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Review Article

Beneficial Reuse and Recycling of Plastic Wastes in Construction of Roads: A Review

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ABSTRACT

Waste is a byproduct generated in many mechanical, chemical as well as electrical processes. Plastic waste and its disposal are a major threat to our environment resulting in pollution and human health hazards. Every year millions of metric tons of plastic are produced in India. In recent years, one of the best ways to reuse plastic waste is considered to be road construction. Plastic roads are different from standard roads in terms of material, durability, strength, and flexibility. The plastics from various sources such as bottles, packaging wrappers, poly bags, cups, and cutlery can be used in powdered form and mixed with bitumen for road construction. Roads constructed using this technique offer more life and strength as compared to conventional roads and this is cost effective as well. Dry and wet processes are generally used in this technique. This is a way forward to solve the menace of environmental pollution, use resources in sustainable manner and give a clean world to future generation. This technique is eco-friendly as well as economical. In this review article, we have discussed the construction methods and various other characteristics of plastic roads.

Key words: Bitumen, Aggregate, Plastic roads, Plastic waste disposal.

1. INTRODUCTION

Most of the world is floating into the sea of discarded plastic, which is harming animals and possibly human health. Can it be managed?

In the present time, disposing of several waste materials produced from different kinds of industries is a big problem. Today, every sector from agriculture to electrical, automobiles, building construction, communication, or info-tech widely produces plastic wastes. Nowadays, it has become an integral part of our daily lifestyle. The usage was started after the age of industrialization because of the need for colossal production of goods, and plastic seemed to be a cheaper and effective primal material. Due to its low cost, easy manufacturing, and impervious nature toward the water, plastics are used in an exorbitant range of products. It is used for packaging, protecting, serving, and even in disposal of different kinds of consumer goods. Plastic has slowly replaced everything such as carrying bags, packaging material, bottles, cups, and various other items that can be of other materials. This huge replacement occurred due to some reasons or we can say advantages of plastic-like plastic has better durability, facile production, no odor, good defiance capacity against chemicals, etc. Utilization of this non-biodegradable product is increasing in large amounts, and causing affliction to the environment as well as human beings and animals. Many recent studies have found that plastic remains undegraded for almost about 1000 years into the landfills [1]. Plastic waste or garbage can be seen all around the planet creating severe problems such as logging of drains causing floods, choking animals' body by intake of plastic made materials, and distant problems such as breast cancer, reproductive problems in humans and animals such as genital abnormalities and decline in sperm count and quality. Plastic found in fields block germination which results in less water absorption and cause soil infertility, that also causes pollution of water bodies. Plastic waste production over the world [2] has crossed 400 million metric tons and 34,69,780 tons per annum in India as reported by the Central Pollution Control Board and only 10% of waste is recycled [3] (Figure 1). A 2019 study calculated the mismanaged plastic waste, in millions of metric tons (Mt) per year (Table 1):

1.1. Observe the Given Plot Regarding Plastic Waste Production (Figure 2 and3)

On the other hand, we are also confronting the issue of Bitumen road failure due to edge cracks, potholes, and scanty strength characteristics of bituminous mixes, movement of overloaded vehicles, poor drainage

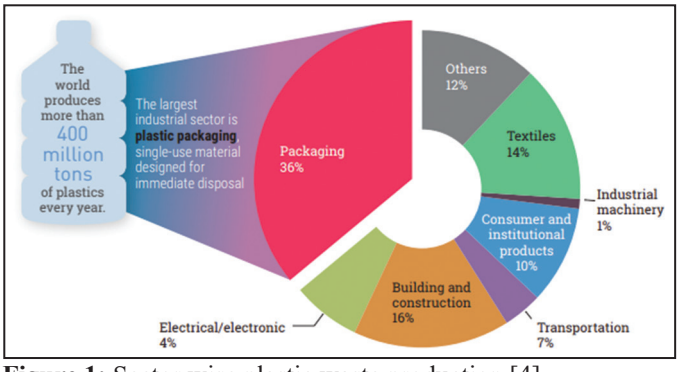

Figure 1: Sector wise plastic waste production [4].

