International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Usage of Waste Plastic in Bituminous Mix for Flexible Pavements

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A B S T R A C T

Plastic is the most widely used material in the present times. Plastics are the non- biodegradable materials and so means to degrade our environment .Plastic wastes are one of the sources of health hazard as it is toxic in nature and it became a big nuisance in today's world. So, this plastic waste should be used as a additive material in construction to eliminate the threat to the surroundings. Also, with the increase in the pavement materials cost, alternative cheap materials are being used and mostly focused on recycled materials. Plastic coated aggregates have proved to offer better resistance to abrasion and wear & tear. According to recent researches plastic waste when mixed with bitumen gives it desired mechanical properties. Bitumen is primarily used in flexible construction pavements and when it is mixed with plastic it improves water resistivity, capacity and stability of the mix. In this process the plastic waste percentage in bitumen has to be checked. Marshall stability test is the most commonly used method to relate with field conditions. These studies showed that added plastic in bitumen mix pavements will enhance engineering properties (Marshall stability, flow, resistance to water, resistance to crack propagation) and the bond between these plastic coated aggregates and the bitumen is also very strong due to increased contact area between plastic (polymers) and bitumen .Such roads show better performance and have increased life spans. The basic intention behind this study is to replace bitumen by a conventional and non-biodegradable material which is plastic.

Keywords: Plastic waste, aggregates, bitumen, Marshall stability, flow, flexible pavement.

1. INTRODUCTION

The present study is to discuss the replacement of waste plastic in bitumen mix for flexible pavements. The replacement is observed at various percentages to see the changes in properties of the pavements, to make eco-friendly and economical.Disposal of various types of waste in different place from various sources has been a matter of concern from a long time. These materials cause several types of pollution to the environment. One of those materials are plastic which have become both a convenience and an inconvenience to society. The increasing volumes of plastics over the years create havoc on the environment, especially the non-biodegradable ones which can stay in the environment for up to 1000 years without decomposing. Plastic bags are the most commonly found sources of plastic waste, we come to see littering of plastics result into the choking of drains etc., this results into stagnation of water and leads to ill hygiene of the locality. The only way to overcome these problems is to reuse the plastic effectively.Today plastic is used in every vital sector of the economy ranging from agriculture to automobiles, electronics, constructions etc.Use of plastic materials such as carry bags, cups, etc. is constantly increasing. Nearly 50-60% of the total plastics are consumed for packing. Governmental agencies, officials, and researchers are evaluating alternative materials to construction projects. Also, with the increase in the pavement material cost, alternative cheap materials are being used mostly focused on recycled materials. Assorted studies were started to evaluate recycled materials in bitumen mixes and their effects on the performance of asphalt pavements.The use of plastic with bitumen in construction of flexible pavement not only increases its smoothness and life but helps in reducing the cost of project. The plastic bitumen roads became more durable, leaves no potholes, can withstand extreme climate changes even with temperature above 50ºc. The plastic roads are found to give better results and performance compared to the conventional bitumen roads.The use bitumen was reduced to 10% on introduction of plastic waste as filler material. Plastic filling increases the softening point of the bitumen. The plastic waste mixing improves the abrasion and slip resistance of flexible pavements allows to calculate splitting tensile strength when the plastic mixed is beyond 30% of the weight of the mix.

2. RESEARCH METHODOLOGY

2.1 MATERIALS USED

The supplies needed & utilised for research include

1. Aggregates
2. Bitumen
3. Plastic waste

Aggregates:

Bituminous materials are utilised to bond the aggregates. In a few cases, water acts as a binder and, when coupled with the rock dust, forms a slurry. Natural and produced aggregates are the two categories into which aggregates can be categorised. Once more, sand-based coarse aggregates and crushed rock-based fine aggregates or gravel make up the natural aggregates. Blast furnace slag, a byproduct of blast furnaces, is the substance that is most frequently utilised for road construction. Stone aggregate used for roadways must be tough, durable, long-lasting, and hydrophobic for bituminous surfaces. Gravel needs to be correctly graded and have a fineness modulus of at least 5.75 (6.4mm to 38mm). Sand needs to be fresh, flaky and evenlu graded.

