USE OF WASTE PLASTIC BLENDED BITUMEN FOR ROAD CONSTRUCTION AND MAINTENANCE

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DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Date: **(Mohammad Abul Kashem)**

Dedicated To

My Parents

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ABSTRACT

In this research work waste plastic (Low Density Polyethylene) is used as modifier to prepare samples required for tests to determine the engineering and rheological properties of the modified bitumen. Other objectives of the research were to analyze the effect of waste plastic modified bitumen on road quality and to assess the field performance of waste plastic blended bituminous pavement sections.

To fulfil the objectives of the study, first of all waste plastic was collected in shredded form (<4.50mm) from old Dhaka. Then a total of 04 (Four) modified binders and mixes are prepared with 2.5%, 5%, 7.5% and 10% waste plastic content to perform the test of penetration, ductility, specific gravity, softening point, flash and fire point, loss on heating etc. At the same time one sample with virgin bitumen and one with 7.5% Pet bottle were also tested. For making this test sample, blending operation is done by mechanically and thermostatically controlled blender prepared by previous researcher (Hossain, 2006) is used. After performing the test of rheological/engineering properties Marshall Specimens were prepared with these binders and Marshall Tests were performed accordingly. The performances of modified bituminous mixes are evaluated by determining stability, flow, density and void in the mixes. In addition, to analyze the effect of waste plastic modified bitumen on road quality, a 100.0 m x 7.5 m road section is paved with this modified bitumen as well as adjoining same area with pure bitumen and performance is evaluated by some parameters like potholes, cracking, rutting, ravelling, edge breaking, and depression etc. for 1.5 years' duration.

The study results conclude that rheological properties like penetration, ductility and specific gravity of LDPE (waste plastic) modified bitumen decreases with increase of waste plastic contents while softening point, flash and fire point increases with increase in polymer contents in bitumen.

The Marshal stability results reveals that the waste plastic (polymer) increases the stability values of the compacted mixes with increasing the waste plastic content in the bitumen up to optimum level (i.e. 7.5%). The flow values obtained in the Marshal test show slightly increasing pattern up to 7.5% waste plastic content, whereas the density of the compacted mixes slightly decreases with the increase of waste plastic contents in the bitumen. The effect of waste plastic on Air Void (Va), Void in Mineral Aggregate (VMA) and Void Filled Asphalt (VFA) is found insignificant.

Data collected from the field demonstration show that less quantity of potholes, crack, ravelling and depression are formed on the road segment constructed with waste plastic modified bitumen than that of normal bitumen. Thus waste plastic bitumen enhances the longevity of the road.

It is expected that using the output this research, the waste plastic materials can be used in bituminous roads works, resulting in minimization of the frequency of rehabilitation work and thereby providing an economic solution. It is also expected to substantially reduce volume of environmentally hazardous plastic and environmental pollution.

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LIST OF ABBREVIATIONS

AASHTO	Association of American State Highway and Transportation officials
ABS	Acronitrile Butadiene Styrene
AC	Asphalt Concrete
ADOT	Arizona Department of Transportation
ASTM	American Society for Testing and Materials
BBMP	Bruhat Bangalore Mahanagra Palike
BS	British Standard
BS	Butadiene-Styrene
BTF	Bangladesh Transport Foundation
CalTrans	California Department of Transportation
CR	Crum Rubber
CRM	Crum Rubber Modified
CRMB	Crumb Rubber Modified Bitumen
CRRI	Central Road Research Institute
CRT	Crumb Rubber from Tyre
CTE	Centre for Transportation Engineering
CVA	Conventional Asphalt
DC	Direct Current
EVA	Ethylene Vinyl Acetate
FDOT	Florida Department of Transportation
GDOT	Georgia Department of Transportation
HDPE	High Density Polyethylene
HEATEC	Chemical Company
HMA	Hot Mix Asphalt
HWTD	Humburg Wheel Tracking Device
IRC	Indian Road Congress
KRATON	Branded Polymer (a product of Shell Company)
LDPE	Low Density Polyethylene
LGED	Local Government Engineering Department
LLDPE	Linear Low Density Polyethylene
NRMB	Natural Rubber Modified Bitumen

OBC	Optimum Bitumen Content
PE	Poly Ethylene
PET	Polyethylene Terepthalate
PMB	Polymer Modified Bitumen
PP	Poly Propylene
PVC	Polyvinyl Chloride
RAC	Rubberized Asphalt Concrete
RHD	Roads and Highways Department
RMA	Rubber Modified Asphalt
RMB	Rubber Modified Bitumen
RPE	Recycled Polyethylene
RUMAC	Rubber Modified Hot Mix Asphalt
SBS	Styrene-Butadiene-Styrene
SE	Styrene-Ethylene
TPE	Thermoplastic Elastomer
VB	Virgin Bitumen
VFA	Voids Filled with Asphalt
VMA	Voids in the Mineral Aggregate
VSS	Valley Slurry Seal
WSS	Western States Surfacing