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conditions, and meagerness of apt and proper maintenance. The question is how to use and sustainably reuse plastic waste?

1.2. Concept of Plastic Roads

In recent years, the applications of plastic wastes in road construction have been considered with great interest in many developing countries. The use of plastic in road construction is gaining importance, because of higher durability, greater performance, more life span, and low construction cost. These roads can stand up to 25 years. This resourceful idea was initially developed by Vasudevan (Dept. of chemistry, Thiagarajar College of Engineering, Madurai). He provided a revolutionary solution for plastic waste problems. In 2001, Dr. R. Vasudevan and his team conducted laboratory and experimental studies, and coating of aggregates with the homogeneous mixture of bitumen and plastic proved to give positive results [8]. He, then applied the same principle to construct the road in his college premises, which remains intact till date. For this timely needed invention, he is also called "Plastic Man of India."

Not only in India but also in Netherland there are two bicycle paths constructed in the Dutch city of Zwolle by the collaboration of three companies (Volker Wessels, Wavin and Total). These paths are made from pure plastic waste [9].

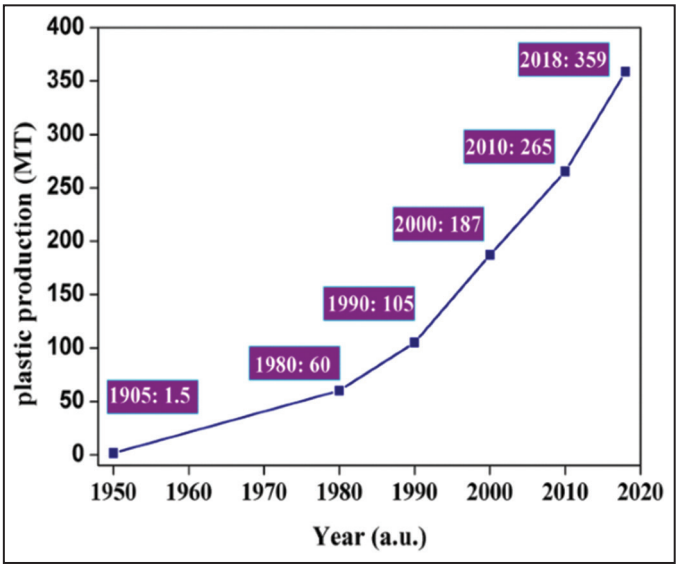

Figure 2: The production in metric tons of plastic waste in different years [6].

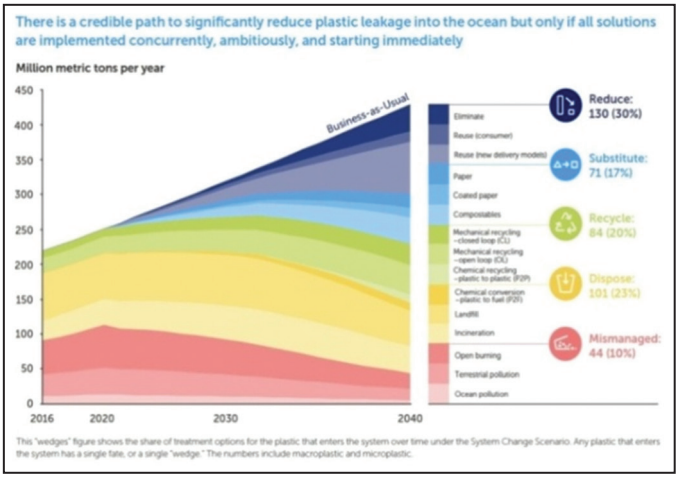

Figure 3: The plans and estimation regarding plastic waste and management [7].

Many companies and contractors started constructing plastic roads in small proportions and taking into consideration all parameters of extravagant usage of plastic waste in road construction, the Government of India in 2015 made it compulsory for every Indian contractor to construct roads using plastic waste [10]. A very famous example of an Indian scientist and businessman named Khan, he made plastic roads by mixing bituminous and powdered recycled plastic waste called polyblend [11]. He resolved the problem of plastic waste in the Indian city of Bangalore by converting it into polyblends through which he constructed roads.