Fig. 1- (a) Types of Aggregates

Fig. 1-(b) Aggregates

Bitumen:

Pavements are made using bitumen, a binding susbstance. Bitumen can be created from the leftovers from the refinement of naturally occuring asphalt." Mixtures of Hydrocarbons of Natural or Pyrogenous Origin, or Combination of Both, Frequently Accompained by their Non-Metallic Derivates, which may be Gaseous, Liquid, Semi-Solid or Solid, and which are completely soluble in Carbon Disulphide,"is how the American Society of Testing Materials defines bitumen. Asphalt, which is bitumen in its natural state, contains substantial amounts of solid mineral matter. When petroleum crude is refined in a refinery,they are separated by fractional distillation in the sequence of decreasing volatility.The residual bituminous residue is distillated to create straight- run bitumen. The bitumen penetration is referred to as petroleum bitumen.

Fig. 1-(c) Bitumen

Plastics:

Chemically, plastics are categorised using the polymer's backbone and side chains. There are also major subgroups within the categories of acrylics, polyesters, silicones, polyurethanes, and halogenated plastics. Additionally, plastics can be categorised into categoriesbased on the chemical techniques used to make them, such as condensation, polyaddition, and crosslinking. The two different types of plastics are thermoplastics and thermosetting polymers. Thermoplastics are plastics that can be repeatedly moulded and heated without altering their chemical composition. Some examples include polyethylene, polypropylene, polystyrene, polyethylene, and polytetrafluoroethylene (PTFE). During the thermosetting process, a chemical reaction occurs that cannot be undone. By using thermosetting technique, rubber is vulcanised. Before sulpjur heating, the polyisoprene is a sticky. Slightly fluid substance, however after vulcanization the product is rigid and non-tacky.

Fig. 1 – (d) Plastic waste

TYPES OF PLASTICS:

PET, Polyethylene terephlate HDPE (High density polyethylene), high- density polyethylene PVC , polyvinyl chloride LDPE (Low density polyethylene) , low – density polyethylene PP , polypropylene PS , polystyrene.

2.2 TESTS CONDUCTED

For bitumen

1. Penetration test
2. Softening point test
3. Ductility test
4. Viscosity test
5. Flash point and fire point

For aggregates

1. Sieve analysis of aggregates
2. Specific gravity and water absorption
3. Aggregates impact value test
4. Aggregate crushing value
5. Flakiness & elongation index test

3. METHODOLOGY

3.1 Dry process

The shredded waste plastic was sprayed over the hot aggregate melted and spread over the aggregates giving a thin coating at the surface. When the aggregate temperature is around 140^0c to 160^0c the coated plastics remains in the softened state. Over this, hot bitumen (160^0c) is added. The added bitumen spreads over the aggregate. At this temperature both the coated plastics and bitumen are in the liquid state, capable of easy diffusion at the inter phase. This process is further helped by the increase in the contact area. Therefore, the bond becomes stronger and the removal of bonded bitumen becomes difficult.

Fig. 2- (a) shredded plastic

Fig. 2-(b) Before and after coating of plastic waste to aggregates

3.2 Wet process

By adding waste plastic directly to bitumen and then heating it to a temperature of around 160^0c to create a good mix with sufficient dispersion of waste plastic into bitumen, this approach aids in the production of plastic modified bitumen. This modified bitumen is combined with the aggregates before being spread over the ground and roller-compacted.

4. LITERATURE REVIEW

Bindhu et al (2010): She investigated 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. 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.

Bharsakale et al (2012): He says that 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. 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. 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. 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 like polymer modified bitumen. The blending of recycled LDPE to asphalt mixtures required no modification to existing plant facilities or technology. Polymer modified bitumen has better resistance to temperature, water etc. the use of recycled plastics composed predominantly of polypropylene and low-density polyethylene in plain bituminous 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. Resistance to deformation of asphaltic modified with low density polythene was improved in comparison with unmodified mixes. 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.

