UTILIZATION OF WASTE PLASTIC AS A BINDER REPLACEMENT IN BITUMEN

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Abstract

Plastic which is toxic in nature is found to be nearly 5% in Municipal Solid Waste (MSW). A major problem now a days is the disposal of plastic wastes. These wastes are non-biodegradable in nature causing environmental pollution and hygiene problems. The experimentation at several institutes indicated that waste plastic can be utilized in asphalting of roads. The use of these wastes in the road construction is based on Economic, Technical and Ecological criteria. Taking an example of PAKISTAN (Karachi) several million metric tons plastic wastes are produced every year. If these wastes can be suitably use in road construction, the disposal and pollution, problems can be minimized to a large extent. In road making process bitumen is used as a binder. The bitumen can be modified with plastic wastes forming a mix which can be used as a top layer of flexible pavement, showing better binding property, stability, density and which is more resistant to water. In this project we use waste plastic in bitumen by 0%, 3%, 5%, 8% and 10%. We conclude from all test results that with addition of plastic penetration and ductility value decreases while softening point, flash & fire point increases.

Keywords : plastic wastes, binding property, road construction, Ecological criteria

I. Introduction

For many years, researchers and development chemists have experimented with modified bitumen mainly for industrial uses, adding asbestos, special filler, mineral fibers and rubber. In the last thirty years many researchers have looked at a wide spectrum of modifying materials for bitumen’s used in road construction.
L. A. Pereide Oliveira (2013) studied the possibility of using finely waste plastic aggregate mix with natural aggregate replacement in road. The results showed a very significant compressive strength improvement with the increase of percentage replacement of plastic aggregate with natural aggregate. A higher compressive strength was obtained with a lower expansion verified by the bar tests. The results of previous studies showed that use of waste plastic in asphalt mixture improved the engineering properties such as Marshall Stability, resistant to water, binding property for the bitumen mix and increase in the road life (Chavan, 2014). Several studies have been conducted to investigate the use of plastic waste in bitumen mixture of the flexible pavement. (Swami and Jirge, 2012). [I]

Study was done by Mahabir Panda and Mayajit Mazumdar using 80/100 penetration grade bitumen and Ethylene Vinyl Acetate (copolymer. The study shows that there was an increase in stability value in case of polymer modified bitumen. Stability value was high as 14kN in case of polymer modified bitumen. Tensile strength was also increased and stripping properties were improved. [II]

Another study was done by Sharma D K and others using 60/70 penetration grade bitumen. Here waste plastic/polymer was used as modifiers. The waste plastic/polymer was added on the aggregate before mixing Optimum Binder Content in dry process at 150-160°C temperature. This type of mixing increases the bonding between aggregates coated with plastic/polymer which increases the strength of the bituminous concrete mixes. Stability values and indirect tensile strength values were observed to be more in polymer modified bitumen than in conventional bitumen. Rutting values were also higher in polymer modified bitumen mixes than in conventional mixes. [III]

Another study was carried out by Shivangi Gupta and Veeraragavan. They used 60/70 penetration grade bitumen and Styrene Butadiene Styrene (SBS) modified binder. Here tests were conducted by two methods, marshal stability and Superpave Gyratory Compactor and results of these two methods were compared. The test results showed that SBS modified bitumen mixes were superior to the conventional mixes but as far as marshall method is concerned method shows better results. Strength parameters like tensile strength, marshal stability values of modified mixes were higher than 21% to 25% than that of conventional mixes. Fatigue life of SBS modified binder mix was 2.1% to 2.4% higher than the conventional. [IV]

Bangalore Process (2002), presented a study regarding plastic roads. A 25 km plastic road was laid in Bangalore. The plastic road showed superior smoothness, uniformity and less rutting as compared to a plastics-free road laid at the same time, which began developing “crocodile cracks” soon after. The process was also approved in 2003 by the (Central Road Research Institute Delhi). Road life improves through improved tackiness and viscosity of the bituminous mix, thereby binding the stones more firmly together and improving the water-resistance of the mix to rain etc. [V]

Justo et al (2002), at the Centre for Transportation Engineering of Bangalore University performed tests on the possible use of the processed plastic bags as an
additive in bituminous concrete mixes. The properties of the modified bitumen were compared with ordinary bitumen. It was observed that the penetration and ductility values of the modified bitumen decreased with the increase in proportion of the plastic additive, up to 12% by weight. Therefore the life of the pavement surfacing course using the modified bitumen is also expected to increase substantially in comparison to the use of ordinary bitumen. [VI]