1.3. Composition

The polymers used for road construction are low-density polyethylene, high-density polyethylene, polypropylene (PP), polystyrene (PS), and Polyvinyl chloride (PVC). These polymers are mixed with bitumen and laying of the roads is done [12,13].

Now, we need to know from where we get the above mentioned polymers? (Table 2).

2. LITERATURE REVIEW

Vasudevan [15] in 2007 investigated that coating of plastic reduces the porosity, absorption of moisture and improves softness and soundness. The polymer-coated aggregate bitumen mix forms better material

Table 1: Collection of data of mismanaged plastic waste in millions of metric tons (Mt) per year with their locations through out the world [5].

Entry	Amount of plastic waste generation	Location (s)
1	52 Mt	Asia
2	17 Mt	Africa
3	7.9 Mt	Latin America and Caribbean
4	3.3 Mt	Europe
5	0.3 Mt	USA and Canada
6	0.1 Mt	Oceania (Australia and New Zealand, etc.)

Table 2: The polymers and as well as their sources [14].

Polymer	Source
Low-density polyethylene	Carry bags, Squeezable Bottles, bin liners, packing films, etc.
High-Density polyethylene	Bottles of pharmaceuticals industries, milk, fruit juice, shampoo, etc.
Polypropylene (PP)	Bottle caps, Medicine Bottles, Chips packing, Microwaves' trays, etc.
Polystyrene (PS)	packing lids, disposable cups, cutlery, etc.
Poly vinyl chloride (PVC)	Water bottles, sanitary pipes, ATM/ Credit card, etc.

- LDP is clear or translucent plastic possessing flexibility, chemical resistance, and waterproofing capabilities.
- HDP provides greater resistance and durability.
- PP can withstand higher temperatures and loads when used for construction.
- PS is light weighted, moisture resistant, versatile, and pace up durability, thermal efficiency.

And this makes way ahead to sustainable development.

for flexible pavement construction as the mix shows higher Marshall Stability value and suitable Marshall Coefficient. Hence, the use of waste plastic for flexible pavement construction is one of the best methods for easy disposal of waste plastics. Raji *et al.* [16] in 2007 analyzed the usage of marginal wastes as an ingredient in bituminous mixes. They found that plastic wastes can be used as an add-on with bituminous pavements. Therefore, the properties of bituminous mix altered with shredded syringe plastic waste were studied. The work was carried out by mixing shredded autoclaved plastic syringes with heated aggregates of dry process.

Gawande *et al.* [17], in 2012, the former summarized his views in a journal that the use of plastic in bitumen improves the mechanical qualities required for a flexible road. Researchers are collecting more data on plastic consumption and generation of plastic waste. Furthermore, this paper described the properties and characteristics of bitumen and plastic. It gives detailed information about the wet and dry processes. The final conclusion of this paper is that modified bitumen is better for the top layer of flexible pavements. This modified bitumen shows more resistance to water, stability, load-carrying capacity, and better binding. Chavan [18] (2013) investigated that small-sized plastic which is passed through a 2-3 mm sieve in a shredding machine is used. The aggregate and chopped plastic blend together, heated thoroughly, and plastic are well coated on the aggregate. And in the bituminous mix design, these coated aggregates are combined together, heated and the mix are used for the construction of pavement. This type of modern technology not only gives good strength but also enhances road life and helps to decrease the environmental pollution.

Bhageerathy *et al*. [19] (2014) experimented with the use of biomedical plastic waste in bituminous road construction. They found that the Marshall Stability value of plastic modified bituminous mix was found to be 51% more than that for a normal mix which indicates an increase in load-carrying capacity. Dombe *et al*. [20] (2014) - This paper elaborates the sectional replacement of bitumen with plastic by the wet-mix process. A number of experiments was conducted using the Marshall Stability testing machine to check the suitability of e-waste and plastic as an alternative to traditional materials such as aggregates and bitumen, respectively. The results obtained in the experimental investigation indicated not only increase in strength but also a valuable reduction in cost. From the experimental work, it has been found that the properties of laboratory designed bituminous mix for Dense Bituminous Macadam are much better than those of the control mixes entirely composed of mineral aggregates and can be effectively used in practical applications.