Chapter 1
Introduction

1.1 Background

Demands of roads are increasing year by year. Ever increasing numbers of commercial vehicles with increased axle loads take their toll and it is clear that this trend will continue in the future. The highway engineers are thinking about the alternative solutions to meet this growing challenge. The addition of polymers to enhance service properties in road paving applications was considered a long time ago and nowadays has become a real alternative. A variety of additives are used in order to obtain enhanced service properties within a wide range of temperature. A number of research works in many countries have confirmed the beneficial effects of polymer addition to bitumen (Hossain, 2006). However, the main restriction in such modifications remains the incompatibility of polymer and bitumen matrix. Recently waste plastic has been used with beneficial effects in paving (BTF, 20008). Waste plastic modified binders provide increased durability, reduced cracking and increased skid resistance. This type of modified asphalt also has shown fatigue resistance to traffic load

In recent years laboratory studies conducted in different countries suggest that plastic, if appropriately blended with bitumen could be used for construction and maintenance of roads. The performance and longevity of roads constructed with plastic blended bitumen are significantly better compared for the normal bitumen roads (CTE, 2002). Recycling of waste plastic for road construction can also solve the disposal problem and environmental hazard by non-biodegradable waste plastic.

In India currently few states are using waste plastics, as Polymer Modified Bitumen (PMB) and among those Karnataka is the pioneer (CRRI, 2002). Virgin polymer is being used in a few states on pilot basis in India. The first waste plastic mixed bitumen road made in Rajarajeshwarinagar, Bangalore revealed that Pavement Serviceability Index (PSI) improves substantially compared to conventional flexible pavement.

Local Government Engineering Department (LGED) of Bangladesh has already constructed pilot trial pavement in three road sections during 2005-06 using crumbed rubber polymers manufactured by KK Plastic Waste Management Pvt. Ltd. Bangalore, India. A post construction evaluation of one of the trial sections has shown 84%, 57% and 15% less Cracks, Depression and Ravelling respectively than the adjoining conventional construction (Islam, 2008).

Both bitumen and plastic are originated from petroleum and thermoplastic in nature, which help good bonding and strength development. However virgin plastic is costly material and waste plastics could be a cheaper substitute. Study shows that Dhaka city produces about 230 ton of waste plastic per day, which is adequate for road works in Dhaka city (Wastesafe-KUET, 2005).

Rheology is the science of deformation and flow of matter. It is concerned with the response of materials to mechanical force. That response may be irreversible flow, reversible elastic deformation, or a combination of the two. The flow properties of matter are defined by its resistance to flow i.e. viscosity. So the usual way of defining the rheological properties of a material is to determine the resistance to deformation. Rheology is also defined in a different way as "the study of the flow of materials that behave in an interesting or unusual manner (Marrison,)". However, the material that exhibits both elastic and viscous properties is viscoelastic. Bitumen is a viscoelastic material with suitable rheological properties for traditional paving and roofing applications because of their good adhesion properties to aggregates (Akmal, 1999). As the bitumen is responsible for the visco-elastic behaviour characteristic of binder, it plays a large part in determining many aspects of road performance, particularly resistance to permanent deformation and cracking.

The above discussion reveals that the use of polymer as well as waste plastic in bitumen to improve its service properties is very common in different countries but the related study carried out in Bangladesh are few. Related research works have recently been completed by two Bangladeshi researchers (Islam, 2003) and

(Hossain, 2006).It should be mentioned here that the two research works carried out at BUET have some limitation. The First researcher used virgin polymer in his research work and the second researcher used scarp tyres. But both research works were laboratory based. In this research laboratory tests as well as field demonstrations are carried out simultaneously using waste plastic as modifier. So it should be envisaged the possibility of disposing of troublesome waste plastics, because waste plastic can show similar performance to those, which contain virgin polymers. Thus the use of waste plastic like polyethylene as a bitumen-modifying agent may contribute to solve a waste disposal problem and to improve the quality of road pavements. Although the use of thin polythene shopping bag is prohibited in Bangladesh in January, 2002, it is being extensively used all over the country. So it is no doubt that their increased volume will cause a great problem in the management of these environmentally hazard wastes. If these waste materials are made possible to use in pavements, it will reduce the cost of management of these disposed wastes and will be environmentally friendly. In view of these, the proposed study is very important and useful in the context of Bangladesh.

In order to experiment with the waste plastic (Low Density Polyethylene, Polyethylene Terepthalate), a thermostatically and mechanically controlled blending system capable of generating enough shear force would be used. Then different tests like density, viscosity, penetration, ductility, loss on heating etc would be conducted on waste plastic blended bitumen and thereby to observe the rheological properties of modified binder which is important in selecting a suitable cheaper modifier. After all necessary tests of the modified binder found to be satisfactory, a field demonstration on a particular segment would be done with this modified binder. At the same time another segment would be done with the traditional pure binder.

