A Critical Review on Performance of Flexible Pavement Using HDPE and Crumb Rubber

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ABSTRACT

With the evolution of urbanization, plenteous amounts of disposed waste products like scrap rubber tires, polythene carry bags, plastic bottles, etc are generating day by day. Total waste plastic generation in India is 5.6 million tons per year, which is 70% of total plastic consumption. Being a non-biodegradable product it could not be dumped in landfills because through the erosion caused by wind and water, it will come back to the surrounding environment, which causes the risk to human health. Similarly, the accumulation of scrap tyres which are stacking up at a rate of 20% per year due to the rapid increase in the number of vehicles worldwide has become the major waste management problem. The main aim of the work is to make partial replacement of bituminous binder by recycled crumb rubber (CR) and recycled High-density polyethylene (HDPE) to improvise the various characteristics of Bituminous Concrete (BC) mix and to use discarded waste in an effective manner. This review details about the properties, advances, effects in bitumen concrete. It also states the background and deep study on pavement design with crumb rubber and HDPE.

Keywords: *Crumb rubber; HDPE; bituminous concrete; scrap tyres; plastic.*

Introduction: India is an emerging world. India's population accounts for 17.74% of the world's total, which is 1.37 billion, with a rate of growth of 1.08%. The population density is 460 per km2 with 33.6 percent of the local population. The massive population count needs not only subsistence services as well as the need for strong infrastructure growth. Since transport infrastructure plays a fundamental role in country social and economic growth. It encourages the growth of the market, seamless exchange of both individuals and commodities. It has always found itself superior to any other means of transport because of its durability, versatility of activities, and ease of access; door-to-door facility. Subsequently, in India, the flow of freight and passengers has increasingly moved to the highways, rather than other forms of transport, over the past few decades.

According to the Government of India's "National Highways Development Project' report, over the 60-year period from 1951 to 2011, the complete road length in India expanded by more than 11 times. The network services expanded from 3.99 lakh kilometers to 46.90 lakh kilometers from 31 March 1951 until 2011. Translation ally, the breadth of the paved path extended in absolute as well as proportional words. As of 31 March 2011, the number of paved highways, which was 1.57 lakh km (39.35 percent with all road lengths) as of 31 March 1951, grew to 25.25 lakh km (53.83 percent with all road lengths). In India, nearly 60 percent of the overall commodities and 85 percent of total people are carried with the usage of transport infrastructure systems. In India, too, automobile numbers are rising at an annualized rate of 12 percent, although the highway network's rate of growth has been 4 percent per annum from 1951. Because of this rise in the number of vehicles compared to road expansion, the growth of potholes, longitudinal and lateral cracks and permanent deformations in flexible pavement has been accounted for (Appiah et al., 2017) [1].

Paving plays an essential function in every road initiative. The design of each road must be conducted in such a manner that this can survive the traffic load without even any degradation and harm during its design life.

Throughout its fractional extraction, bitumen is usually produced as a synthetic oil by-product. The bitumen binder consists of a colloid multiphase structure. There are generally three groups with substances within it that are oils, resins, as well as asphalt. The separation of molten shapes petroleum and resin. Distinctive dimensions of these mixtures can prompt different types of bitumen microstructures. (Partal et al., 1999) [5]. Bitumen was used to build versatile roads for such a long period of time thanks to its water insulation and linking abilities.

The mechanical performance of bitumen depends primarily on the chemical makeup of molten as well as the quantity of asphalt that consequently reduces the binder's temperature and stress-strain behavior (Cheung and Cebon, 1997)[6].

Paving level bitumen especially used to build surface and binder courses. Bitumen continues to remain semi-solid, moist, and venomous at standard surface temperatures however its viscosity reduces and reaches fluid uniformity with temperature rises. The bitumen is heated to a temperature range of 135 to 180 ° C based mostly on the bitumen grade being used and the method of design adopted for the development of the durable pavement. The bituminous mixture is produced by combining in the hot combining plant preset amounts of "fine and coarse aggregates, filler including bitumen binder". The efficiency of bituminous blends depends on the bitumen's rheological and physical characteristics (Chen et al., 2016; Pan et al., 2015) [7, 8]. Rutting tolerance of the versatile pavement relies on the properties of a bitumen binder for 40 percent (Sybil ski et al., 2013) [9].

