88
3	PVC	0.49	0.87	1.29	2.87
4	PET	0.03	0.14	0.29	0.75
TOTAL		1.69	3.72	6.64	14.62

The comparison of per capita plastic consumption in India with rest of the word is presented in Table 4.

Table 4 Plastic Waste Consumption (P/C/YEAR) [17]

Country/Continent	Per Year Consumption (Kg)
India	6.0
East Europe	10.0
South East Asia	10.0
China	24.0
West Europe	65.0
North America	90.0
World Average	25.0

India has among the lowest per capita consumption of plastics and consequently the plastic waste generation is very low as seen from the table. 5 [17, 19]

Table.5 Plastic Waste Consumption [19]

Description	World	India
Per capita per year consumption of plastic(kg)	24-28	12-16
Recycling (%)	25	60
Plastic in solid waste (%)	7	9

3.1 PLASTIC WASTE CLASSIFICATION

Plastics can be classified in many ways, but most commonly by their physical properties. Plastics may be classified also according to their chemical sources. The twenty or more known basic types fall into four general groups: Cellulose Plastics, Synthetic Resin Plastics, Protein Plastics, Natural Resins, Elastomers and Fibers. But depending on their physical properties, may be classified as thermoplastic and thermosetting materials. Thermoplastic materials can be formed into desired shapes under heat and pressure and become solids on cooling. If they are subjected to the same conditions of heat and pressure, they can be remolded. Thermosetting materials which once shaped cannot be softened /remolded by the application of heat. The examples of some typical Thermoplastic and Thermosetting materials are tabulated in Table 6.

Table. 6 Typical Thermoplastic and Thermosetting Resins [17]

Thermoplastic	Thermosetting
Polyethylene Teryphthalate (PET)	Bakelite
Polypropylene (PP)	Epoxy
Poly Vinyl Acetate (PVA)	Melamine
Poly Vinyl Chloride (PVC)	Polyester
Polystyrene (PS)	Polyurethane
Low Density Polyethylene (LDPE)	Urea – Formaldehyde
High Density Polyethylene (HDPE)	Alkyd

Most of thermoplastics on heating soften at temperature between 130-1400C. The TGA analysis of thermoplastics has proven that there is no gas evolution in the temperature range of 130-180 0C and beyond 180 0C gas evolution and thermal degradation may occur. Thus the waste plastic can easily be blended with the bitumen as the process for road construction using bitumen is carried out in the range of 155-1650C. Table 7 gives the source of waste plastic generation.

Table 7. Waste Plastic & Its Source

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

3.2 BITUMEN
Bitumen is a sticky, black and highly viscous liquid or semi-solid, in some natural deposits. It is also the residue or by-product of fractional distillation of crude petroleum. Bitumen Composed primarily of highly condensed polycyclic aromatic hydrocarbons, containing 95% carbon and hydrogen (± 87% carbon and ± 8% hydrogen), up to 5% sulfur, 1% nitrogen, 1% oxygen and 2000ppm metals. Also bitumen is Mixture of about 300 - 2000 chemical components, with an average of around 500 - 700. It is the heaviest fraction of crude oil, the one with highest boiling point (525ºC).

3.2.1 DIFFERENT FORMS OF BITUMEN Cutback Bitumen: A suitable solvent is mixed to reduce viscosity. Bitumen Emulsion: bitumen is suspended in finely divided condition in aqueous medium 60% bitumen and 40% water.

Bituminous Primers: Mixing of penetration bitumen with petroleum distillate.

Modified Bitumen: Blend of bitumen with waste plastics & or crumb rubber.

3.2.2 Various Grades of Bitumen used for pavement purpose
Grade: 30/40; Grade: 60/70; Grade: 80/100

- Water repellant property.

PS is shows in Table 8

3.2.3 The desirable property of bitumen for pavement:

- Good cohesive and adhesive binding property.
- It is its thermoplastic nature, (stiff when cold liquid when hot), that makes bitumen so useful.

3.2.4 Drawbacks of Bitumen

- Temperature Effect: At high temperature bleeding of road occurs reducing performance of road.
- Oxidation Effect: Due to oxidation bitumen may led to cracking & crazing phenomenon.
- Water Effect: Due to water, bitumen strip off from the aggregate forming pothole on roads as being water repellent material. Reducing life of roads.
- High Cost – Being petroleum product it costs much higher.