Bilal et al (2016): He says that the earth which is the ultimate home for all organisms, nature, and even nonliving constituents is today aggressive for the survival, the way it gets polluted, reveals that in some coming hundreds of years it will be nearly impossible for organisms to live on it. The rate of waste is increasing repeatedly with time including Common food wastes, plastics, paper, cardboard, wood, leather, glass, tin cans, and textiles, yard wastes etc. World watch Institute estimates that about 100 billion polyethylene bags are thrown away each year after being used (for hauling away trash and garbage, for carrying groceries and for other routine purposes), with less than 1% being recycled. Due to the industrial revolution, Plastic is widely used not only for packaging but also for protecting, serving, and disposing all kinds of consumer's goods. Which is non-biodegradable and can stay unchanged for about 4500 years. And there for it is linked with different problems like breast cancer, reproductive and genital abnormalities' and even can affect human sperm count and quality. Countries of the world are facing problems due to inadequate disposal facilities for the solid wastes and hence commonly one can see can see open dumps of wastes not only in residential areas and road sides but also on the river banks. After disposal, a plastic bag stays for a long time in the environment and take about over 1,000 years to degrade by photo degradation a process in which sun light breaks down the plastic bags into smaller toxic particles and hence pollute air, water, and land by producing toxic substances into the environment. Hundreds of thousands of animals like sheep, goats, crows, fish, turtles etc., ingest plastic bags and get killed. One can see the plastic bags hanging in the trees and bushes, floating in the lakes and rivers, and scattered in the public recreational parks and roads. Plastic waste particularly the plastic shopping bags are responsible for the clogging and blocking of sewerage system and leads to overflow of waste or rain water to the roads and hence affecting the durability of roads infrastructure. Because changes in water content and temperature, especially excess moisture, in pavement layers combined with traffic loads and freezing and thawing can significantly reduce pavement service life. Stopping the production and usage is not going to solve the problem, efforts are needed to get rid of the load already created in our environments. For this purpose, use the plastic waste in such a way which not only reduce the plastic waste load but also improve our roads durability and make it able to cope climate change and supply opportunities to reduce oil usage, carbon dioxide emissions and the quantities of waste requiring disposal. Addition of plastic polymers to the road pavement decrease the cost and reduce pressure on landfills as well increase rate of waste reusing to strengthen road pavement. This not only make the roads resistive against permanent deformation, but also enhance the service life of the road pavement, reduce viscosity, improve stability and stiffness, crack, fatigue, abrasion improved and reduce the thickness of the road pavement.

Agrawal et al (2016): He says, flexible pavements are especially important in present scenario. But Bituminous binders are causing bleeding in hot climate, cracks in cold climate, rutting, pot holes and its water resistance is poor. So, they think for alternative, plastic waste are non-biodegradable thus they can be used as bitumen modifier and aggregates to increase their strength. It is economical as well as the uses of plastic waste improve abrasion and slip resistance of flexible pavement. Here the author followed wet process of mixing of waste plastics in bitumen. Here plastic waste is grounded & converted into powder form; now 3 - 4 % plastic is mixed with bitumen. By this, melting point of bitumen is increased by using plastic, thus during winter season flexibility is preserved. He also said that the ability of bitumen to withstand higher temperatures can be increased by mixing plastic with bitumen. He saw that Blending occurs when temperature reaches 45.5ºC but when plastic is mixed; it remains at 55ºC. The test proves that bitumen concrete mixes made from treated bitumen binder fulfilled every Marshall Mix design criterion for road pavement. Another observation is that it can withstand adverse soaking condition for higher duration. He also explains the dry process. The shredded plastic is to spray over the hot aggregate is melted and spreaded over the aggregate; it gives a thin coating at surface of aggregate. At 140 - 160ºC temperature, the coated plastic stays in the softened state, in the next process; hot bitumen (160ºC) is added.

Abdo et al (2017): He says that, the cost of bitumen increased day by day, so we need to think for alternatives. Waste plastics are good alternative and improving properties of aggregates in place of bitumen and the use of recycled waste materials as modifier additives in hot mix asphalt (HMA) could have several economic and environmental benefits. The use of recycled waste materials as modifier additives in hot mix asphalt (HMA) could have several economic and environmental benefit. He says based on recent studies determine asphalt mixes containing plastic waste exhibited improvement in engineering properties (i.e., Marshall stability, resistant to water, and resistant to crack propagation). They include plastic different percentages, the use of plastic waste as an asphalt binder modifier with 4, 6 and 8% by weight of optimum binder content and conduct different tests. Results showed that Plastic Waste Modified Bitumen (WPMB) mix yielded higher Marshall Stability, higher retained stability, and higher indirect tensile strength than a conventional mix with an increase of 10% in Marshall Stability, 7% in Marshall retained stability and 9% in indirect tensile strength. The penetration values and the temperature susceptibility decreased and the softening point increased with the increase of plastic waste content. In addition, modified asphalt mixes performed better than conventional mixes when it came to stability, tensile strength ratios (TSRs), and resilient modulus values at high temperatures with smaller strain values. Here they investigated that addition of shredded plastic waste bottles to asphalt mixes by evaluating various mix properties; Marshall Stability, flow, bulk density, air voids, and voids filled with binder. They concluded that adding 8% plastic waste to coat aggregates led to the highest Marshall stability. He conducted Dynamic modulus test used to determine the stiffness of the mix at different temperatures. He also uses 3D move analysis software, the software can apply different moving traffic load, traffic velocity, axle configurations, and tire contact area to a pavement structure with different material properties.