1.2 Statement of the Problems

Flexible pavements of Bangladesh, particularly in the urban (City corporation, Municipality, Pourashava) areas, deteriorate quickly after its construction due to poor quality of pavement work and lack of proper drainage facilities. From the field observation it is found that even a good quality of pavement losses its longevity due to inadequate drainage system and movements of heavy traffic under submerged condition. Stripping of aggregates is root causes of pavement failure in our country and the stripping occurs due to the combined effect of wheel load and rain or floodwater causes the loss of bond between aggregates and bitumen that typically begins at the bottom of the Hot Mix Asphalt (HMA) layer and progresses upward. When stripping begins at the surface and progresses downward it is usually called ravelling, which causes to loose debris on the pavement, roughness, water collecting in the ravelled locations resulting in vehicle hydroplaning and loss of skid resistance. Frequent heavy rain during the monsoon, inundates the roadway pavement in cities and towns. A large portion of roadways pavement undergoes water due to recurrent high flood. The void in bituminous pavement is filled with water under submerged condition. At this condition, pore pressure is developed by the action of wheel load. This pore pressure creates a tremendous uplift force that eventually breaks the bond between aggregate and binder. Thus aggregate is loosened and lifted by the action of wheel. As a result, striping of aggregate initiated and "pot hole" occurred in the pavement. Thereby, the frequent and prolonged submergence of road causes maximum damage to our pavement. Polymer modified bituminous binder is more viscous than conventional bitumen. As, higher viscosity of polymer (waste plastic) modified bitumen (PMB) increases the thickness of aggregate coating, it has the potential to make aggregates more water-resistant and to increase adhesion between asphalt binder and aggregate in the presence of moisture to reduce the possibility of stripping(Hossain,2006).

In Bangladesh, premature failure of pavement occurs due not only to the lack of proper drainage facilities but also to high temperature in summer period. In summer the weather becomes very hot and the ambient temperature of the pavement reaches near to the softening point of the traditional bitumen and flow condition arises in the pavement. This condition is called bleeding which causes serious riding problems. Bleeding is film of asphalt binder on the pavement surface. It usually creates a shiny, glass-like reflecting surface that can become sticky when dry and slippery when wet. Bleeding occurs when asphalt binder fills the aggregate voids during hot weather and then expands to the pavement surface. The usage of polymer (waste plastic) with bitumen increases the softening point of the binder and may slow reduce future bleeding

Rutting is another cause of pavement failure in Bangladesh. Rut is a vertical depression along the vehicle wheel tracks caused by traffic loading. This is a surface defect more prominent and evident in the outer wheel track. Rutting is caused by the permanent deformation in any of a pavement's layers or sub grade usually caused by consolidation or displacement of the pavement edge due to traffic loading. Permanent deformation of pavement may occur that if the pavement binders do not have sufficient elasticity. Because a poor elastic binder do not return to its original position after removing wheel loading. If PMB is used in pavement construction, it sufficiently increases the elasticity of the binder.

Cracking is also another main cause of pavement failure in Bangladesh. Generally it causes the potholes on the pavement surface. This is due not only to traffic loads but also to the capability of the asphalt concrete to sustain temperature changes. As the conventional bituminous binder is highly susceptible to temperature usage of PMB may be the alternative solution

Because of traditional construction practice and severe weather condition of our country, every year almost all of the major roads in urban area need a massive rehabilitation work immediately after the monsoon period. This maintenance work not only involves large amount of money but also interrupt normal traffic flow that causes road users' discomfort and delay.

In this regard the use of waste plastic (polymer) in pavement construction as well as maintenance work could minimize the" frequency of rehabilitation work and thereby provide an economical solution. A second benefit of reuse of waste plastic is to improve the solid waste disposal problem.

1.3 Objectives of the Researches

The specific objectives of the study can the summarized as follows.

→ To determine the engineering and rheological properties of waste plastic modified binder

→ To analyze the effect of waste plastic modified bitumen on road quality

→ To assess the field performance of waste plastic blended bituminous pavement road section

It is expected that the research would help to explore the potential use of waste plastic in flexible pavement construction in Bangladesh and minimize the environmental hazards.

1.4 Scope of the Study

There are many types/forms of waste plastic pure and recycled forms of polymer but all of them are not compatible with bitumen and could not be used as a modifier if it is not properly blended. A mechanically and thermostatically controlled blender would be used for blending waste plastic. The selection of compatible waste plastic, production of blend, process of test and evaluation etc require huge laboratory work. The investigation would be performed mainly on waste polythene and waste PET bottle. Finally field demonstrations would also be carried out to assess the field performances of waste blended bituminous road.

1.5 The Research Program

To fulfil the objectives of this research work as well as to obtain adequate information and knowledge on polymer modification, first a comprehensive literature review on PMB would be carried out. Then trials would be given with different types of recycled polymer to select a compatible one to work with.

However the research program consists of three distinct phases of activities. Firstly, a thermostatically and mechanically controlled blending device fabricated by previous researcher (Hossain, 2006) would be used for proper blending of the waste plastic with bitumen.

In the second stage, laboratory tests of pure bitumen and waste plastic modified bitumen are to be carried out to study the rheological properties of the traditional and modified binder. In these tests, waste plastic would be used as modifiers in lieu of pure form of polymer/scarp tyres used by the previous researchers. In order to study the rheological properties of modified binders with various proportions of waste plastic, the related tests like penetration, ductility, specific gravity, softening point etc tests would be Performed. Several sets of Marshal Test specimens would be prepared by varying proportions of bitumen and waste plastic contents in order to determine the optimum amount of waste plastic and mix properties of polymer modified binder. Finally field demonstrations would be carried out with the optimum amount of waste plastic modified as well as pure binder and field performance would be assessed for 1.5 year. The details of the research program are schematically shown in the Figure 1.1

1.6 Organization of Thesis:

In this research project work carried out is divided into different topics and presented in six chapters.

A brief introduction of statement of the problem is presented in the first chapter with special emphasis on the objectives of the proposed study.