3.2.5 Why Waste plastic? - As A Binder And Modifier

- Soften at around 130°C.
- No gas evolution in the temperature range of 130-180°C.
- Have a binding property hence used as a binder.
- Can also be mixed with binder like bitumen to enhance their binding property.

4. CHARACTERIZATION OF WASTE PLASTICS
4.1 Thermal Study
Thermal behavior of the polymers namely PE, PP and [20]

Table 8. Thermal behavior of PE, PP, PS

Polymer	Solubility		Softening Temp in Deg.C	Products Reported	Decom position Temp Deg.C	Products Reported	Ignition temp. range in Deg. C	Products reported
	Water	EPT*						
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_2H_6	>700	CO, CO_2

4.2 Binding Property
The molten plastics waste exhibits good binding property. Various raw materials like granite stone, ceramics etc. were coated with plastics and then molded into a stable product. On cooling, it was tested for compression and bending strengths. Vasudevan et al. found that the values of the compression strength and bending strength increases with above formulation shows that the plastics can be used as a binder [20].

5. PROPERTY REQUIREMENTS FOR MATERIALS IN ASPHALTING OF FLEXIBLE PAVEMENTS
In order to withstand tyre and weather, pavement surface layers contain the strongest and most expensive materials in road structures. Characteristics they exhibit like friction, strength, noise and ability to drain off surface water are essential to vehicles' safety and riding quality. Some are already associated with a standard test method. Apart from the nature of component binder and aggregates, asphalt performance strongly depends on the mixture type. Selection of a type for surface layers has to consider a multitude of factors including traffic, climate, condition of existing surface, and economics. No single mixture type could provide all the desired properties, often some are improved at the expense of others, making the selection difficult and contentious.

a number of properties are required of the component (particularly the coarse) aggregates such as resistance to fragmentation, affinity with bitumen, water absorption resistance, leaching etc. Dense bituminous macadam (DBM) is commonly used in binder course and base.[21]

6. CHARACTERISTICS OF PLASTIC COATED AGGREGATE (USED FOR FLEXIBLE PAVEMENT)

6.1 Moisture Absorption and Void Measurement For the flexible pavement, hot stone aggregate (1700c) is mixed with hot bitumen (1600c) and the mix is used for road laying. The aggregate is chosen on the basis of its strength, porosity and moisture absorption capacity as per IS coding. The bitumen is chosen on the basis of its binding property, penetration value and viscoelastic property. The aggregate, when coated with plastics improved its quality with respect to voids, moisture absorption and soundness. The coating of plastic decreases the porosity and helps to improve the quality of the aggregate and its performance in the flexible pavement. It is to be noted here that stones with < 2% porosity only allowed by the specification.

6.2 Soundness Test
Soundness test is intended to study the resistance of aggregate to weathering action. The weight loss is attributed to the poor quality of the aggregate. The plastic coated aggregate, did not show any weight loss, thus conforming the improvement in the quality of the aggregate.

6.3 Aggregated Impact Value
A study on the effect of plastic coating was extended to study on the aggregate impact value. Aggregate was coated with 1% & 2% plastics by weight and the plastic coated aggregate was submitted to Aggregate Impact Value test and the values were compared with values for non coated aggregate.

6.4 Los Angel's Abrasion Test
The repeated movement of the vehicle with iron wheeled or rubber tire will produce some wear and tear over the surface of the pavement. This wear and tear percentage of an aggregate is determined with the help of Los Angeles abrasion study. Under this study the percentage of wear and tear values of the plastic coated aggregate is found to be in decreasing order with respect to the percentage of plastics. When the Los Angeles abrasion value of plain aggregate value is compared with the Plastic coated aggregate the values are less for polymer coated aggregate.

6.5 Marshall Stability:
Marshall stability measures the maximum load sustained by the bituminous material at a loading rate of 50.8 mm/min. Marshall stability is related to the resistance of bituminous materials to distortion, displacement, rutting and shearing stresses.

6.6 Softening point test.
This test is conducted using Ring and ball apparatus. The principle behind this test is that softening point is the temperature at which the substance attains a particular degree of softening under specified condition of the test

6.7 Penetration Index Test
It is measured using Penetrometer. The penetration of a bituminous material is the distance in tenths of a millimeter, which a standard needle would penetrate vertically, into a sample of the material under standard conditions of temperature, load and time.

