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UTILIZATION OF NON-BIODEGRADABLE PLASTIC WASTE FOR THE PLASTIC-BITUMEN MIX: A REVIEW

Divyanshu Bhatt

Department of SWCE

GBPUAT Pantnagar, Uttarakhand, India

Suman Markuna

Department of SWCE

GBPUAT Pantnagar, Uttarakhand, India

Abstract—Disposal of solid waste becomes a global issue due to it contains a large amount of non-degradable polymers. The use of plastic waste in the construction of flexible pavement found to be an excellent alternate conventional method for the extraction and recycling of non-biodegradable polymers from solid waste. Recycling techniques are alternatives and advancements in the plastic waste management process. Alternative techniques nowadays used for raw material creation for construction and another purpose. The paper reviews the performance and properties of plastic modified bitumen based on a comparative study conducted based on past research work. Physical properties of unmodified and plastic (LDPE, PET, and SBS) coated aggregate compared, the use of plastic enhanced the physical properties i.e. decreased moisture content, soundness value and bulk density, increased toughness, hardness, and strength of aggregate. The dry process suggested because high workability achieved during mixing the aggregate with plastic and bitumen. Replacing the bitumen binder with fine plastic waste reduces the different construction cost i.e. hauling cost, additional bitumen cost. Plastic modified bitumen found to be suitable for flexible pavement construction. The modification process for plastic-bitumen mix discussed and sorted based on their effectiveness and workability. This approach is economic and environment friendly can be adapted to modification in construction techniques.

Keywords—Plastic waste, plastic-bitumen mix, dry process, wet process.

I. INTRODUCTION

Nowadays solid waste management becomes major and a particularly serious problem at the global level. With the increase in the population, solid waste generation increase rapidly, therefore, management techniques i.e. composting, dumping, recycling, and thermal treatment, etc. used in

worldwide are not sufficient or environmental point of view they are pessimistic. The large volume of solid waste needs a large area for dumping that should be far from valuable natural resources (Water bodies, Agricultural land area) and residential colonies. Most of the countries or their legislation imposed taxes on the disposal of solid waste and that fund is used for proper disposal of transport of waste ethically from residential and industrial areas (Zoorob et al. 2000).

Plastic waste one of the most used polymer for domestic and industrial purpose, source of a significant amount of solid waste and also known as non-decomposable waste that took up to 1000 year to decompose but same time if that much of plastic segregated from solid waste and used for recreation purpose i.e. pavement construction, building construction, etc. The segregation process is not an unflappable task but at the initial level, segregation is quite economic and swift task. Recycling techniques are alternatives and advancements in the plastic waste management process. Alternative techniques nowadays used for raw material creation for construction and another purpose. Material recycled from plastic waste decreased the cost of raw material used for the purpose and improved the desirable properties of the structural component. The United States, India, and China followed by Brazil and Russia are the countries that have a huge road network for transportation. For the construction of one-mile paved road around 10,000 to 20,000 tonnes of aggregate and the cost depends upon the availability of aggregate and binder material (Sherwood 1995). Plastic consumption increased rapidly after 1990 for multiple uses with an increase in population due to favorable properties of plastic i.e. low-price, lightweight, durable, etc. (Banerjee et al. 2014). The U.S. placed first with 6,853,024 km roads and 75,932 km expressways followed by India 5903293 km roads and 1643 km expressways, every year expansion of road network and replacement of damaged pavement results demand of huge quantity of aggregate and binder material and high cost of raw material based on available literature minimization of cost and