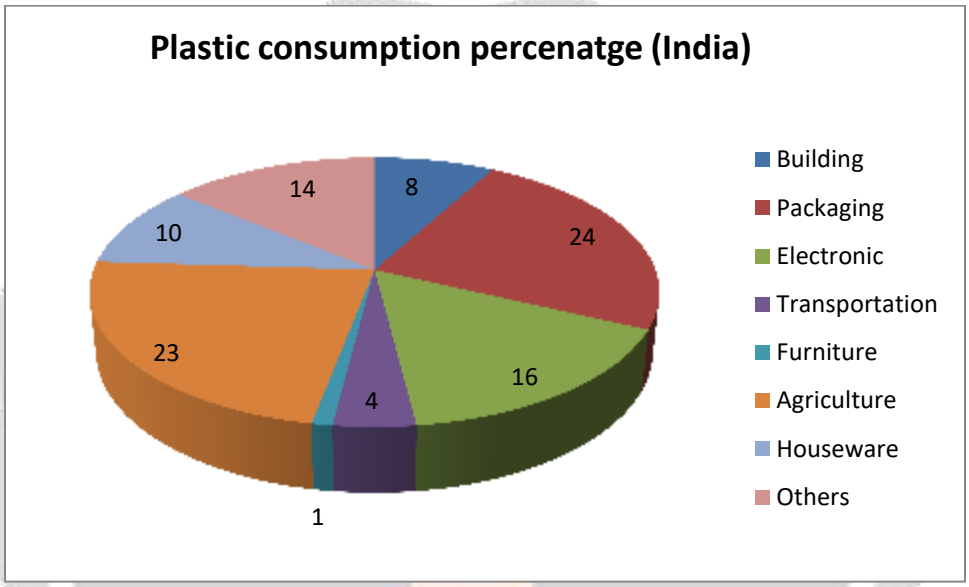

Figure 1: Plastics consumption in India

- **Need for the Modification of Asphalt Mix:** The bitumen viscosity varies considerably with a degree because about which the surface is much more heat reactive. Under high weather events, the resilient worn surface of the pavement is too elastic for the likelihood of irreversible deformation across the rim line of the automobiles and is too steep under lower temperature conditions, resulting in fractures developing under the repeated movement of a load (Masad et al., 2008)[10].
- **Desirable Properties of the Asphalt Mix:** The asphalt blend will have the following characteristics for building the levels of durable pavement:
  - Bituminous mix will have ample flexibility to withstand the permanent deformation & stresses that evolve as a consequence of repeated wheel loading conditions. The desired stiffness of the blend may be achieved by careful selection of aggregates uniformity, bitumen binder and its ratio.
  - Throughout the pavement's construction period, the bituminous blend will stay stable to tolerate the creation of cracking and wear impact. Adequate combining of binding material and aggregates may accomplish this.
  - The mix will also have the up nearly of air voids because more redevelopment of a mix with both the bleeding of bitumen mix will occur underneath the traffic flow, so that will allow the reduction of resistance to skid on the slippery roads.
  - The bituminous top surface will have ample resistance to skid right just after start of traffic movement and during pavement's maintenance window. To fulfill this criterion, coarse aggregates included in the paving will have a highly reflective appearance of marble.

Day after day weather shifts and intensified strain on tires, axle weights, auto mobiles rely on requests to improve the characteristics of the bituminous blend. Alteration of a bituminous blend has been the main approach to enhance the multiple properties. Some of the best solutions are to adjust polymers that boost the temperature sensitivity of its binding material, which implies that they improve the rigidity of the mixture at extreme temps and minimize its rigidity under lowered conditions of temperature. (King and King, 1986; Airey, 2002) [11,12].

❖ **Modification of Asphalt Mix by Use of Polymers**: Normally, the fusion of polymer compounds in the bitumen mix by chemical change or mechanical mixing will greatly enhance the properties of the traditional binder (Ahmedzade, 2013) [13]. There really are different polymers used during bitumen modification that would generally be divided into two categories: thermoplastic plastomers and elastomers (Zhu et al., 2014) [14]. Table 2.1 describes the description of the different types of polymers according to IRC: SP: 53-2010, used to adjust asphalt blend. Thermoplastic elastomers which are the form of copolymers exhibit each elastomeric and thermoplastic characteristic. Bituminous blend that is produced by adjusted elastic polymer bitumen exhibits considerably high durability which has less density modulus than traditional blends. While the blend formulated by improved bitumen from plastomeric polymer does have the same or stronger stiffness modulus than the traditional mix with no noticeable improvement in durability. But elastomeric style polymers could be used in lower temperature areas whereby larger versatility is necessary (Isacsson and Lu, 1995) [15].

