A Study of Enhancement of Bituminous Mix by Use of Modifiers

Mr. Ghorpade M. R. ¹ & Prof. Mr. Desai D. B. ²
¹PG Student, Civil Engineering Department, Dr.J.J.Magdum College of Engineering, Jaysingpur, Maharashtra, India.
²Professor, Dr.J.J.Magdum College of Engineering, Jaysingpur, Maharashtra, India.

Abstract: Flexible pavements with bituminous surfacing are widely used in road construction. The high traffic intensity in terms of commercial vehicles, overloading of tracks and significant variations in daily and seasonal temperature of the pavement have been responsible for early development of distress like rutting, cracking, bleeding, shoving and pitholing of bituminous surfacing. A factor, which causes concern in India, is very high and very low pavement temperature conditions in some parts of the country. Under these conditions the bituminous surfacing tends to become soft in summer and brittle in winter.

Bitumen as a visco-elastic material plays a prominent role in determining many aspects of road performance. A bituminous mixture needs to be flexible enough at low service temperatures to prevent pavement cracking and to be stiff enough at high service temperature to prevent rutting. Flexible pavements containing conventional bitumen do not always perform as expected. The properties of bitumen and bituminous mixes can be improved/modified with the incorporation of certain additives or blend of additives which are called as “modifiers”. Use of modified bitumen in the top layers of the pavement is expected to significantly enhance the life of the surfacing and extend the lifetime of the next renewal.

1. Introduction:

Bitumen is an oil based substance. It is a semi-solid hydrocarbon product produced by removing the lighter fractions (such as liquid petroleum gas, petrol and diesel) from heavy crude oil during the refining process. The vast majority of refined bitumen is used in construction: primarily as a constituent of products used in pavement wearing (surface) course and roofing applications. Bituminous materials are also used for stabilizing the other layers of flexible pavements. Basically bituminous materials are thermoplastic hydrocarbons which possess high molecular weight. They tends to soft on heating and hard on cooling. Bitumen has been widely used in the construction of flexible pavements for a long time. This is the most convenient and simple type of construction. In some of the applications, however, the performance of conventional bitumen may not be always considered satisfactory because of the following reasons:

- In summer season, due to high temperature, the bitumen becomes soft resulting in bleeding, rutting and segregation finally leading to failure of pavement.
- In winter season, due to low temperature, the bitumen becomes brittle resulting in cracking, raveling and unevenness which makes the pavement unsuitable for use.
- In rainy season, water enters the pavement resulting into pot holes and sometimes total removal of bituminous layer.
- In hilly areas, due to subzero temperature, the freeze thaw and heave cycle takes place. Due to freezing and melting of ice in bituminous voids, volume expansion and contraction occur. This leads to pavements failure.
- The cost of bitumen has been rising continuously. In near future, there will be scarcity of bitumen and it will be impossible to procure bitumen at very high costs.

To overcome these difficulties, the properties of bitumen and bituminous mixes can be improved/modified with the incorporation of certain...
additives or blend of additives. These additives are called “modifiers”. Use of modified bitumen in the top layers of the pavement is expected to significantly enhance the life of the surfacing and extend the lifetime of the next renewal. The (IRC SP: 53 :2010) has given classification of Rubber and Polymer based Bitumen modifiers as:

i. Plastomeric thermoplastic based,
   ii. Elastomeric thermoplastic based,
   iii. Synthetic Rubber Latex,
   iv. Natural Rubber,
   v. Crumb rubber/ treated crumb rubber.

Modified bitumen shows greater strength, versatility and it is also economical. Due to these features, they are accepted across the world. The bitumen reserves are degrading fast everywhere, hence to preserve the bitumen the modified binders are greatly helpful.

2. **Modifiers:**

Unmodified asphalt is a highly viscous liquid, and so becomes brittle at low temperatures and soft at high temperatures, which poses a major challenge to its utilization. Despite the continuous studies on asphalt production processes, mix design and pavement design, there are limits to the extent that asphalt can surmount the challenge. Recently, large number of investigations have demonstrated that bitumen properties (e.g. Visco elasticity and temperature susceptibility) can be improved using an additive or a chemical reaction modification. To get some desirable properties of the bitumen, it must added with some modifying agents, in this case it is said to be modified bitumen.