Bharadwaj *et al.* [21] in year 2017 investigated the variation of the properties of bitumen on addition of plastic at different percentages. They concluded that by adding plastic waste in bitumen, the properties of bitumen and bituminous mixture were enhanced.

Mir (2015) [22] plastic waste in pavement construction, he introduced that viscos elastic nature of binder has complex modulus phases of angles in binders, need to be measured at different temperature, loading rates which are resembling the weather and climatic condition. Verma (2008) [23] studied that plastic increases the melting point of bitumen. This technology not only strengthens the road but also increase the life of the road. Prasad *et al.* (2015) [24] proves that the bitumen a conventional material used in the road construction can be partially replaced by the waste plastic and rubber. They added rubber and polyethylene terephthalate in 3%, 4.5%, 6%, 7.5%, and 8% in bitumen and found that the optimum content was obtained at 6%. Thus, according to their study, the use of plastic in 6% by weight of bitumen improves the pavement stability. Eneh [25] in 2015 discussed application of recycled waste plastic and its composite materials in the built environment. In his studies, he compared benefits of use of plastic over new or "virgin" materials. Barad (2015) [26] showed that bitumen modified by adding polymer shows better properties than normal bitumen. In dry process, the aggregate is coated with plastic which then shows improved binding properties as area of contact between bitumen and polymer increases. Rokande (2012) [27] he prepared semi dense bituminous concrete mix using Marshall Method, in his study of use of waste plastic and waste rubber tyres in flexible highway pavements. His study concluded that with 5% Bitumen content, higher value of Marshall stability and greater density was achieved. Sarker *et al.* [28] in 2011 carried out investigation on conversion of waste plastic into useful chemical products. In their experimentation, the fraction of liquid produced by the thermal degradation of waste plastics, containing about 29%, naphtha chemical, was subjected to thermal reactions. The waste plastic was first converted to slurry, and then thermal liquefaction was done at 370–420°C of the slurry followed by distilling, recovering, and condensing. Rajasekaran *et al*. (2013) [29] proved that coating aggregate with polymer has many advantages and it ultimately helps in improving the quality of flexible pavement and also increase the aggregate quantity. The dry process is better as it dispose about 80 % of waste polymer in eco-friendly way. And use of polymer reduces the equivalent bitumen quantity decreasing the cost of road construction. Swami *et al*. (2012) [30], according to them, use of waste plastics in road construction has helped to provide a better place for burying plastic waste without causing disposal problems. It also provided better roads. In same year as swami's Rai *et al*. [31] they prepared a number of concrete mixes in which waste plastic flakes partially replaced sand in varying percentages by volume. They tested plastic mix concrete with and without super plasticizer at room temperature and found that the workability, compressive strength, due to partially replacement of sand by waste plastic, was minimal and can be enhanced by addition of superplasticizer. Around 2015 Raut *et al*. [32] worked on use of waste plastic bottles as construction material. According to them, cost of house construction can be brought down by using waste plastic material along with construction material. Furthermore, according to them, the bottle houses are bio-climatic in design, which means that when it is cold outside is warm inside and vice versa. Nearly about 2013 Wayal and Wagle [33] In their research they found rubber and polymer as a binder with respect to aggregate and bitumen. They examined the material for crushing value, impact value, softening point, abrasion value, bitumen penetration value, ductility, specific gravity, and found that the use of waste plastics and rubber tyres in the form of powder for flexible pavement material is one of the best ways for easy disposal of wastes. Around same as previous time Nkwachukwa *et al.* [34] discussed sustainable development and plastic recycling in developing countries. Their study indicates that due to poor facilities and awareness, most of the plastics, are currently disposed of in unauthorized dumping sites or burned uncontrollably in the fields. Their paper outlined environmental concerns of so many applications of plastics. Rokdey (2015) [35] conducted a study on recycling of plastic waste material and to blend it with bitumen for laying roads in India and compare them with the environmental and economic conditions. Trimbakwala (2017) [36] described that plastic wastes can be used as a modifier to enhance the properties of bituminous mix which will not only increase the durability and life span of roads but will also create a way for income. Pandi (2017) [37] explained the various aspects of utilization of waste plastic in road construction. The addition of plastic wastes to bitumen makes it a better material for pavement as it shows higher Marshall stability value and Marshall coefficient. Patel (2014) [38] Studied that the disposal of plastic wastes can be best done by an economic method, that is, using them in constructing roads that perform better than ordinary roads. Sethy (2019) [39] conducted an experiment to study the change