Table 1 Polymer Modifier Categorization

Polymers		**Examples**
Thermoplastics	Elastomeric	Ethylene TerPolymer (ETP) SBR, SBS block copolymer ,Styrene Isoprene Styrene (SIS) etc.
	Plastomeric	Ethylene-Methyl-Acrylate copolymers (EMA), PE, Ethylene Butyl Acrylate (EBA)etc.
Rubber	Crumb Rubber/ Treated Crumb Rubber	Powdered scrap Rubber
	Natural Rubber	Rubber Powder or Latex
	Synthetic Rubber Latex	SBR latex and any other suitable synthetic rubber

❖ **Use of waste plastic for the modification:** As per the CPCB report, gross plastic waste produced in the country is 5.6 million tons each year, which constitutes 70 percent of the overall plastic use. Because of the non - recyclable existence of plastic, they will create significant environmental concerns if they spill in an unjustified manner. Plastic wastes materials are combusted to create poisonous gases like HCL, CO, and N3 - etc. Inappropriate waste disposal plastics such as HDPE, LDPE, and PP may contribute to surface water pollution due to contamination of radioactive materials such as cadmium and lead. Uses new polymers to change the binder contributes to expensive concrete development owing to their significantly higher costs relative to the traditional

binding material. Many experiments have also been produced today using the reused polymers to adjust the bitumen blend to address these problems. Basically, reused plastic wastes are grouped into seven groups, as seen in table 2.2.

Table 2 Categorization of Waste Plastics

Plastics	**Use**
PS	Loading with gel, ice cream cups, tea cups, etc.
LDPE	Bear Boxes, films
HDPE	Detergent-milk bottles, pots etc.
PET	PET flasks, water cups, etc.
PVC	Pipes, wires, flooring etc.
PP	Container films, drug tubes, snack liners, etc.
Others	Multilayer and varnished fabrics, fabrics of thermoset, acrylic Bakelite, melamine, polycarbonate etc.

As per the analysis performed by Murphy et al. (2001) [16], polypropylenes really aren't effective in changing the bituminous mix since they exhibit functional problems during processing and combining, resulting in low bitumen cohesion. It was also observed that there was not sufficient stiffness of the adjusted blend throughout the Indirect Tensile Stiffness Modulus check as LDPE used as a replacement for SBS.

Garcıa-Morales et al. (2004) [17] performed an examination using Low-Density Polyethylene (LDPE) & Ethylene Vinyl Acetate recycled as modifications as well as the findings showed the mechanical characteristics of bitumen could be strengthened by using reused polymers while the adjusted binder is used as a layer cover. Bitumen alteration by waste materials increases the thermo physical, thermal and physical characteristics of bitumen, but impact strength relies on the polymer quality in the changed binding agent. **(Naskar et al., 2010)** [18]. The key issue for reused waste polymers is the isolation between phases owing to the inadequate chemical reaction of binding material and polymers. The physical and thermal characteristics of a changed binding material could be improved by applying an irradiation method to reused polymers, that allows achieving stronger contact among binding material and polymer thanks to the gradual chain cross-linking (**Hawryluk et al. 1974; Berejka et al. 2010)** [19, 20] .

❖ **High Density Polyethylene (HDPE):** High-density polyethylene, officially shortened as HDPE or PEHD, is a synthetic polymer that due to its versatile characteristics has a broad variety of applications. While the title indicates, HDPE's absolute gravity is higher to LDPE, but the disparity isn't really that much. Because of its limited spreading, the HDPE has variation in its physical characteristics, irrespective of which it has greater tensile strength than the LDPE. HDPE exhibits strong intermolecular forces rendering it a regular polymer. Since with its

favorable properties, it can also be used in the production of different products. The HDPE's real gravity varies from 0.93 to 0.97. Being rigid and immune to a motion of effects, this can withstand the temp up to One hundred twenty ° C without even being affected. Like PP this is not autoclavable, goods should be sterilized with the usage of high temperature and pressure through the use of autoclave circumstances. HDPE holds a transparent or opaque feel. It is usually used to produce engine oils cans, chlorine jars, water bottles, or dairy pots.