2.1 **General requirements of Modifiers :**

Modified Bitumen is obtained with the incorporation of selected thermoplastic polymers (Plastomeric or Elastomeric), crumb rubber or natural rubber in bitumen. When used as bitumen modifier, selected polymers/rubbers or a blend of these should have the following properties:

i) Compatible with bitumen.

ii) Resist degradation at mixing temperature

iii) Capable of being processed by the conventional mixing and laying machinery.

iv) Produce coating viscosity at application temperature.

v) Maintain premium properties during the storage, application and in service.

vi) Capable of providing homogeneous blend with bitumen.

2.2 **Types of Modifiers :**

Over the years, different types of materials have been investigated as modifiers for bitumen modifications. The commonly used modifiers are given in Table 2.1. The modifier should be compatible with bitumen to achieve the required properties.

<table>
<thead>
<tr>
<th>Types</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastomeric Thermoplastics</td>
<td>Polyethylene(PE),Ethylene Vinyl Acetate (EVA), Ethylene Butyl Acrylate(EB),Ethylene-Methyl-Acrylate copolymers (EMA) etc.</td>
</tr>
<tr>
<td>Elastomeric Thermoplastics</td>
<td>Styrene Isoprene Styrene (SIS), Styrene-Butadiene-Styrene (SBS) block copolymer, Styrene-Butadiene Rubber, Ethylene Ter Polymer (ETP) etc.</td>
</tr>
<tr>
<td>Synthetic Rubber Latex</td>
<td>Styrene Butadiene Rubber (SBR) latex and any other suitable synthetic rubber</td>
</tr>
<tr>
<td>Natural Rubber</td>
<td>Latex or Rubber Powder</td>
</tr>
<tr>
<td>Crumb Rubber/treated Crumb Rubber</td>
<td>Crumb Rubber, Treated Crumb Rubber</td>
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Plastomer polymers attain very high strength at a rapid rate, but are brittle and resistant to deformation at low temperature. An example of Plastomer material is ethylene vinyl acetate (EVA). Elastomer polymers is a flexible polymer that can be stretched up to ten times without breaking and quickly return to its original shape once the load has been removed. Styrene butadiene rubber (SBR) latex is an example of synthetic elastomer. Plastomer modify asphalt by forming a tough, rigid, three-dimensional network to resist deformation, while elastomer have a characteristic of high elastic response and therefore, it can resist permanent deformation by stretching and recovering their initial shape.

2.2.1 **Polyvinyl Acetate (PVA) :**

Polyvinyl acetate is one of the clear, water-white, thermoplastic synthetic resins produced from its monomer by emulsion polymerization. The degree of polymerization of polyvinyl acetate typically is 100 to 5000. PVA has the advantage over the other resinous adhesives in that it is available in the form of an emulsion that is readily diluted with water, is easily applied, and is safe to use because it contains no flammable solvents. The compressive strength of the cold mix that use asphalt emulsion modified with PVA was not improve with regards to the cold mix with unmodified asphalt emulsion. However, for the cold mix where the aggregates were coated with a diluted PVA emulsion before blended with asphalt emulsion modified with PVA,
rubber latex by coagulation to form a solid material. In 1970’s a patented process known as ‘Ralumac’ process was develop to modify asphalt emulsion with natural rubber latex. This process involves mixing anionic natural rubber latex in aqueous phase with cationic asphalt emulsions during asphalt emulsification.

2.2.6 Crumb Rubber :

Tire rubber is manufactured using a vulcanization process, which is an irreversible action between elastomers, sulfur and other chemicals, producing cross links between the elastomer molecular chains and leading to the formation of three dimensional chemical networks. The resulting cross-linked solid product is infusible and insoluble in thermoset liquids, and so the direct reprocessing and recycling of tire rubber is impossible. Furthermore, disposal of waste tires is a huge task because tires have a long life and are non-biodegradable. Conventionally, the methods of waste tire management have been stockpiling or illegal dumping or land filling, all of which have proved to be short-term solutions.