Chapter 2 of this thesis covers a review of recent studies on polymer/waste plastic-modified bitumen conducted home and abroad. It includes a detail description of polymer including its type, sources, blending, mixing process as well as mechanics of polymer modified binder (PMB). The benefits and drawbacks of modification of bitumen as well as brief history and application of PMB are also highlighted in this chapter. Finally, a summary of the whole literature review is added at the end of the chapter.

Chapter 3 describes the methodology and investigation techniques employed in this research and also describes the short description of the tests and the properties of raw materials to perform those tests in the study.

The Chapter 4 describes the compatibility test of waste polymer, production of blend, process of blending, blending device, tests procedure, preparation of samples and tests on binder and mixes.

Chapter 5 enumerates the analysis of test results on binder and mixes. It also includes the finding on evaluation of PMB as compared to that of traditional binder and mixes regarding rheological properties as well as field performances.

The conclusions of the whole study and some recommendations for future research are presented in Chapter 6. An appendix is attached at the end of this report, which contains all raw data used in this research.

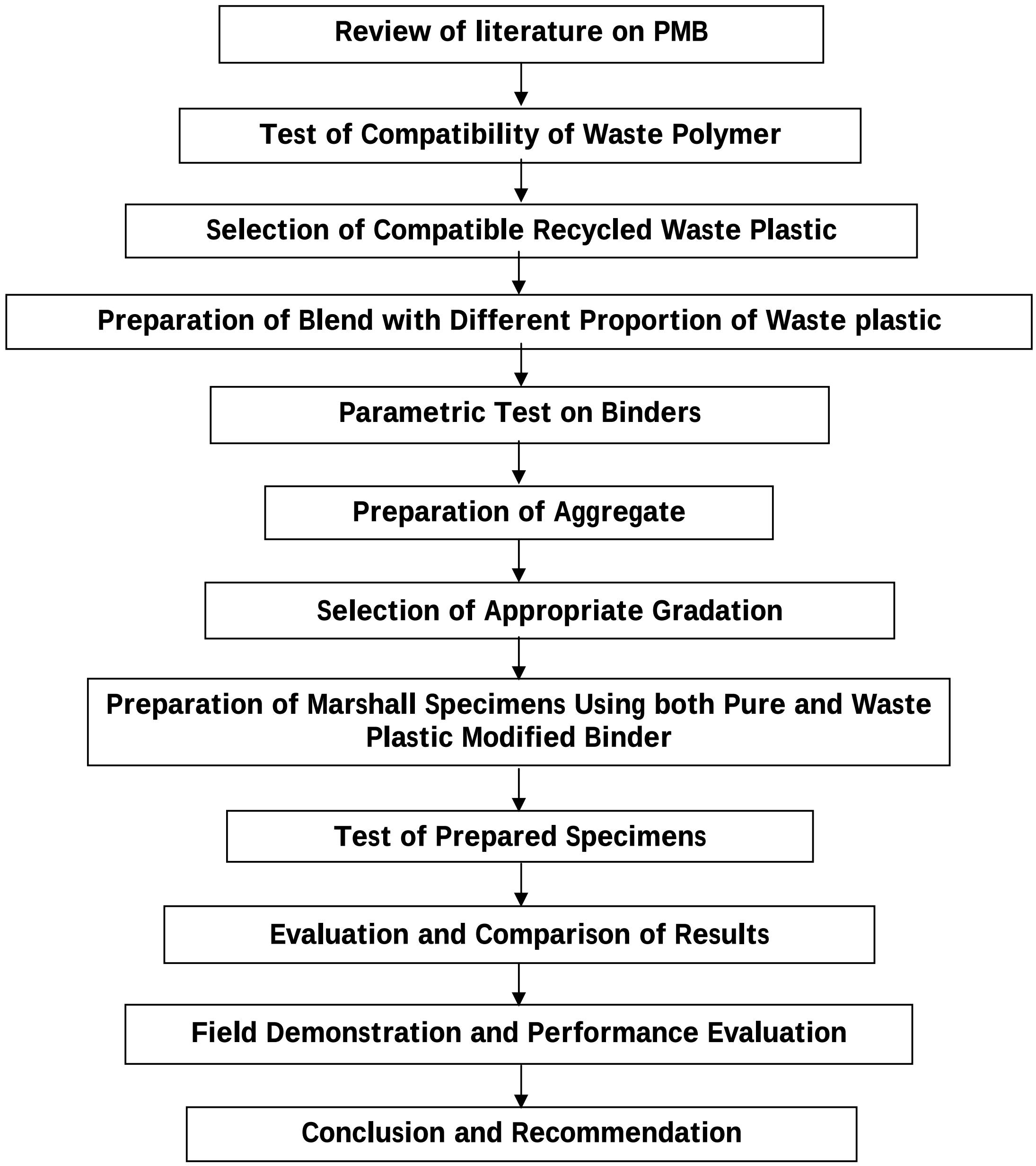

Figure 1.1: Flow Chart Showing the Details of Project Work

Chapter 2
Literature Review

2.1 Introduction

This chapter includes the description of different types of the polymer, blending mechanism, common sources of polymers and its application around home and abroad. The history of polymer modification, its benefits and drawbacks and field performance evaluation are also highlighted in this chapter. The use of polymer as a modifier of bitumen is not very new. Polymer modified bitumen (PMB) is becoming an increasingly important material for building and maintaining roads. Many countries have been using polymer with bitumen from the last few decades. Scientific research is going on the modification of bitumen with different types of polymer and purposefully new types of polymers are being invented. Besides, some countries are trying to use scarp tyre, waste polythene bag, pet bottle and other waste plastic materials from the economic and environmental considerations. This chapter includes a brief discussion on these study reports. It also contains, a comprehensive review of literatures collected from different international journals as well as down loaded from the web site of different pavement construction and chemical companies. Finally, a summary of the literature review is given at the end of this chapter.