❖ **Recycling of High-Density Polyethylene:** The garbage materials are obtained also by recycling firms whereby their sorting is carried out. At first, there was plastic washing, to remove any unused garbage. The plastic is then homogenized, with both the intention of recycling only HDPE, so if there are certain plastic polymers in such a collection, these can kill the finished version after reusing. The specific gravity of HDPE is far weaker than those of PET (1.430-1.450) which means that such plastic polymers may be separated by using the "Sink-Float Separation" technique. Yet HDPE does have a particular gravity close to PP's, meaning that such a product cannot be utilized. NIR devices should be used for such cases, even when the plastic becomes extremely dark and unifies those infrared waves. Before that, the HDPE is shredded and melted to enable further processing. Then the plastic is chilled in the shape of flakes which can be used again during the manufacture of plastic goods.

❖ **Modification of Asphalt mix by Recycled HDPE:** HDPE is among the polymers that could be used more quickly.

Hınıslıogluet al. (2004) [21]: A research on the alterations including its bituminous concrete blend was carried out utilizing various HDPE amounts, i.e. 4, 6 and 8%. It was observed from the tests also that 4 percent HDPE was the optimal material and for alteration with mixing time of 30 minutes and mix temperature of 165 ° C. Tests show also that HDPE adjustment dramatically improves the mix's Marshall Stability and Marshall Quotient performance that can provide improved tolerance to irreversible deformation. So, although changed BC mix flow value was expected to be comparable to those of standard mix.

The temperature vulnerability as well as the resistance to moisture of an asphalt blend could be decreased by adding HDPE throughout the asphalt binder. It is attributed to rise of the adjusted mix's tensile strength & rupture modulus. Updated HDPE blends have lower strain values than unmodified blends (Attaelmanan et al., 2011**)** [22]. As per studies carried out by Kofteci (2016) [23], the strongest results were obtained with 4 percent HDPE when various percentages of up to 4 percent were being used to change the asphalt blend. The features of the adjusted blend up to 3 percent are not much changed. Therefore, the change above 3 percent could produce the asphalt mix's beneficial benefits.

There seems to be an inappropriate chemical reaction among bitumen and reused HDPE polymer, owing to which phase separation chances occur. To solve this issue recycled HDPE is subjected to irradiation that enhances the chemical exchange between them. Because of its stiffening effect, the thermal sensitivity of bitumen could be reduced by irradiated reused HDPE (Ahmed zadeet al., 2017) [24].

❖ **Crumb Rubber:** Crumb rubber is a reused rubber that is collected from vehicle waste tyres. The tyres main components are plastics, fiber, steel, black tar, plant, and vulcanized rubber. Reuse of such products may create certain products with such a small risk of contamination. When recycled washed out tyres are collected, crumb rubber is produced.

- ❖ Cryogenic Grinding
- ❖ Ambient Mechanical Grinding

In cryogenic procedure grinding is achieved with the use of industrial refrigerants or liquid nitrogen to cool the tire chips at temperatures below - 80 ° C. In this annealing temperature, the rubber begins to lose its strength that becomes porous in nature and it could be damaged or shattered quickly.

Table 3: Chemical Properties of Crumb Rubber (Mohammad et al., 2000)