in bituminous concrete mix behavior modified with plastic polythene. He concluded that the effective use of waste plastic to bituminous mix improves the Marshall properties of the mix in order to obtain an environment friendly bituminous concrete. Mundhe (2018) [40] She gave an overview on the economical, technical and ecological criteria of making plastic roads that proofs to be a boon for our country and in future will provide strong roads with reduced porosity, absorption of moisture, and improve soundness. Surendran [41] in 2018 investigated the methodology for exploitation of plastic waste in hydrocarbon mixes and gives various tests performed on aggregates and hydrocarbon. They concluded that plastic waste mixed with bitumen help in the reduction of bitumen by 10%, increases strength and performance of road, avoid the use of incineration and landfilling, and develops a technology that is eco-friendly.

3. METHODOLOGY

3.1. Materials

In plastic road construction, generally following materials are used [42]:

3.1.1. Aggregates

Aggregates of size 10 mμ, 20 mμ, are used and stone dust/lime as filler.

3.1.2. Bitumen

60/70 grade of 80/100 grade bitumen is used.

3.1.3. Plastic waste

Collected from various garbage dumps in form of shreds, films of hard foam PS and soft foam PP and polyethylene of any thickness, films of PS, PP and polyethylene up to 60 micron thickness can be used for road construction.

3.2. Types of Processes [43]

Two types of processes are used for mixing of bitumen and plastic waste in construction of roads. They are dry process and wet process, respectively. The main difference between the two methods is that in the wet process mechanical stirrer machine is needed which is a costly equipment. Due to high cost maintenance of wet process, generally dry process is used by most of the contractors for laying of plastic road pavement across the country. The two processes are explained briefly below:

3.2.1. Dry process

This process involves heating of small aggregates up to 170°C in the hot mix plant as first step. In the heated aggregate, shredded plastic waste is added in equal proportions. Then bitumen is heated and the above mixture of plastic coated aggregate is added to the heating bitumen. The mixture is thoroughly mixed before laying. When it is ready, the laying of road is done.

3.2.1. Wet process

In this process, the plastic waste is directly mixed with hot bitumen at 160^0C and this mixture is then mixed using a mechanical stirrer. The mixture also contains external stabilizers and proper cooling is required. It is not used commonly because it involves huge investments and larger plants and requires more funds (Figure 4).

3.3. Construction Procedure of Plastic Roads [26]

Plastic wastes (such as disposed carry bags, films, cups, and thermocole) are collected from various sources.

3.3.1. Segregation

Other wastes are separated from the plastic wastes collected.

3.3.2. Cleaning and drying

The separated waste is cleaned properly and dried.

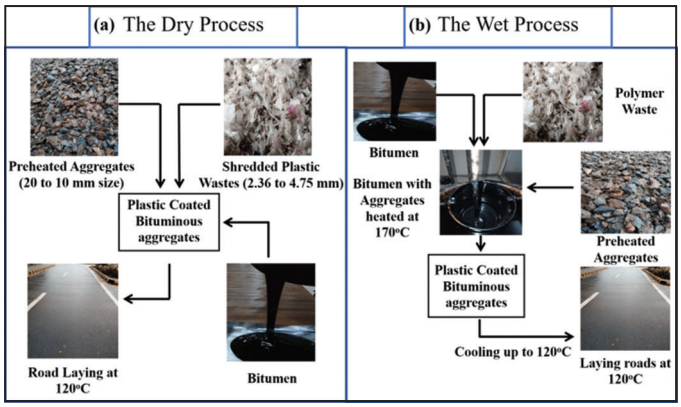

Figure 4: Flow chart diagrams of dry and wet processes [44].