2.2 Modifier

Additives, which are used to modify or improve the quality of virgin materials is simply called the modifier of it. Modifiers are blended directly with the binder or added to the asphalt concrete mix during production to improve the properties and or to performance of the pavement. It should be mentioned here that a huge quantity of bituminous binder is required every year for pavement construction. This quantity of bitumen terms from the petroleum product and natural sources. The sources of bituminous materials are not unlimited. Hence the researchers have been thinking of quality improvement of bitumen and trying to extend the live span of bituminous pavement since long ago.

To improve the rheological and mechanical properties of bituminous binder different types of additives are added to it in different forms and in different ways (Table 2.1). The recent trend of pavement industry is to use polymer as a modifier of bitumen as polymer is to some extent similar in nature to some constituents of bitumen. Bitumen itself is a complex mix of different compound. The major constituents of bitumen are asphaltenes and malthenes. Aromatic malthenes and asphaltenes content (Baker, 1998) play a major role in the suitability of bitumen modification. Due to the similar in nature polymer and copolymer of different category and grade are being used as the modifier of bitumen for its overall quality improvement. Polymer increases the viscosity (Murphy, et al, 2001) of bitumen and increases the thickness of coated film around the aggregates. Thus the adhesive and cohesive properties of bitumen are .improved. Natural rubber (in powder or latex form) (Kumar, et al, 2001) or recycled rubber dust (Hossain, et al, 1999) are another potential modifier of bitumen. The waste plastic (Scrap Polythene) (Panda, et al, 1999) is also possible to use in modification of binder.

Table 2.1: Some Additives Used to Modify Bitumen

Type of modifier	Example
Thermoplastic Elastomers	Styrene-butadiene-styrene (SBS) Styrene-butadiene-rubber (SBR) Styrene-isoprene-styrene (SIS) Styrene-ethylene-butadiene-styrene (SEBS) Ethylene-propylene-diene terpolymer (EPDM) Isobutene-isoprene copolymer (IIR) Natural rubber Crumb tyre rubber Polybutadiene (PBD) Polyisoprene
Thermoplastic Polymers	Ethylene vinyl acetate (EVA) Ethylene methyl acrylate (EMA) Ethylene butyl acrylate (EBA) Atactic polypropylene (APP) Polyethylene (PE) Polypropylene (PP) Polyvinyl chloride (PVC)

Continued

Type of modifier	Example
	Polystyrene (PS)
Thermosetting polymers	Epoxy resin Polyurethane resin Acrylic resin Phenolic resin
Chemical modifiers	Organo-metallic compounds Sulphur Lignin
Fibres	Cellulose Alumino-magnesium silicate Glass fibre Asbestos Polyester Polypropylene
Adhesion improvers	Organic amines
	Amides
Antioxidants	Amines Phenols Organo-zinc/Organo-lead compounds
Natural Asphalts	Trinidad Lake Asphalt (TLA) Gilsonite Rock asphalt
Fillers	Carbon black Hydrated lime Lime Fly ash

[Source: Hossain, 2006]

2.3 Rubber

Rubbers are materials that display elastomeric properties. This means they can be stretched and will spring back when the stress is removed. Rubber is produced from the juice of a tropical plant or manufactured artificially. Natural rubber is found as a milky liquid in the bark of the rubber tree, *Hevea Brasiliensis.* This raw rubber is called latex. Latex contains about 30 percent dry rubber content. Latex is centrifuged to increase the percentage of rubber content in it. Natural rubber is vulcanized with sulphur and other materials to make it less susceptible to temperature. The tyres of vehicles and automobiles are made of vulcanized rubber. To produce the raw rubber used in tyre manufacturing, the liquid latex is mixed with acids that cause the rubber to solidify. Presses squeeze out excess water and form the rubber into sheets, and then the sheets are dried in tall smokehouses, pressed into enormous bales, and shipped to tyre factories around the world. Synthetic rubber is produced from the polymers found in crude oil. Rubber is more elastic than polymer. Both natural rubber and the crumb rubber from the used tyres of vehicles can be used for the modification of bituminous binder. Scrap rubber may be used in aggregate during pavement construction to improve riding quality (Infratech Polymers Inc.; Rubberized Asphalt Concrete Technology Centre, 2000) and reduce noise of vehicular movement.

2.4 Polymer

Polymer comes from the two Greek words "poly", which means many, and "meros", which means unit. A polymer may have one type of repeating unit of many different types of repeating units. A polymer is indeed made by covalently linking small simple molecules together. Polymeric molecules are gigantic in comparison to the hydrocarbon molecules. Therefore, they are often referred to as macromolecules. Within each molecule, the atoms are bound together by covalent bonds. For most polymers, these molecules are in the form of long and flexible chains in which a string of carbon atoms constitutes the backbone. Furthermore, these long molecules are composed of structural entities called mer units, which are repeated along the chain. A single mer is called a monomer, and the term polymer means many mer units. As an illustration, a mer unit and the zigzag backbone structure of polyethylene are shown schematically in Figure 2.1. Molecular structures of polymer can be classified into four different categories: (i) linear, (ii) branched, (iii) cross linked and (iv) network (Hossain, 2006). In linear polymers, the mers are joined together end to end in single chains (Fig. 2.2(a)). The long chains are flexible and may be considered as a mass of spaghetti. Extensive Van Der Waals bonding between the chains exists in these polymers. Some of the common linear polymers are polyethylene, polyvinyl chloride, polystyrene, nylon and the fluorocarbons.