enhancement in quality both could be possible by mixing 5 to 15% (by weight of bitumen) of waste plastic with bitumen mix. Plastics found in different forms cause they are artificial long-chained synthetic polymeric particles (Scott et al. 1999). Two processes widely used in industries first involve the production of olefin with the method of splitting double chemical bond and further polymerization to form C-C bonds, known as C-chain polymer i.e. polypropylene and polyethylene this reaction also known by the general reaction. Another method comprises the condensation process among the carboxylic acid and alcohol to form polyester, carboxylic acid, and amine to form polyamide. General reaction describes before furthermore used for the production of Polyurethane (Scott et al. 1999). Plastic classified into two categories, based on their thermal behavior i.e. thermoplastics and Thermoset plastics. Thermoplastics are the polymers that can harden and soften with the variation of temperature and produced from the general chain reaction. Monomers of thermoplastics connected end to end with long singular carbon chain those are independent to another chain. Exclusively build a carbon chain resist the formation of chemical bonds due to this thermoplastic can be remolded in any shape without affecting the initial physical and chemical properties of the polymer. Consequently, due to the chemical behavior of thermoplastic, they are non-biodegradable or not affected by ambient atmosphere conditions. Thermoset plastics are cross-linked heterogeneous polymer forms irretrievable chemical bonding between monomers so they harden after applying high temperature or melting. There is a completely irreversible process of converting from liquid state to solid form (Alauddin et al. 1995). Since thermoset comprises heterogeneous cross-linked monomer units, there are possibilities that thermoset plastic potentially undergoes degradation by the hydrolytic cleavage of the chemical bond, for example, ester bond or amide bonds (Muller et al. 2001).

Thermoplastics are widely used in our daily life in the form of wrapping, bottlings, and packaging materials, etc. Foremost forms of thermoplastics material consist of linear Low-density polyethylene (LLDPE and LDPE) and polyvinylchloride (PVC) use in films and packaging industries. High-density polyethylene, polyethylene terephthalate (HDPE and PET), PVC used for the production of bottles, tubes, pipes, and electric insulation molding. Polystyrene, polypropylene (PS and PP), and PVC used for manufacturing tanks, jugs, containers. Polyurethane (PUR) use for coating, insulation, paints, and packaging industries. PET and PUR are the major types of thermoset plastics out of the above-mentioned polymers (Avella et al. 2001). According to the American plastic council, at the end of the year (2004) non-biodegradable plastic comprises 92% of total plastic and remaining only 8 percent of total plastic shared by biodegradable thermosets plastic. It shows that the waste generated by thermoplastics contribute significance amount in industrial and domestic solid waste, therefore this much amount of waste can use in the construction of flexible

bituminous road construction due to its excellent properties at a high temperature helps in prevention of deformation of pavement and make bitumen mix durable at high in-service temperature. A small quantity of those synthetic polymers added to bitumen result in a high-cost reduction in the construction of road pavement. At high temperatures, low viscosities help in the reduction of power consumption costs and allow handling of bitumen at safe conditions.

This paper recapitulates the advantage of plastic waste used in flexible pavement construction and suggests the future enhancements that can help in enhancing the quality of flexible pavement and encourage the use of plastic waste as a plastic-bitumen mix binder material that reduces the plastic contamination generated from different sources. In the paper modification process for plastic-bitumen mix discussed and sorted based on their effectiveness and workability.

II. RELATED WORKS

Zoorob and Suparma (2000) investigated LDPE (low-density polyethylene) based Asphaltic concrete with the help of laboratory design. A portion of mineral aggregate, swapped by recycled shredded LDP pellets of sieve size 5.00 to 2.36 mm in the bituminous mix. The result divulged that by mixing plastic waste the bulk density of the plastiphalt blend or mix (1.99 gm/cm³) decreased as compared to the control asphaltic mix (2.37 gm/cm³) at same ambient conditions. It was stated that the total 16% reduction in bulk density of compacted mix achieved by replacing 30% (volume basis) of mineral aggregate by LDPE. Reduction in bulk density help in minimizing the haulage costs of mineral aggregate as well as mix asphaltic concrete. Marshall Stability test was designated to inspect the performance of the Plastiphalt and Asphaltic mix. It was found that the Marshall Stability value increased from 16.9 to 41.3 kN and an increase from 4.63 to 5.23 kN in the Marshall Quotient value was observed in the case of Plastiphalt with 30% LDPE, both values indicates strength and resistance to deformation on the application of load. Creep stiffness at 40°C for 1h of the loading period for Plastiphalt was found around 45% as that of Asphaltic mix but at 60°C creep, stiffness found near to each other (7.99 and 6.55 MPa for Asphalt mix and Plastiphalt mix respectively). Result also stated that creep recovery values of Plastiphalt mix (14% and 12% at 40°C and 60°C respectively) were higher than that of Asphaltic mix (3 and .6% at 40°C and 60°C respectively), which were remarkable for performance under reparative load. ITSM (indirect tensile stiffness modulus) was lower for the Plastiphalt mix but ITS (indirect tensile strength) value of Plastiphalt mix was comparatively higher than that of Asphaltic mix. The aged mix contains plastic as aggregate was also recycled and propertied after mixing 1.0% additional bitumen was compared, recycled Plastiphalt mix divulged excellent properties.