Sr. No	Major Rubber Components	Percentage
1.	Natural Rubber Content	31.0

2.	Carbon Black content	30.0
3.	Rubber Hydrocarbon	25.0
4.	Ash Content	4.0
5.	Acetone extract	10.0

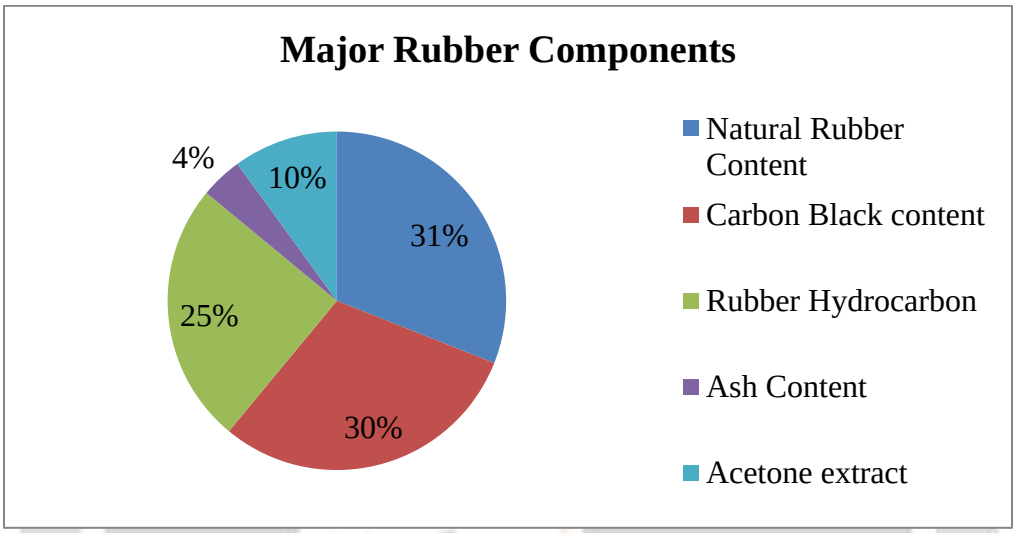

Figure 4: Major components of crumb rubber

Scrap tyres split up at the temperature of the air setting, which is either at or near the usual room temperature. This grinding method has been used where tyres are split into tiny parts by utilizing the granulator strategies and bagel mills.

For each of these methods, the magnetic current is used to isolate the steel wires from the tyres and the rubber compounds are removed with the application of vibrating sieves. Cryogenic methods used during crushing are much more costly but result produces tinny and finer crumbs.

- **Modification of Asphalt Mix by Crumb Rubber:** As per the analysis undertaken by Column et al. (2007) [25] about one billion tires are regarded as waste per year and this figure could hit 1200 million by 2030. There have been several reports about the usage of crumb rubber to adjust the bitumen blend. Modified blends of crumb rubber are far less vulnerable to humidity and temperature. We perform flexibly at a low temp and at high-temperature environments provide greater tensile strength and steadiness. CR-modified blends and traditional mixes have no variation throughout the Marshall properties; however, the CR-modified mixes' exhaustion and rutting activity is considered to be stronger than traditional (Palit et al., 2004) [26].

Xiao-qing et al. (2009) [27]: A research on the usage of mechanically devulcanized field tyre rubber (m-GTR) with SBS for bitumen modification was performed, as well as the findings revealed that both traditional and rheological characteristics of modified SBS / m-GTR binder were stronger than those of updated SBS binder.

If the dry cycle is used to adjust the bituminous blend, the density declines even as the amount of CR rises, leading to a change in the number of air voids. Regardless of its robust properties that are attributed to the recovery impact of rubber and that allows the combination less lightweight. Both of these factors, only with the introduction of a greater proportion of CR, more bitumen binder is required to ensure good consistency of the blend. (Moreno et al., 2011) [28]. The abrasion tolerance, fatigue function, creep resistance & indirect tensile strength are enhanced with the usage of crumb rubber in the BC mix (Masllam and Asi, 2018) [29].Use CR throughout the bitumen blend helps

minimize noise pollution throughout traffic flow, while provides travelers with convenience while protection while minimizing break size.

❖ **Advantages of crumb rubber:**

- An impermeable wearing course layer.
- Greater cohesion, which makes it possible to obtain structure with more critical granule metrics.
- Greater resistance to fatigue, reducing the risk of cracking.
- Greater service durability, since greater resistance to aging is achieved in adverse conditions (Juniad et al., 2014).

❖ **Salient features of the polymer-waste-bitumen mix 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.

❖ **Benefits of modified binder:-**

- Improved resistance to surface-initiated cracking due to high binder content.
- Improved ageing and oxidation resistance.
- Improved resistance to fatigue and reflection cracking due to higher binder contents.
- Improved resistance to rutting due to higher viscosity and softening points.
- Increased night time visibility due to contrast between pavement and stripping.
- Reduced tyre noise due to increased binder film thickness and opening texture.
- Reduced construction time on site.
- Lower pavement maintenance costs due to improved quality pavement.
- Help in managing hazardous waste.
- Eco-friendly method of construction, and helps maintaining balance of environment.

Conclusions

The plastic used in road construction is not new. It is already in use as PVC or HDPE pipe mat crossings built by cabling together PVC (polyvinyl chloride) or HDPE (high-density polyethylene) pipes to form plastic mats. The plastic roads include transition mats to ease the passage of tyres up to and down from the crossing. Both options help protect wetland haul roads from rutting by distributing the load across the surface. But the use of plastic-waste has been a concern for scientists and engineers for a quite long time. Recent studies in this direction have shown some hope in terms of using plastic waste in road construction i.e., Plastic roads. Waste plastic is ground and made into powder; 3 to 4 % plastic is mixed with the bitumen. The durability of the roads laid out with shredded plastic waste is much more compared with roads with asphalt with the ordinary mix. The use of innovative technology not only strengthened the road construction but also increased the road life as well as will help to improve the environment and also creating a source of income.

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