Mohammad T. Awwad et al (2007), polyethylene as one sort of polymers is used to investigate the potential prospects to enhance asphalt mixture properties. The objectives also included determining the best type of polyethylene to be used and its proportion. Two types of polyethylene were added to coat the aggregate high density polyethylene (and low density. The results indicated that ground polyethylene modifier provides better engineering properties. The recommended proportion of the modifier is 12% by the weight of bitumen content. It is found to increase the stability, reduce the density and slightly increase the air voids and the voids of mineral aggregate. [VII]

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

Bindu et al. investigates the benefits of stabilizing the stone mastic asphalt mixture in flexible pavement with shredded waste plastic. Conventional (without plastic) and the stabilized stone mastic asphalt mixtures were subjected to performance tests including Marshall Stability, tensile strength and compressive strength tests. Triaxial tests were also conducted with varying percentage bitumen by weight of mineral
aggregate (6% to 8%) and by varying percentage plastic by weight of mix (6% to 12% with an increment of 1%). Plastic content of 10% by weight of bitumen is recommended for the improvement of the performance of Stone Mastic Asphalt mixtures. 10% plastic content gives an increase in the stability, split tensile strength and compressive strength of about 64%, 18% and 75% respectively compared to the conventional stone mastic asphalt mix. Triaxial test results show a 44% increase in cohesion and 3% decrease in angle of shearing resistance showing an increase in the shear strength. The drain down value decreases with an increase in plastic content and the value is only 0.09 % at 10% plastic content and proves to be an effective stabilizing additive in 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. Stabilizing additives are needed in the mastic which is rich in binder content to prevent the binder from draining down from the mix. Polymers and fibers are the commonly used stabilizing additives in stone mastic asphalt. Based on many research reports and engineering case studies has been shown that the use of stone mastic asphalt on road surfaces can achieve better rut-resistance and durability. Recycled low density polyethylene of a size between 0.30 and 0.92 mm replacing 15% aggregates in asphalt surfacing nearly doubled the Marshall quotient, and increased the stability retained by 15%, implying improved rutting and water resistance. A 20% increase of binder content was required in this case. [IX]

Sangita et al. (2011) suggested a novel approach to improve road quality by utilizing plastic waste in road construction. According to them India spends Rs.35,000 crores a year on road construction and repairs, including Rs.100,000 crores a year just on maintenance and roads by bitumen modification lasts 2-3 times longer, which will save us Rs.33,000 crores a year in repairs, plus reduced vehicle wear and tear.[X]

Sabina et al. (2009) evaluated the performance of waste plastic/polymer modified bituminous mix and observed that the results of marshal stability and retained stability of polythene modified bituminous concrete mix increases 1.21 and 1.18 times higher than that of conventional mix by using 8% and 15% (by weight of bitumen) polythene with respect to 60/70 penetration grade of bitumen. But modified mix with 15% polyethylene showed slightly decreased values for Marshall Stability than that of the mix with 8% modifier in their results [XI].

Yousefi (2009) stated that the polyethylene particles do not tend to rip in bitumen medium and these particles prefer to join together and form larger particles due to interfacial and inter-particle attractive forces and the only obstacle in the modification process was the existence of partitions made from molten bitumen. According to the author whenever, particles had enough energy to come close together and overcome the thin remained bitumen film which was separating particles, the coalescence of polyethylene particles occurred and lead to polymer phase separation [XII].

Verma (2008) studied that plastic increases the melting point of the bitumen and makes the road flexible during winters resulting in its long life. According to author
while a normal “highway quality” road lasts four to five years, plastic-bitumen roads can last up to 10 years and it would be a boon for India’s hot and extremely humid climate, where temperatures frequently cross 50°C and torrential rains create havoc, leaving most of the roads with big potholes [XIII].

Moghaddam and Karim (2012) reported that the utilization of waste material in asphalt pavement would be beneficial in order to find an alternative solution to increase service life of asphalt pavement and reduce environmental pollution as well. From their study it is concluded that Polyethylene Terephthalate (PET) reinforced mixtures possess higher stability value, flow, fatigue life in comparison with the mixtures without PET [XIV-XV].