3.3.3. Shredding

After drying, the plastic with a maximum thickness of 60 μ waste is broken and shredded into small pieces to a size of 2.3 mμ to 4.75 mμ with the help of shredding.

3.3.4. Heating

The aggregate mix is heated to 165–170°C in a mini hot mix plant and transferred to a mixing chamber. Bitumen is heated up to 160°C to prevent weak binding.

3.3.5. Surface coating

In the mixing chamber, the shredded plastic waste is added to the hot mix when it gets uniformly coated over the surface of aggregate mix and appears as an oily texture within 1 min of time.

3.3.6. Mixing

Heated bitumen is added immediately and the contents are mixed well.

3.3.7. Construction

The combined mixture of aggregate, plastic waste, and bitumen is used for laying the road between 110°C and 120°C. The roller is used to make it compact and uniform. Construction process of plastic pavements can be understood by flow chart also which explains all of the above described steps with the help of diagrams (Figure 5).

3.4. Pros and Cons of Plastic Roads [46-48]

3.4.1. Advantages

Benefits of plastic road are stated below:

a. Strength and performance of roads is increased to a higher extent.
b. Using Plastic with bitumen helps reduce bitumen requirement by about 10% resulting in reduction of overall cost.
c. Creates employment opportunities for rag-pickers.
d. Plastic roads have hollow space built in it to allow ease of wiring, connecting pipes, etc.
e. No pot-holes are formed and no stripping occurs.
f. It helps in disposal of plastic waste in a good way minimizing pollution.
g. Life of roads increases.
h. These are eco-friendly and economic.
i. It reduces the exploitation natural resources.

3.4.2. Disadvantages

Some drawbacks of plastic roads are given below:

a. During burning of PVC plastics, harmful mixture of gases such as *HCl* are formed and when other plastics such as PP, PS, and PE are burned gases such as CO, acetone, toluene, and formic acid are formed which are dangerous to environment.
b. The water percolation is restricted so groundwater table is affected.

Figure 5: Flow chart diagram of construction of plastic pavements [45].

Table 3: Differences between plastic pavements and ordinary roads.

Plastic roads	Ordinary roads
Hollow and light weight	Solid and heavy
Tensile strength is high	Tensile strength is low
More durable	Less Durable
Life span around 25 years	Life span around 4–5 years
Penetration of rainwater is less	Penetration of rainwater is more
Construction cost is high while maintenance cost is low	Construction cost is high.

c. The cleaning process is one of major issue because it contains toxic substances.
d. During melting of plastic, the structural weakness may occur and cause premature failure.
e. The first rain after the road has been laid may cause leaching problems. The plastic will merely form a sticky layer
f. Plastic in roads can break down into micro plastics and may find their way into soil and water bodies and pollute them.

3.5. Comparison of Plastic Roads and Ordinary Roads [33,49] (Table 3)

Comparision of plastic roads with ordinary roads can be easily understood from Table 3.

4. CONCLUSION

After studying various research papers, the following conclusions are made. The use of this innovative technology not only strengthens the roads but also increase road life and is environment friendly too.

a. Plastic mixed with bitumen and aggregate exhibit better road performance.
b. Plastic roads can withstand heavy traffic and are more durable and flexible pavement roads.
c. This technique helps in elimination of voids and path-holes, etc.
d. The plastic roads are cost efficient.
e. The process of construction of roads using plastic is easy and does not require any new equipment.
f. There is a less maintenance required and hence is more economical.
g. The idea of using plastic utilizes tremendous amount of waste plastic thus controls pollution level.

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