An effective way to recycle scrap tire is by producing crumb rubber modifier (CRM) for the modification of asphalt. It is believed that the asphalt industry has the capacity to utilize over 40 % of scrap tires produced annually. During the recycling process, the steel and the fluff are removed and the rubber is ground to a granular consistency. The mass could be reduced to the desired dimensions with the aid of cryogenics or other mechanical means. The particles can be sized and sorted based on certain criteria such as mesh size.

2.2.7 Warm Mix Additives :

Warm mix additives are waxes or liquid surfactant-based chemicals used to improve the workability of hot mix asphalt. They lower the viscosity of asphalt mix, thereby reducing production and compaction temperatures by as much as 40°C. This translates to huge economic benefits and high production rates and less energy cost is expended on field operations. Also, better environmental working condition is attained as there are less particulate and gaseous emissions.

2.2.8 Chemical additives :

PPA (Hn+2PnO3n+1), a polymer of orthophosphoric acid (H3PO4), has been used to modify asphalt binders in North America for over 30 years. PPA is commercially graded based on the content of orthophosphoric acid (H3PO4), pyrophosphoric acid, triphosphoric acid and higher acid mixture, and so 115% and 105% orthophosphoric acid grades are commonly available.

the compressive strength was improved in 31% relative to the unmodified cold mix.

2.2.2 Ethylene Vinyl Acetate (EVA) :

EVA is a commonly used as plastomeric modifier which represents a copolymer of ethylene and vinyl acetate. EVA polymers have been used in road construction for more than 20 years in order to improve both the workability of the asphalt during construction and its deformation resistance in service. Normally, EVA is used in asphalt modification that is purposely used for hot application. It is seen that asphalt mixture using EVA modified asphalt increased the value of Marshall stability and air voids and at the same time decreased the flow and unit weight value.

2.2.3 Styrene Butadiene Rubber (SBR) :

SBR is synthetic latex that has random structure of copolymers. SBR latex particles in a polymer modified asphalt emulsion remain in the aqueous phase and spontaneously transform into a continuous microscopic polymer film surrounding asphalt particles upon curing. Takamura has demonstrated the benefits of SBR modification of asphalt emulsions and micro surfacing mixes, with significant increases in rutting resistance temperatures observed with increasing polymer content . Asphalt emulsions modified with 3 percent SBR latex performed significantly better than did unmodified emulsions or neat non-emulsified asphalt. As the temperature susceptibility of SBR latex modified asphalt emulsion became lower, which was more favorable for practical application, such as slurry seal and micro-surfacing.

2.2.4 Styrene Butadiene Styrene (SBS) :

SBS block copolymers are classified as elastomers that increase the elasticity of bitumen and they are probably the most appropriate polymers for bitumen modification. SBS copolymers derive their strength and elasticity from physical cross-linking of the molecules into a three dimensional network. It is observed that emulsified SBS modified asphalts show excellent adhesion to various types of aggregate compare to hot applied SBS modified binder and it can even be sprayed on damp surfaces. Moreover, emulsified asphalt applications also show to tolerate higher SBS dosing levels than modified hot mixes, resulting in improved stone retention, cohesion and visco elasticity.

2.2.5 Natural Rubber Latex :

Natural rubber latex (NRL) is an elastomeric hydrocarbon polymer that exists as a natural milky sap produced by several species of plants. Natural rubber is produced from natural plants. Natural rubber is produced from natural milky sap produced by several species of elastomeric hydrocarbon polymer that exists as a natural milky sap produced by several species of
PA at some of the components of asphalt, when used as an additive in the air blowing oxidation process. This increases the high temperature performance rating of the asphalt binder without affecting the low temperature properties. Additionally, it allows for significant reduction in the level of polymer required to meet elastic recovery requirement in polymer modified asphalt.