II. MATERIALS AND METHODS

The main objective of this chapter is to discuss the materials and test methods involved in our research. The Plastic as a binder in bitumen, their mixtures and laboratory properties. Also the methods of sample preparation from the above materials and find penetration, ductility, softening, flash and fire point at different percentages of plastic waste as a binder in bitumen.

a. Materials

Three main ingredients, plastic waste aggregates, natural aggregates and bitumen were used in this project. We collected plastic waste aggregates from Marks Company, Industrial State, and Hayatabad. This locally available low density polyethylene plastic aggregate were brought to Transportation Laboratory, Iqra National University Peshawar.
Figure 1. Both High density & low density

b. Methodology: Flash and Fire Point Test

Aim: To determine the flash and fire point of bitumen.

Bituminous material leave out volatiles at high temperatures depending upon their grade. These volatile vapors catch fire causing a flash. The flash point is the lowest temperature at which flash occurs due to ignition of volatile vapours when a small flame is brought in contact with the vapours of a bituminous product, gradually heated under standardized condition. When bituminous material is further heated to a higher temperature, the material itself catches and continues to burn; the lowest temperature causing this is the fire point. Fire point is always higher than flash point.

c. Flash Point:

The flash point of a material is the lowest temperature at which the application of test flame causes the vapours from the material to momentarilry catch fire in the form of a flash under specified conditions of the test.

Figure 2. Flash point
d. Fire Point:
The fire point is the lowest temperature at which the application of test flame causes the material to ignite and burn at least for 5 seconds under specified conditions of the test.

![Fire Test Image](image)

Figure 3. Fire Point

III. Procedure of flash point:

i. Soften the bitumen between 75 and 100°C. Stir it thoroughly to remove air bubbles and water.

ii. Fill the cup with the material to be tested upto the filling mark. Place it on the bath. Fix the open clip. Insert the thermometer of high or low range as per requirement and also the stirrer, to stir it.

iii. Light the test flame, adjust it. Supply heat at such a rate that the temperature increase, recorded by the thermometer is neither less than 5°C nor more than 6°C per minute.

iv. Open flash point is taken as that temperature when a flash first appears at any point on the surface of the material in the cup. Take care that the bluish halo that sometimes surrounds the test flame is not confused with the true flash. Discontinue the stirring during the application of the test flame.

v. Flash point should be taken as the temperature read on the thermometer at the time the flash occurs.

a. Procedure of Fire point:

i. After flash point, heating should be continued at such a rate that the increase in temperature recorded by the thermometer is neither less than 5°C nor more than 6°C per minute.

ii. The test flame should be lighted and adjusted so that it is of the size of a bead 4mm in dia.
IV. Determining the Ductility of Bitumen:

Aim:

i. To measure the ductility of a given sample of bitumen

ii. To determine the suitability of bitumen for its use in road construction.

The ductility test gives a measure of adhesive property of bitumen and its ability to stretch. In flexible pavement design, it is necessary that binder should form a thin ductile film around aggregates so that physical interlocking of the aggregates is improved. Binder material having insufficient ductility gets cracked when subjected to repeat traffic loads and it provides pervious pavement surface. Ductility of a bituminous material is measured by the distance in centimeters to which it will elongate before breaking when two ends of standard briquette specimen of material are pulled apart at a specified speed and specified temperature.

![Figure 4. Ductility in Bitumen](image)

a. Procedure:

i. Melt the bituminous test material completely at a temperature of 75°C to 100°C above the approximate softening point until it becomes thoroughly fluid.

ii. Strain the fluid through IS sieve 30.

iii. After stirring the fluid, pour it in the mould assembly and place it on a brass plate. In order to prevent the material under test from sticking, coat the surface of the plate and interior surfaces of the sides of the mould with mercury or by a mixture of equal parts of glycerine and dextrine.

iv. After about 30-40 minutes, keep the plate assembly along with the sample in a
v. Water bath. Maintain the temperature of the water bath at 27° C for half an hour.
vi. Remove the sample and mould assembly from the water bath and trim the specimen by levelling the surface using a hot knife.

vii. Replace the mould assembly in water bath for 80 to 90 minutes.

viii. Remove the sides of the mould.

ix. Hook the clips carefully on the machine without causing any initial strain.

x. Adjust the pointer to read zero.
xii. Note the distance at which the bitumen thread of specimen breaks.

Mean of two observations rounded to nearest whole number is ductility value.

b. Precautions

i. The plate assembly upon which the mold is placed shall be perfectly flat and level so that the bottom surface of the mold touches it throughout.

ii. In filling the mold, care should be taken not to distort the briquette and to see that no air pocket is within the molded sample.