Kumar et al. (2006) examine the Polymer (linear low-density polyethylene) and Styrene butadiene styrene (SBS) based



modified bitumen mix. Bitumen of grade 60/70 and the specific gravity of 1.01 was used for the study. Oven fitted with mixing and speed regulating unit used for doping the polymer in bitumen. 3.5% of polymer separately mixed with binder at 150°C with 150rpm speed for 2h (SBS) and 30min (LLDPE). Quartzite aggregate designated for bitumen concrete and Marshall test used for calculation of optimum binder content as per ASTM D1559(1989). The optimum content 5.3 and 5.4% by weight of aggregate were found for unmodified and modified bitumen mix respectively. Viscosity curve used for calculating the mixing and compaction temperature at 0.17 and 0.28Pa s corresponding temperature for SBS and LLDPE were 175°C and 165°C respectively. Results revealed that the Marshall Stability value hike from 11.6kN (unmodified) to 16.7kN and 14.5kN for SBS and LLDPE based blend respectively. It was shown the flow value decreased slightly from 3.5mm (unmodified) to 3.3mm (SBS) and 3.1mm (LLDPE) but same time there was a slight increase in Air void percent of modified bitumen mix. ITS(indirect tensile strength) test conducted on Marshall Core's highest tensile strength 990kPa was found in the case of LLDPE mixed asphalt concrete followed by SBS mixed asphalt concrete and found negligible changes after conditioning the specimen. Dynamic creep test result divulged that at 60°C average creep strain are 2.7%, 0.9%, and 1.3% for unmodified, SB, and LLDPE mixed at the end of standard 3600 load cycles, it indicates that there was less permanent deformation in case of modified Asphalt concrete. The overall study stated that the performance of asphalt concrete or mix can be enhanced by using polymer waste material like plastic and fibers.

Bindu and Beena (2010) studied the plastic waste based modified stone mastic asphalt (SMA). Stone aggregate, Bitumen of 60/70 grade, and shredded plastic of size vary from 2 to 3mm, and OPC was used for the preparation of stone mastic asphalt. Marshall test used for the determination of the optimum quantity of binder material at 3 to 5% of air voids. The result reveals that at 4% air voids, optimum asphalt content was 6.63%. For the preparation of SMA fixed amount of 5 to 12% of finely shredded waste plastic is added with hot aggregate followed by mixing of optimum bitumen and filler material. Ordinary aggregate and plastic coated aggregate were tested for comparing their physical properties. Plastic coated aggregate shows excellent physical properties. Water absorption, soundness reduced from 0.4% and 5% to nil. Aggregate impact value and abrasion value test reveal that coated plastic increased the toughness and hardness of aggregate. Marshall Stability test results reveal that maximum stability (16.82kN) can be achieved by mixing 10% plastic waste in the mixture. Flow value was decreased with an increase in percent plastic content and Air void significantly decreased with a min value of 2.94% at 12% plastic content. Triaxial test also performs for cohesion, it was examined that at 10% plastic content cohesion increased 44% to the SMA with zero plastic content. At different temperatures from

25°C to 60°C split tensile strength was measured, the result divulged that split tensile strength increased using the plastic in SMA. Results revealed that plastic content (10%) found suitable for use in SMA.