Lime additives have been considered as a means of reducing moisture susceptibility of asphalt mixtures. They could be in the form of hydrated lime (Ca(OH)2), quick lime (CaO). Usually 1-1.5 % lime by dry weight of aggregate is added to the mix, more quantities are required when more fines are present in the aggregates, due to the relatively large surface area.

3. Literature study:

3.1 Study of modified bitumen:

IRC SP: 53 (2010), specify the properties of bitumen and bituminous mixes can be improved/modified with the incorporation of certain additives or blend of additives which are called as “modifiers”. Use of modified bitumen in the top layers of the pavement is expected to significantly enhance the life of the surfacing and extend the lifetime of the next renewal. The performance studies on the overlay carried out by the various research institutions which revealed that the use of Modified Bitumen in construction & maintenance of bituminous roads significantly improve the pavement performance and is cost effective, when life-cycle cost is taken into consideration. The classification of Rubber and Polymer based Bitumen modifiers as, Plastomeric thermoplastic based, Elastomeric thermoplastic based, Natural rubber or SBR latex based, Crumb rubber/ treated crumb rubber based.

Pareek et al. (2012) prepared the property performance of polymer modified bitumen (PMB-70) and conventional bitumen of 60/70. For flexible pavement that a bituminous mixture needs to be flexible enough at low service temperatures to prevent pavement cracking and to be stiff enough at high service temperature to prevent rutting. Bitumen modified with polymer offers a combination of performance related to benefits as the physical properties of the bitumen are improved without changing the chemical nature of it. For the experimental study they used polymer modified bitumen, PMB-70 and conventional bitumen of 60/70. The design of bituminous concrete mix prepared with both binders (PMB-70 and 60/70 grade bitumen) separately was carried out by Marshall Method of mix design. The results of the experimental study shows that the performance of Polymer Modified Bitumen is better than that of conventional bitumen (60/70) in the terms of high elastic recovery (79%), better age resistance properties, increment in Marshall stability by 27%.

Sabina et al. (2009) studied comparative performance of bituminous concrete mixes containing plastic/ polymer (PP) (8% and 15% by weight of bitumen) with conventional bituminous mix (60/70 penetration grade bitumen) shows that there is significant improvement in properties like Marshall stability, retained stability, indirect tensile strength and rutting. It was observed that 60/70 penetration grade paving bitumen and aggregates satisfy limits of MoRTH. Marshall stability of modified mixes with addition of modifiers (8% and 15% by weight of bitumen) was respectively 1.21 and 1.18 times higher than conventional mixes, as fine layer formed around aggregate enhanced strength of bituminous concrete mix. However, modified mixes containing modifier (15%) showed slightly decreased values for Marshall stability and retained stability amongst three mixes i.e. conventional 60/70 grade bitumen, 8% waste plastic/polymer , 15% waste plastic/polymer.

Rokade S (2012) prepared SDCB (Semi Dense Bituminous Concrete) mix using Marshall Method of bituminous mix design. The SDCB mix was prepared with 5.506% increment of 0.5% bitumen. This study used LDPE Low Density Polyethylene and CRMB Crumb rubber modified bitumen 3% increment of of the (LDPE) for 3%, 6%, 9% and CRMB used for 8%, 10%, 12% respectively by weight of bitumen. The study on the use of LDPE and CRMB reveals that the Marshal Stability value, which is the strength parameter of SDBC has shown increasing trend and the maximum values have increased by about 25 % by addition of LDPE and CRMB. The density of the mix has also increased in both the cases of LDPE and CRMB when compared with 60/70 grade bitumen.

Sangita, Tabrez Alam Khan, Sabina, D.K. Sharma (2011) carried out study of the effect of waste polymer (natural rubber and polyethylene in 1:4 ratio) modifier on various mechanical properties such as Marshall stability, flow, Marshall quotient (stability to flow ratio), resilient modulus and permanent deformation potential of bituminous concrete overlays has been evaluated.