Polymers may also' have a molecular structure in which side-branch chains are connected to the main ones, as shown schematically in Fig. 2.2(b). These polymers are called branched polymers. The branches result from side reactions that occur during the synthesis of the polymer. The formation of side branches reduces the chain packing efficiency, resulting in a lowering of the polymer density. In cross inked polymers, adjacent linear chains are joined to one and another at various positions along their lengths as depicted in Fig. 2.2(c). Generally, cross-linking is accomplished by additive atoms or molecules that are covalently bonded to the chains. Many of the rubber materials consist of Polybutadiene cross linked with S atoms. Trifunctional mer units, having three active covalent bonds, form three-dimensional networks as shown in Fig. 2.2(d). Polymers consisting of trifunctional units are termed network polymers. Epoxies belong to this group.

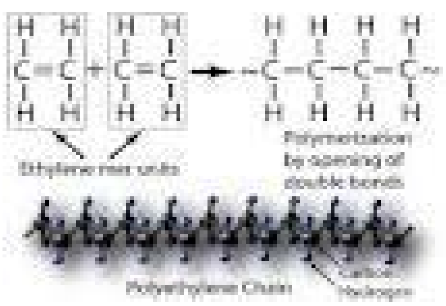

Figure 2.1: Schematic representations of polyethylene. (a) The “mer” and chain structure of carbon and hydrogen atoms. (b) A perspective view of the molecule showing the zigzag backbone structure.

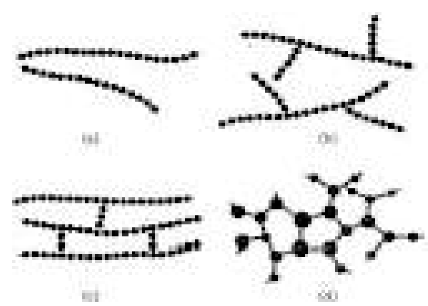

Figure 2.2: Schematic illustrations of (a) linear, (b) branched, (c) cross linked and (d) network(three-dimensional) molecular structures. The circle designate individual mer units.

When polymers are added to bitumen, the properties of the modified bitumen depend on the polymer systems used (Peterson, 1998). The molecules of polymers are very much larger than that of bitumen. So, when combined with bitumen, polymer creates drastic changes in the physical properties of the final binder.

Polymers are visco-elastic material. Polymer will recover its original shape from deformation after the removal of stress. Again it will reach the flowing condition when heated to temperature near the melting point. The response of polymer can be classified into three types - elastic response, elastomeric response (time dependent elasticity) and viscous (plastic) response. The response of any polymer will depend upon the structure and the conditions of loading in terms of time and temperature.

When mixes with bitumen the polymer will impart its elasticity and flow resistance to the bitumen if the polymer and the bitumen are compatible. Different types of polymers and copolymers are available in the market. Each type polymer may have different grade. All types of polymer available in the market cannot be used for modification of binder; some polymers are thermoplastic in nature whereas some are elastomeric. Elastomeric and thermoplastic polymers play an important role in the modification of bitumen. Bitumen modified with elastomer behaves very differently from conventional bitumen. It becomes more elastic throughout the temperature experienced on the road. At low temperature, it is less stiff and its ductility and Fraass breaking points (Shell Chemicals) are improved.

2.4.1 Types of Polymers

Polymer is a chemical compound. It is manufactured artificially in chemical industry to use in various purposes. Polymers can be classified according to their origin, structure chain, molecular weight, density, thermal and deformation properties etc. However, in asphalt research the focus falls on thermal and deformation properties. A simple classification (Hossain, 2006) of polymer based on their properties can be as follows:

a) Thermoplastic Polymer (plastic like): Thermoplastics are the most common type of polymer used. These polymers deform in a plastic or viscous manner at melting temperatures and become hard and stiff at low temperatures, i.e. the structure is reversibly broken down with the application of heat. These types of polymer are linear or slightly branched. These polymers can be melted and reshaped. They are recyclable. Thermoplastic polymers are used for pavement application. Examples of this type polymers are polyvinyl chloride (PVC), poly ethylene (PE), ethylene vinyl acetate (EVA), poly propylene (PP), polyethylene terepthalate (PET), linear low-density polyethylene (LLDPE), high-density polyethylene (HDPE), acronitrile butadiene styrene (ABS), polyethylene methacrylate (Acrylic).

b) Elastomer (rubber like): An elastomer is a polymer that has a flexible 'rubber' backbone and large side-chains in its structure. The molecular structure of this type polymer is usually linear. The copolymers of this group have radial form of molecular chain. The most potential modifiers are available in this family. Examples of these types of polymers are styrene butadiene styrene (SBS), synthetic rubber, neoprene latex, natural latex etc.

c) Thermo-harden Polymers: Thermo-harden or thermosetting polymers are heavily cross-linked polymers, which are normally rigid and intractable. They consist of dense three-dimensional molecular networks and degrade rather than melt on the application of heat. They are not recyclable. They cannot be remolded or reshaped if once manufactured to final product. The most common thermo-harden polymers are celluloid, bakelite, epoxy resins, poly euro thanes etc.