Mahrez and Karim (2010) studied the characteristics of bitumen and waste plastic modified bitumen. An 80/100 grade bitumen with less than 100cm viscosity and having 1.03 g/cm³ bulk density used for binder material and ground waste of PET (Polyethylene terephthalate) in powder form of size between 0.45 to 0.701 mm and density of 1.37 gm/cm³ used in bitumen mix. 2, 4, 6, and 8% of waste plastic added to bitumen by weight of bitumen at 130°C for 3min. The result reveals that the penetration value continuously decreased with increase in the percent of waste material, it was stated that PET makes bitumen harder and affect the flexibility, therefore, it improve rutting resistance but also distress the resistance to fatigue strength in another hand min penetration observed 8.04 mm which comes between the 8 to 10mm penetration value. Softening point vs percent percentage PET content curve found to be linear positive, softening point increased 5% to 13% by increasing PET content from 2 to 8%, which indicates modified bitumen mix less susceptible to high and low service temperature. Brookfield viscosity test designated for observing the effect of plastic waste on the viscosity of bitumen mix. The study reveals that the viscosity at lower temperatures increased with an increase in the percentage of waste plastic but there were no significant changes observed above the 120°C temperature. DSR (Dynamic Shear Rheometer) test used for characterization of viscoelastic properties of modified and unmodified bitumen, Result divulged that there was an increase in maximum temperature for modified bitumen for better viscoelastic performance as compared to bitumen without plastic content. Corresponding max temperatures to the complex shear modulus elastic portion less than 1kPa were found 60°C, 65°C, 67°C, 67°C and 62°C for 0%, 2%, 4%, 6%, and 8% respectively and it was stated that the maximum temperature of the component of pavement helps in the hindrance of deterioration for the time of service that was maximum for 4% and 6% addition of plastic waste. The study found that adding plastic waste in bitumen with an adequate amount increased the valuable properties of binder material.

Vasudevan et al. (2010) investigated the polymer modified bitumen (PMB), the plastic used (1to 3% by weight of total) for coating for aggregate. The innovation introduced to modify the bitumen mix effectively with plastic coated aggregate (PCA). The different physical experiment was done in a laboratory, results reveal that physical properties like water absorption and void in mix decreased from 4% to below 2 % that divulged good quality for pavement. PCA shows lower impact value, crushing value and aggregate abrasion value than the aggregate without coating therefore PCA found to be more appropriate for pavement construction. Marshall Stability test conducted on the blend of 4.5% of fixed bitumen content and varying percentage of plastic from 0.25% and 0.50%, for PP (polypropylene) and LDPE respectively and



0.50% to 1% for PE (polyethylene) Foam by the percentage of total weight. Marshall Stability result divulged that the value of stability and Quotient both increased with the addition of more plastic content. The study stated that the plastic molecule and bitumen molecule namely asphaltene act together, and form interconnected highly linked structures, which makes it strong, and high elastic. Marshall Quotient value and VFB (void filled bitumen) were found around 500Kg/mm and 65% respectively, those were desirable. Finally, it was stated Dry process found to be more appropriate than the wet process, it reduces around 10% of bitumen content with desirable high strength of pavement and there has been no need used of an anti-stripping agent. An amount of rupees 20000/km reduction was initiated in the study for a single lane road.