Khater et al (2018): He says Asphalt pavements are deteriorating rapidly and pavements life is becoming shorter than what asphalt pavements were designed for. They noticed that asphalt pavements are not performing as expected, especially with permanent deformation (rutting). In addition to that asphalt pavement materials cost increases rapidly, so there is necessity to replace with alternative material which are effective and economical. They decided to use of recycled waste materials as modifier additives in hot mix asphalt (HMA) could have several economic and environmental benefits .Based on certain experiments they concluded that, asphalt mixes containing plastic waste exhibited improvement in their engineering properties (i.e. Marshall stability, flow, resistant to water, and resistant to crack propagation).Based on their findings, the use of plastic in these roads proved to enhance their resistance to monsoons and everyday wear and tear when compared to traditional pavements and it extended the life of asphalt pavements by two more years (Khulla, 2009).He examined the use of plastic waste as an asphalt binder modifier with 4, 6 and 8% by weight of asphalt binder content. Test results showed that mixes with 4% plastic waste were highly resistant to permanent deformation (rutting) and yielded the highest Marshall stabilities and the smallest flows. Results showed that Waste Plastic Modified Bitumen (WPMB) mix resulted in higher Marshall stability, higher retained stability, and higher indirect tensile strength than a traditional mix with an increase of 10% in Marshall stability, 7% in Marshall retained stability and 9% in indirect tensile strength. Plastic waste was obtained by collecting waste mineral water plastic bottles. Plastic bottles were then cut, shredded, then grinded to obtain plastic waste powder with a particle size passing 150μm and retained on 75μm sieves. Then the plastic waste powder was added to the tested asphalt binders at 0.2, 0.5, 1.0, and 5.0% by weight. Here, they conducted Rotational Viscosity Test for determining stiffness of the asphalt binder at different temperatures and Binder Dynamic shear modulus determined using the Dynamic Shear Rheometer (AASHTO T315-12 (AASHTO, 2012)). By these tests they concluded that, adding plastic waste to asphalt binder increased its viscosity for all tested asphalt binders. Thus, it is expected that adding plastic waste to asphalt binder would increase it stiffness, which would enhance its rutting resistance at operational temperature.

Asare et al (2019): He stated that, indiscriminate disposal of plastics by the roadside, riverside and public places have resulted in the choking of gutters as well as cattle consume plastic wastes that is exposed to them mostly at refuse dump sites leads to suffocating of castles. He says plastic waste is usually handled using the three R's, namely re-use, recycle and recovery (or disposal). He can determine the optimum percentage of asphaltic materials that could be incorporated with plastic wastes for road construction. The consequences of not properly managing plastic wastes are far reaching from health-related issues to increasing future financial burdens. Plastic roads or roads made from plastic have been tried and proven to be the best way by which plastic wastes can be managed. This is because such roads are more durable, leaves no potholes, can withstand extreme climate changes even with temperatures above 50°C and can last up to 10 years compared with conventional roads that can last up to 5 years Verma (2008). According to Vasudevan et al. (2012), a tonne of plastic waste is used for every 1 km of road laid. This is supposed to reduce carbon dioxide emission by 3 tonnes. The number of roads built with plastic wastes in India is over 2500 km and this led to a reduction of about 7500 tonnes of carbon dioxide from the environment. He said that, there are two main methods that are needed for the process. They are Dry process and Wet process. He explained, in Dry process after the separation of plastic wastes from non-plastics, the plastics are washed and shredded to smaller sizes. After the shredding is done, the aggregates are heated up to 170°C and the plastic wastes are added which softens and melts (but does not burn) to form a coating around the aggregates. The bitumen is also heated to 160°C. The plastic-coated aggregates are mixed with the bitumen and used for road construction. The road properties were improved with this practice. In wet process, After the washing, the plastics are ground into powder. 6–8% of this is directly mixed with the bitumen before adding to the aggregates. The used low-density polyethylene (LDPE) plastic was used for the dry process and crumb rubber was used for the wet process. Different percentages of these were used for the experiment where the Marshall method was employed. Five per cent of the bitumen content of the 60/70 grade was used whereas 3%, 6% and 9% of LDPE and 8%, 10% and 12% of the crumb rubber were used in the experiment. The results for the LDPE mix showed that increasing the percentage of the plastic also increased the Marshall Stability and bulk density. On the other hand, values for the Marshall stability increased with that of the crumb rubber up to 10% and then decreased but the bulk density increased up to 12%. He the author conducts different tests in waste plastic coated aggregate to assess their behavior.