Classification of Polymers Based on Different Basis

a) Based on Structure

Linear: The molecular chain of this type polymer is un-branched. It has low melting point and high flow index compared to others; such as linear low-density polyethylene (LLDPE), linier high-density polyethylene (LHDPE) and linier polypropylene (LPP)

Nonlinear: The chain of this polymer is branched. This type of polymer has high melting point.

b) Based on Density

Low Density Polymer: The molecular weight of this polymer is less compared to other. Example of low-density polymer is LLDPE.

High Density Polymer: The molecular weight of this type polymer is high compared to other polymers. Example of high-density polymer is HDPE (high-density polyethylene).

c) Based on Physical Form

Pellet: Most of the polymers available in the market are in pellet form.
Powder: Polymer also available in powder or latex form.
Latex: Natural rubber collected from the trees is in latex form.
Recycled: Recycled rubber or polymer is at present being used in binder modification.

d) Based on Deformation Properties:

Elastomer: Elastomer exhibits high extensibility (up to 1000%) from which they recover rapidly upon removal of the stress.

Plastomer: Plastomer, which exhibit plastic behavior at service temperature, will deform, but will not return to original dimension when load is released.

2.4.2 Identification of Potential Polymer as Modifier

It is stated earlier that available polymers of all kinds is not used to improve the performance of bitumen. The polymers that are compatible with bitumen can improve its property. The compatibility of polymer with bitumen depends on not only the type of polymer but also on its structure, molecular weight and chemical composition. Compatibility also depends on the characteristics of base bitumen. The source of base bitumen, its constituent compound and its grade are the key factors (www.2001 link RACCTC) that determine weather the polymer will improve its quality or not. Hence the identification of potential compatible polymer is the first stage of modification of bitumen. Incompatible polymer cannot be blended with bitumen. The better way is to find compatible polymer is the preparation of several trial blends with the candidate polymer and testing its properties. Ibrahim, et al (1998) at the King Fahad University has performed test on some selected polymers. To blend the polymer they assembled a special blender. The blender comprised of a shear blade, a heating oil bath and a DC motor capable of producing rotation up to 3000 rpm. They followed the recommendations of the manufacturer of the polymers to approximate the tentative polymer concentrations, blending time and blending temperature for each of the collected polymers. They have used 500 gm of base bitumen for each type of polymer to prepare blend. The homogeneity of blending was ensured by visual inspection using an optical microscope. They performed shear modulus test, phase angle test, and softening point test on the prepared blend. They also performed economic analysis on the blend. Based on the technical and economic analysis they suggested PP, LLDPE, SBS, CRT as appropriate polymers. Their recommended blending temperature for some selected polymers is presented in Table 2.2.

Table 2.2: Recommended Blending Temperature for Some Selected Polymers

Polymer Type	**Recommended blending temperature (°C)**	**Maximum blending temperature (°C)**
Linear Low Density Polyethylene (LLDPE)	160-170	200
Polypropylene (PP)	170-180	200
Styrene-Butadiene-Styrene (SBS)	160-170	200
Crumb Rubber	170-180	200

[Source: Hossain, 2006]

2.4.3 Polymer that can be used as Modifier

Two basic types of polymer are used in modifying bitumen for road applications VIZ. **thermoplastic** and **thermo harden**. The product of thermo harden polymer cannot be remolded. So this type of polymer cannot be used as modifier of bitumen. Thermoplastic polymers are recyclable. Polymers that will be used as modifier of bitumen must be recyclable. In fact any thermoplastic polymer can be used as modifier of bitumen if it is compatible to bitumen. Thus selection of polymer to be used in bitumen primarily depends on compatibility. Any thermoplastic elastomer (TPE) (Shell

Chemicals) can be used as modifier based on economic and technical analysis. Investigations were made on low-density polyethylene (LDPE), poly propylene (PP) (Ibrahim, et al, 1998), ethylene vinyl acetate (EVA) (Panda, et al, 1999). Crumb rubber (CR) (Hussein et al, 1999), and recycled polyethylene (RPE) (Murphy, et al, 2001) by many investigators. EVA, CR and RPE have potential to be used in bitumen modification. Shell and Exxon chemicals introduce styrene butadiene styrene (SBS) and POLYBILT polymers respectively. These two polymers are specially manufactured to use as bitumen modifier. Shell chemicals supply SBS in powder or latex form. POLYBILT is available in pellet form. HEATEC (a chemical company) supplies polymer-bitumen blending system. Valley Slurry Seal (VSS), Colas, Vogele and Akzo Nobel are working with PMB. Rubberized roads are being built in USA, UK, Portugal, Egypt and Middle East .India is using waste polythene in pavement (BTF, 2008).