Jeong et al. (2011) investigated the effectiveness of asphalt blend mixed with low-density polyethylene (PE), Styrene butadiene styrene (SB), and Waste polyethylene (WPE). Binder of grade 80/100 (AP-3) and 60/70 (AP-5), an aggregate of size less than 19mm and 5 to 20%, 6%, and 3% (by weight of binder) of WPE, PE and SB were used for study PMA (polymer-modified asphalt). Results reveal that the optimum value of binder bitumen for the different cases was found to be 5.1%, 5.5%, 5.2%, and 5.3% for unmodified, WPE, PE, and SB respectively. The result for 12% WPE was found satisfactory. Marshall Test for all the mix compared to the standard of Korea Ministry of construction and Transportation, test results were satisfied all criteria (Marshall Stability min 500kg and flow value should be between 20 to 40). Indirect tensile strength (ITS) test result shown that modification with plastic waste increases the tensile strength and it was highest 58% for 12% of WPE and 20% and 15% for 6% of PE and 3% of SB respectively. Wheel tracking test divulged that WPE (12%) increased more than 10-time resistance to permanent deformation than normal bitumen followed by SB. The study stated that more investigation needs to investigate the quality and performance of plastic waste for different aggregate used in pavement construction.

Manju et al. (2017) used the dry process of mixing fine plastic polymer to the aggregate; CMP (central mixing machine) was used for uniform coating over the aggregate and maintain adequate temperature. Composite study of aggregate and bitumen mix conducted with adding 10% (by weight of binder) waste plastic and without the addition of plastic. Aggregate crushing, Los Angeles abrasion test, and impact test were used for investigating the physical properties of aggregate. For bitumen penetration test, softening point, viscosity test, and widely used Marshall Stability test used for performance evaluation. Results revealed that 40% crushing value decreased by coating aggregate with 10% plastic that enhances the strength of aggregate, the toughness of aggregate was also increased due to a 9% reduction in aggregate impact value. Los Angeles abrasion test result indicated (21% reduction) that plastic coated aggregate increased the hardness of aggregate. Penetration value decreased with the adding 10% plastic content that reveals high resistance to deformation,

Softening point increased around 16% in case plastic bitumen mix that shows less susceptibility against the higher service temperature.

III. MATERIALS AND METHODS

A. Materials

The materials used for the plastic-bitumen mix are Shredded plastic (LDPE, PET, SBS) of the desirable size of 60micron, the coarse aggregate of size 9.5-4.75mm, the fine aggregate of sieve size 4.75-.075mm, filler material like inert mineral dust or other desirable powdered of size less than 100 microns.

B. Modification Process

There are two methods to use plastic waste with the bitumen: wet process and dry process. Any process can be used depending on the availability of mixing equipment.

B.a. Wet process

The wet process comprises the segregation, collection, and shredding of waste plastic into fine particles. A desirable size between 4.75mm to 2.36mm sieved and remaining plastic waste again shredded to desirable sieve size. Before mixing a desirable amount of 5% to 10% of fine plastic waste (by weight of bitumen use), bitumen heated to melting temperature of 160°C to 170°C and shredded fine plastic added to melt bitumen. Constant temperature maintains at 160°C to 170°C for 20min to 30min for well stirring and mixing of plastic and bitumen. Modified plastic bitumen further used for testing and mixing with the aggregate.

B.b. Dry process

Softening point increased around 16% in case plastic bitumen mix that shows less susceptibility against the higher service temperature.

C. Bitumen mix

A bitumen mix is a well-defined mixture of bitumen, fine aggregate, coarse aggregate, and filler. Mix designs for different components of pavement are different to maintain their stability, durability, and adequate strength of pavement components. Different types of the mix can be designed like the open-graded mix, well-graded, gap-graded. In open-graded bitumen mix filler and fine aggregate are not used which makes it high frictional material. Well-graded mix has all size aggregate and in case of gap graded large or medium size aggregate are missing.

D. Plastic-bitumen mix

Plastic-bitumen mix is an advancement in the construction of wearing components of flexible pavement. Fine shredded low-density polyethylene or other polymer mixed with bitumen with the help of dry or wet process as described above could be used directly in the construction of flexible pavement.



Generally melting point of plastic is around 110°C to 160°C, aggregates, and bitumen heated above the 160°C to ensure the easy melting, mixing, and coating of plastic over the surface of aggregate and bitumen. The dry process of plastic-bitumen mix usually uses for increasing the workability and effectiveness. Plastic and bitumen both used as a binder in the plastic-bitumen mix because plastic coated aggregate highly interconnected with the bitumen binder material and make a viscoelastic bond to resist the high and low service temperature deformation.