Bhardwaj et al (2020): He says that there are certain properties of plastic which are like that bitumen such as melting point, setting time and ductility; they both can be used as a binder. The water repellent property of plastic can also be utilized to make more durable road in regions receiving higher annual average rainfall. Till now, only 8% of partial replacement of bitumen has been achieved via wet mix process, and15% partial replacement of aggregates has been seen via dry mix process. Bitumen is a by-product which is obtained during the distillation of crude oil and owns favorable properties. So that it can be used in road construction such as having a melting point of around 110–120 °C. Bitumen is nontoxic and has high molecular density, so it acts as a strong adhesive; hence, it can bind the aggregate all together even in loading conditions of vehicles. Opting Marshall mix design method for design of wearing course of flexible pavement. This test helps to figure out the optimum bitumen and plastic content that can be mixed. Thermal behavior

of bitumen is quite suitable for working with bitumen; when plastic heated at 165 °C, there is no evolution of toxic gases. When heated above 270 °C, they start to decompose and around 750 °C they get burnt and evolve harmful gases. Recycle plastic is generally of low-density polyethylene, and their use has increased the durability and fatigue life of flexible pavement. Polymer bitumen bland helps in better binding of plastic-coated aggregate and bitumen. The effective ways to reutilize the rigid plastic into road construction; where plastic is used as a bitumen modifier, the plastic content can be increased 5–10% by weight of bitumen. Fatigue life and abrasion value are found to be increased due to introduction of modified bitumen. The optimum quantity of the waste plastic is 10% in most of the investigations. Investigation shows that PVC up to 10% can be used for bitumen pavement in warm regions so that bleeding can be cured. Plastic bottles, cups, mugs, etc. can be reused by powdering and blending.

Arora et al (2021): He says that the bitumen roads are not performing well. Maintenance cost of the road increases and it causes economic burden to the tax payers. It is also not safe to travel on the deformed (rutting) roads. Plastic waste helps to increase the melting point of bituminous pavement. Waste plastic added over hot aggregate with bitumen to give higher strength and resistance to water. On these roads the main cause factor is heavily loaded trucks and continuous moving vehicles and after that heavy rainfall. Study investigated that the coating of plastic layer reduces the porosity, cavity of aggregates, absorption of moisture and improves soundness. Use of bio-medical plastic waste in bituminous road construction, in this study that the Marshall stability value of waste plastic to change bituminous mix that found to be 51% more than normal mix then it gives and found it increases the load carrying capacity of pavement. The rutting performance of asphalt mixtures that percentages (0%,0.25%,0.5%,0.75%,1%) and PET sizes 10 × 2.5, 20 × 2.5, and 30 × 2.5 mm were evaluated through dynamic creep test and Hamburg wheel tracking device. Results got that the rutting resistance of mixtures increases by addition of PET contents with increase in PET sizes. Using rice husk ash (RHA), as a waste byproduct of rice milling addition of 20% RHA with bitumen penetration grade, ductility, softening point, rotational viscosity and dynamic shear rheometer were conducted result got 20% RHA sample was the better mix about rutting resistance.

CONCLUSION

Usage of waste plastic in bituminous road is found to be sustainable practice by incorporating a waste material into bituminous roads and making the roads to sustain for a longer life. From the past studies it has been observed that waste plastic incorporated into bituminous road either by dry process or wet process. The dry process includes coating of aggregates with waste plastic and wet process includes direct mixing of waste plastic into bitumen.

The literature review reveled that the plastic incorporated bituminous mix are observed to have a better performance in terms of Marshall stability, moisture sensitivity, fatigue, and rutting performance. The bitumen obtained from the wet process is blended with waste plastic therefore the bitumen thus obtained is a modified bitumen. The modified bitumen can have the properties like viscosity and fatigue resistance quite difference from virgin bitumen.

Several studies were done on types of plastic to be incorporated into bituminous mix. Types of plastic used in bituminous mix are Low density polyethylene (LDPE), High density polyethylene (HDPE), Polyethylene terephthalate (PET), Polyurethane.

LDPE is mostly used for bags (grocery, dry cleaning, bread, frozen food bags, newspapers, garbage), plastic wraps; coatings for paper milk cartons and hot & cold beverage cups; some squeezable bottles (honey, mustard), food storage containers, container lids.

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