V. Results

This chapter discusses results obtained from various tests carried out in the lab and their results are shown in the following tables.

![Graph of Penetration Test](image)

Table 4. 1 Penetration test results
The penetration test determines the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. The bitumen grade is specified in terms of penetration value. Samples having different percentages of plastic waste in bitumen were prepared and their penetration values determined as in above Table 4.1. The penetration value of blends is decreasing depending upon the percentage of polymers and the type of polymers added. The increase in percentage of polymer decreases the penetration value. This shows the addition of polymers increases the hardness of bitumen.

| Penetration Value |
|-------------------|
| 56 | 60 | 64 | 69 | 74 |
| 56 | 61 | 65 | 74 | 80 |

Table 4.2 Softening point test results

The softening is the temperature at which the substance attains a particular degree of softening under specific conditions of test. The softening point of bitumen is usually determined by ring and ball test. Generally, higher softening point indicates lower temperature susceptibility and is preferred in warm climates. The blend of different percentages of plastic waste has been prepared and their softening point were determined in the above Table 4.2. It is observed that the softening point increases by the addition of plastic waste to the bitumen. Higher the percentage of plastic waste added, higher is the softening point.
It is important that the binder from ductile thin films around the aggregate. The ductility is expressed as the distance in centimeters to which a standard briquette of bitumen can be stretched before the thread breaks. Sample with different percentage of plastic in bitumen were prepared and ductility was checked. The table 4.3 shows that the ductility is decreasing by the addition of plastic waste to bitumen. The decrease in the ductility value may be due to interlocking of polymer molecules with bitumen.
The studies of fire point of plastic waste-bitumen helps to understand the inflammability nature of the blend.

“Fire point” the fire point is the temperature at which the material get ignited and burns under specific conditions of test. Open cup are used for conducting the test. Fire point of bitumen is 175°C-210°C. From the experimental result it is observed that the inflammability of blend is decreasing as the percentage of polymer increases. The blend has develop better resistance to burning. The polymer bitumen blend rod surfaces will be less effected by fire hazards.

Table 4. 4 Fire point test results

| Polymer Percentage | Low density (°C) | High density (°C) |
|--------------------|------------------|-------------------|
| 0%                 | 210              | 210               |
| 3%                 | 210              | 210               |
| 5%                 | 210              | 210               |
| 8%                 | 210              | 210               |
| 10%                | 210              | 210               |

Table 4. 5 Flash point test results

| Polymer Percentage | Low density (°C) | High density (°C) |
|--------------------|------------------|-------------------|
| 0%                 | 170              | 170               |
| 3%                 | 170              | 170               |
| 5%                 | 170              | 170               |
| 8%                 | 170              | 170               |
| 10%                | 170              | 170               |
The studies of flash point of plastic waste-bitumen helps to understand the inflammability nature of the blend.

Flash point “the flash point of a material is the lowest temperature at which the vapours of the substance momentarily takes fire in the form of a flash under a specified conditions of test.

From the experimental result it is observed that the inflammability of blend is decreasing as the percentage of polymer increases. The blend has develop better resistance to burning. The polymer bitumen blend rod surfaces will be less effected by fire hazards.

VI. Conclusion

There is no proper solid waste management system for Peshawar city. Mostly people throw the waste in their streets, where it is either picked up by scavengers or dumped there for years. In relatively developed areas of the city, scavengers collect the waste and dump it in an open area usually at a distance from densely populated area. Existing landfills of the city are not well designed. Open burning of waste on the dumpsites was observed.

I. Recommendation

- The effect of modification on moisture susceptibility of asphalt mixes was not studied in this research it is recommended that research should be conducted on this aspect.
- The effect of other modifiers such as Crumb Rubber, fiber Glass etc. should be evaluated to enhance the hot mix asphalt properties according to local load climatic conditions.
- Field performance of modified asphalts should be studied. Wheel tracking test can be referred as simple performance test for the comparison of rutting resistance of various asphalt mixes.
- Compressibility and compressive strength after compaction by vibration test should be performed for further investigation.
- Adhesion of bitumen test should be performed
- Should be tried with different grain sizes. In this research retained on Sieve # 4 were used.
- Mixtures of Low Density Polyethylene with other plastics may be used
- Different grade of bitumen and different percent compaction can be used.
- Binder content may be changed for future research.
- Cost analysis should be done for aggregates preparation.
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