IV. GENERAL DISCUSSIONS

Bitumen at its pure form show excellent desirable properties for the construction of flexible pavement component wheatear it uses for repair work or construction of newly laid pavement but the cost of standard 60/70, and 80/100 coated pavement is around Rs.25lakh/km that also depend on the availability and distance of the source of material from the construction site. Plastic wastes are also carbon-rich polymer those can be used to decrease the cost of construction and to improve the durability and other physical properties as discussed in peer literature reviews. The use of plastic waste not only increased the quality of pavement but also help in the sustainable management of plastic waste generated from different sources. Commercialization of segregation and processing types of machinery could be advancing this technique that supports the reduction in plastic contamination and recycling of solid waste. Based on previous works of literature following statements could be considered:

- 1 The mixing process of plastic waste, dry process, and wet process both are effective but for comfortability and high workability Dry process should be followed.
- 2 Properties of mix depend on the percentage of plastic content and type of polymer plastic. Normally most of the plastic waste content low-density plastic in abundance, so as per the previous work mentioned about 6% to 10% of plastic waste by weight of binder material desirable for pavement construction. Higher values make the blend stiffer and cause permanent deformation of pavement.
- 3 Aggregate properties after coated with plastic i.e. moisture content, bulk density, strength, hardness, significantly improved due to lamination action over the surface of aggregate.
- 4 As per literature plastic modification makes the bitumen desirable susceptible to temperature. Low susceptibility helps asphalt to better performance at high-service-temperature and low-service-temperature.
- 5 Based on works of literature ITS and Stability test results show that modification with LDPE (5%-10%) in asphalt increased the ITS (indirect tensile strength), MS (Marshall Stability), MQ (Marshall Quotient) increased significantly. Flow value and air void decreased with an increase in percent plastic content.

The present study focused on the appropriateness of plastic-bitumen mix for its uses in the construction of flexible pavement and recycling of different waste plastic by using them in plastic-bitumen. An effective method of using plastic in bitumen discussed and reviewed. The study also focused on the complexity of the methods used for the modification of bitumen with plastic.

V. CONCLUSION

Solid waste i.e., plastic, fiber, and another polymer can be used for an alternative of aggregate for different bituminous work. Plastic waste modification not only enhances the properties of binder material but also decreases the cost of aggregate, bitumen, and hauling cost of the material. Modification processes dry process and wet process both are easy and can be used at the construction site. Dry process for plastic-bitumen mix found to be more effective than that of wet process and increase the use of high plastic content in the mix that helps in recycling of waste plastic. The plastic-bitumen mix used for flexible pavement road could be a better method to enhance the quality of flexible pavement and recycle plastic contamination generated from the different sources. Plastic and bitumen both used as a binder in the plastic-bitumen mix because plastic coated aggregate highly interconnected with the bitumen binder material and make a viscoelastic bond to resist the high and low service temperature deformation. So that the approach is effective and economic for the construction purpose.

VI. FUTURE ENHANCEMENTS

Properties of fiber-based flexible pavement could be enhanced with new techniques like mixing polymer waste with a sub-base layer in an appropriate manner; therefore, it can resist the decay of the adjacent layer of the pavement by checking water content from groundwater and another source. Local municipal authorities have to encourage and aware of the local peoples for separation of consumed waste plastic or polymer waste at an initial level that helps in easy segregation and transportation of polymer waste. Another solid waste polymer from industries and municipal waste could be used for a different component of pavement according to their wearing resistance against the repetition of loading. Normally fatigue strength of plastic and fibers are high so it could be a better option for heavy traffic volume in urban areas. Thermoplastic waste has high resistivity against chemical reaction at atmospheric ambient temperature that makes it extremely waterproof matter; therefore, plastic modified asphalt could be used in the hilly and humid area where most of the wearing surface damaged due to water.

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