P Sreejith (2010) carried out Polymer modified bitumen is emerging as one of the important construction of flexible pavements. The polymer modified bitumen show better properties for road construction and plastics waste can find its use in this process and this can help solving problem of pollution. The studies on the thermal behaviour and binding property of molten plastics promoted a study on the preparation of plastic waste-bitumen blend and its properties to find the suitability of the blend for road construction.
Kumar et al., (2013) studied the three commercially available modified binders crumb rubber modifier (CRM) styrene-butadiene-styrene (SBS) and ethylene butyl acrylate (EBA) and 60/70 grade base bitumen were used for construction of test sections of delhi-yamanotri marg near Herbertpur; which were compared for their performance. Various physical tests like elastic recovery, softening point, penetration, viscosity and fail temperatures were carried out on modified binders and post construction evaluation tests like unevenness index measurement and Benkelman Beam Deflection tests were carried out on test sections. The results shows the improvement in engineering properties like Marshall stability, retained stability of road compared to unmodified bituminous road in terms of traffic and weather conditions of Uttarakhand.

Habib et al., (2010) carried out experimental study for rheological properties of bitumen modified by thermoplastic namely linear low density polyethylene (LLDPE), high density polyethylene(HDPE) and polypropylene (PP) and its interaction with 80 pen base bitumen. As it is known that the modification of bitumen by the use of polymers enhances its performance characteristics but at the same time significantly alters its rheological properties. It was observed that thermoplastic copolymer shows profound effect on penetration rather than softening point. The visco-elastic behavior of polymer modified bitumen depend on the concentration of polymer, mixing temperature, mixing technique, solvating power of base bitumen and molecular structure of polymer used. PP offer better blend in comparison to HDPE and LLDPE. The viscosity of base bitumen was also enhanced with the addition of polymer. Best results were obtained when polymer concentration was kept below 3%.

Tabatabaei et al.,(2010) studied the rheological properties of bitumen and the modified bitumen with 3, 4, 5 percent of Styrene-butadiene-Rubber were analyzed. To evaluate the effect SBR polymer on bitumin mix, dynamic mechanical analysis was conducted. According to this research by using SBR as bitumen modifier, the results of 5 percent of SBR as bitumen modifier will increase the performance of bitumen more than 3 to 4 percent of this polymer modifier. In higher temperature than 40°C the bitumen modified with 5 percent of SBR has better results for all parameters include complex modulus, phase angle. But for temperature lower 40°C in all three cases the changes were same. The modified bitumen with SBR will have better performance against some distresses such as rutting and fatigue cracking.

Singhal et al., (2016) concluded that the modified bitumen mix shows better binding property, stability, density and more resistant to water. When used for road construction it can withstand higher temperature. The bitumen required can be reduced depending upon the percentage of polymer added. The binding properties of polymer also improve the strength of mastic flooring. The use of waste plastics on the road has helps to provide better place for burying the plastic waste without causing disposal problem. At the same time, a better road is also constructed. It also helps to avoid the general disposal technique of waste plastics namely land-filling.

4. Experimental study:

4.1 Use of Polymer waste for modification of bitumen in road construction:

Generation of plastic waste is increasing day by day and necessity to dispose this waste in proper way is arising. This waste is disposed by using different methods such as incineration, landfilling which affects the environment; but by adding polymer into roads is the eco-friendly process. The addition of polymer into dry bitumen improves the service properties of bitumen.

Plastic products have become an indispensable part of our daily lives as many objects of daily use are meant from some kind of plastic. Use of this non-biodegradable product is growing rapidly and creating problem of disposal of plastic waste. Disposal of plastic waste is particularly plastic bag menace and has become a serious problem especially in urban areas in terms of its misuse, its dumping in the dustbin, clogging of drains, reduce soil fertility and aesthetic problems, etc. Every increasing use of polymer in day to day life is generating enormous plastic and rubber waste disposal of which by land filling and incineration is non eco friendly. The utilization of plastic waste in bituminous mix to improve the properties of the binder offers as such very promising alternative.