6.8 Ductility Index Test
The ductility of a bituminous material is measured by the distance in cm to which it will elongate before breaking when a standard briquette specimen of the material is pulled apart at a specified speed and a specified temperature

6.9 Softening point test.
(Ring and ball apparatus):-The principle behind this test is that softening point is the temperature at which the substance attains a particular degree of softening under specified condition of the test

6.10 Flash and Fire point test
In the interest of safety, legislation has been introduced in most countries fixing minimum flash point limits to prevent the inclusion of highly inflammable volatile fractions in kerosene distillates.

7. PROCESSES FOR MANUFACTURING BITUMEN MIX ROAD USING WASTE PLASTIC
There are two important processes namely dry process and wet process used for bitumen mix flexible pavement.

7.1 Dry Process
For the flexible pavement, hot stone aggregate (1700C) is mixed with hot bitumen (160 0C) and the mix is used for road laying. The aggregate is chosen on the basis of its strength, porosity and moisture absorption capacity as per IS coding. The bitumen is chosen on the basis of its binding property, penetration value and viscoelastic property. The aggregate, when coated with plastics improved its quality with respect to voids, moisture absorption and soundness. The coating of plastic decreases the porosity and helps to improve the quality of the aggregate and its performance in the flexible pavement. It is to be noted here that stones with < 2% porosity only allowed by the specification.

7.1.1 Advantages of Dry Process
- Plastic is coated over stones - improving surface property of aggregates.
- Coating is easy & temperature required is same as road laying temp.
- Use of waste plastic more than 15% is possible.
- Flexible films of all types of plastics can be used.
- Doubles the binding property of aggregates.
- No new equipment is required.
- Bitumen bonding is strong than normal.
- The coated aggregates show increased strength.
- As replacing bitumen to 15% higher cost efficiency is possible.
- No degradation of roads even after 5 -6 yrs after construction.
- Can be practiced in all type of climatic conditions.
- No evolution of any toxic gases as maximum temperature is 180ºC.

7.1.2 Disadvantages of Dry Process
a. The process is applicable to plastic waste material only.

7.2 Wet Process
Waste plastic is ground and made into powder; 6 to 8 % plastic is 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. Use of 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 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.

7.2.1 Advantages of Wet Process:
- This Process can be utilized for recycling of any type, size, shape of waste material (Plastics, Rubber etc.)

7.2.2 Disadvantages of Wet Process:
- Time consuming- more energy for blending.
- Powerful mechanical is required.
- Additional cooling is required as improper addition of bitumen may cause air pockets in roads.
- Maximum % of waste plastic can be added around 8 %.

8. CASE STUDIES IN INDIA
- Laboratory studies were carried out at the Centre for Transportation Engineering of Bangalore University, in which the plastic was used as an additive with heated bitumen n different proportions (ranging from zero to 12% by weight of bitumen) The results of the laboratory investigations indicated that, the addition of processed plastic of about 8.8% by weight of bitumen, helps in substantially improving the stability, strength, fatigue life and other desirable properties of bituminous concrete mix, even under adverse water-logging conditions. The additions of 8.0% by weight of processed plastic for the preparation of modified bitumen results in a saving of 0.4% bitumen by weight of the mix or about 9.6% bitumen per cubic meter of BC mix.

- In Tamil Nadu, length of roads around 1000 m in various stretches were constructed using waste plastic as an additive in bituminous mix under the scheme "1000 km Plastic Tar Road", and found that, the performance of all the road stretches are satisfactory.

- The performance of the road stretches constructed using waster plastic in Karnataka is also found to be satisfactory.

The construction of rods using Waste Plastic in the above states is based on the guidelines developed by Bangalore University. CRRI and College of Engineering, Madurai. However, standard specifications are not available on the use of waste Plastic in Bituminous road Construction. In this regard, IRC was specially requested by NRRDA for the preparation of such Guidelines for enabling the construction of Rural Roads under PMGSY using Waster Plastic. In order to facilitate the development of Guidelines on this, an Expert Group has been appointed by NRRDA for preparation of interim guidelines for the use of Waste plastic which will be sent to IRC for approval and releasing as IRC guidelines.

9. CONCLUSIONS

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. The use of modified bitumen with the addition of processed waste plastic of about 5-10% by weight of bitumen helps in substantially improving the Marshall stability, strength, fatigue life and other desirable properties of bituminous concrete mix, resulting which improves the longevity and pavement performance with marginal saving in bitumen usage. The process is environment friendly. The use of waste plastics in the manufacture of roads and laminated roofing also help to consume large quantity of waste plastics. Thus, these processes are socially highly relevant, giving better infrastructure.

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