4.1.1 Waste plastic & its sources:

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. Waste plastic origin are as follows:

- Low density polyethylene (LDPE) Carry bags, sacks, milk pouches, bin lining, cosmetic and detergent bottles.
- High density polyethylene (HDPE) Carry bags, bottle caps, house hold articles etc.
• Polyethylene terephthalate (PET) Drinking Water bottles etc.
• Polypropylene (PP) Bottle caps and closures, wrappers of detergent, biscuit, vapors packets, microwave trays for readymade meal etc.
• Polystyrene (PS) Yoghurt post, clear egg packs, bottle caps. Foamed polystyrene : food trays, egg boxes, disposable cups, protective packaging etc.
• Polyvinyl chloride (PVC) Mineral water bottles, credit cards, toys, pipes and gutters, electrical fittings, furniture, folders and pens, medical disposables etc.

Most of thermoplastics on heating soften at temperature between 130-104°C. The waste plastic can easily be blended with the bitumen as the process for road construction using bitumen is carried out in the range of 155-165°C.

4.1.2 Methodology:

Waste plastic HDPE, LDPE, PP, Crumb rubber were procured from the local scrap plastic supplier & the bitumen (60/70 grade) and aggregates were obtained from local area in Akola. By mixing plastic with bitumen the brittleness was overcome and elastic nature enhances. The plastic waste is melted and mixed with bitumen in a particular ratio. There are two important processes namely dry process and wet process used for bitumen mix flexible pavement.

In dry process, hot stone aggregate (170°C) is mixed with hot bitumen (160°C) and the mix is used for road laying. The bitumen is chosen on the basis of its binding property, penetration value and visco elastic property. The aggregate, when coated with plastics improved its quality with respect to voids, moisture absorption and soundness. The coating of plastic decreases the porosity and helps to improve the quality of the aggregate and its performance in the flexible pavement.

In wet process, the waste polymer directly added with bitumen and heated up to temperature of 160°C so that proper blend is to be formed with proper dispersion of waste polymer into bitumen, then the hot mix is then cooled up to 120°C into another chamber, which is then added to the aggregate in paddling chamber. After addition of modified bitumen at 110°C on aggregate, it is then laid on the road and then spreader material is compacted by 8 tonne roller.

4.1.3 Experimental observations:

It was observed that, the addition of polymers into bitumen improves the service properties of bitumen improves the service properties of bitumen. This is the only reason for selecting polymer waste as a modifier for bitumen. The use of this innovative technology not only strengthen the road construction but also increases the road life.

(i) For olefin waste, optimum results were obtained as 6% loading by weight addition of plastic waste in bitumen. As the plastic content increases, there is reduction in ductility because of the plasticity of bitumen increases at services temperature. Minimum value of ductility (in cm) is required for proper application of bitumen in road is 62; otherwise it will tend to form cracks and crazes at heavy load.

(ii) For Crumb rubber, it is found that 4% of waste can be successfully added in bitumen but there is non-uniform mixture observed as increase in the % addition of crumb rubber which affects the surface of road.

(iii) The mixture of crumb rubber-HDPE loading obtained optimum results. This kind of mix polymer waste was added up to 8% i.e. 4% crumb rubber and 4% HDPE.

(iv) The addition of LDPE waste plastic optimum results were obtained at 6% percent loading with respect to weight of bitumen.

(v) The addition of crumb rubber and HDPE waste optimum result were obtained up to 8% loading with respective weight of bitumen. The maximum amount of polymer waste that can be added in bitumen was 8%. Above which the properties of bitumen considerably falls.

5. Conclusion:

With the study of modified bitumen, it can be concluded that,

1) The physical properties of the plain bitumen are increased by modification of EVA polymer and crumb rubber.
2) Pavements made with modified bitumen are more resistant to fatigue, thermal cracking, rutting and temperature susceptibility than neat bitumen.
3) As the EVA polymer and crumb rubber increases the penetration of the modified bitumen decreases.
4) The viscosity of the modified bitumen increases with the increase in EVA polymer and crumb rubber.
5) Polymer Modified Bitumen improves cohesive and adhesive properties of the bitumen. In surfacing, use of modified bitumen extends the service period by 50% as compared to unmodified bitumen.

6. References