2.4.4 Benefits of Polymer Modified Bitumen

The purpose of polymer modification of bitumen is to construct durable pavement with greater stiffness and stability in Order to minimize maintenance cost. Use of polymer some time may increase cost of construction. In this case the benefit is evaluated by quality improvement of pavement. The use of RPE (recycled polyethylene) and CR (crumb rubber) give benefits in quality improvement and cost effectiveness as well as environmental hazards. The benefits of PMB are assessed in three ways (Hossain,2006)

Quality improvement of binder: Polymers in bitumen improve the following quality of bitumen:

- Polymer Increases binders viscosity that allows greater film thickness in paving mixes without excessive drain down or bleeding
- It increases the binder's qualities to better cope with cracking and dynamic deformation of the pavement internal layers.
- It improves the binder's behaviour to fatigue by increasing its mechanical resistance particularly to tractive force.
- It raises the softening point of binder that helps in reducing bleeding.
- It increases elasticity and resilience at high temperatures

- It increases the cohesion of binder.
- It reduces thermal susceptibility to both low and high temperature.
- To rejuvenate aged asphalt binders.

A significant improvement in pavement is possible as-

- It increases flexibility of pavement.
- It reduces deformation in pavement.
- Improved aging and oxidation resistance due to higher binder contents, thicker binder films, and anti- oxidants in the tire rubber.
- It provides greater fatigue resistance.
- It provides greater resistance to stripping.
- It provides improved self-healing properties.
- It provides greater durability.

Environmental improvement

Use of waste plastic in road construction could lead a significant consumption of waste plastic daily generated which would be helpful in, keeping the environment clean, reducing clogging of drains causing various hazards including health hazard , reducing dumping of plastic materials wastes going into land fill etc.

2.4.5 Limitations of Polymer Modified Bitumen

Polymer modified binder are not the solution to all pavement problems. It must be properly selected, designed, produced, and constructed to provide the desired improvements to pavement performance. Pavement structure and drainage must also be adequate. Limitations on use of PMB include:

- Mobilization costs for polymer modified bitumen production equipment. For large projects, this cost can be spread over enough tonnage so that increased unit price may be offset by increased service life, lower maintenance costs, and reduced lift thickness. For small projects, however, mobilization cost is the same, resulting in greater increase in unit price that may not be economically viable.

- Construction may be more challenging, as temperature requirements are more critical.
- Potential odour and air quality problems
- Polymer modified binders are often difficult to hand work because of stiffer binder and coarser mixture gradations.
- If work is delayed more than 48 hours after blending the asphalt rubber, some binders may not be usable. The reason is that the Crumb Rubber Modified (CRM) has been digested to such an extent that it is not possible to achieve the minimum specified viscosity even if more CRM is added in accordance with specified limits.
- For chip seals in remote locations, hot and/or pre coated aggregate may not be available because there may not be a hot-mix plant within reasonable haul distance of the job site.

2.5 Comparing Waste Plastic Modified Bitumen and Conventional Bitumen:

Use of bitumen modified by virgin polymers has been going on since mid-seventies of the twentieth century. However, environmental pollution with the aggressive disposal of plastic goods has made researchers to find ways to recycle the disposed plastics. One such way is its application in road construction. Since virgin bitumen has been modified with the application of polymers - the source of virgin plastics, it was thought that the waste or recycled plastics would do the same and accordingly research works have been carried out.

Plastics can be divided into six major categories (BTF, 2008). These are PET (Polyethylene Terepthalate), LDPE (Low Density Polyethylene), HDPE (High Density Polyethylene), PVC (Polyvinyl Chloride), PP (Polypropylene) and PS (Polystyrene). Studies found that LDPE, HDPE and PP are suitable for use in road construction. LDPE and HDPE are together known as PE.

In general, plastics have low melting point and it possesses very good bonding properties. The aggregates used in bituminous mix are crushed stones, which have rough surfaces. The low melting point of plastic caused the shreds to form a thin film around the aggregates. Higher penetration of plastic film into surface cavities due to lower viscosity gives higher bonding surface area and this gives higher strength to the mix when inter-particle gaps have been filled by the addition of bitumen. The good bonding between plastic and bitumen is also important for this good mixing and strength.

Table 2.3 shows thermal properties of different types of plastics and 80/100 penetration grade bitumen. It is seen that Sp. Gravity and Melting Point of LDPE, HDPE and PP are almost similar to that of 80/100 grade bitumen. This similarity ensures proper bonding of the two materials for the specified maximum heating temperature of bitumen for best result.

Table 2.3: Some Properties of Different Polymers and 80/100 grade Bitumen.

	LDPE	HDPE	PP	PS	PVC	PET	Bitumen (80/100 grade)
Sp. Gravity	0.918-0.93	0.94-0.96	0.91-0.97	1.04-1.12	1.35-1.39	1.45-1.50	1.01-1.06
Melting Point, °C	100-120	130-140	120-170	235-250	130-190	265-310	54-173
Flash Point, °C	>231	>360	400		>388		>220
Thermal Decomposition, °C	>270	>270-350	270-300	>300			>300

[Source: BTF, 2008]

Waste plastics of any category in pure state would be difficult to get for road works because of difficulty in sorting. It is likely that a mixture of PP and PE (HDPE and LDPE) would have to be used in real field. As such basic properties of 80/100 grade bitumen mixed with PE and PP in two different proportions were tested. Table 2.4 shows BUET findings of the two mixes and common value to that of virgin 80/100 grade bitumen (BTF, 2008). It is found that the addition of polymers modify the bitumen properties. The mix of PE and PP in different ratio makes the bitumen harder with reduced penetration value and higher softening point. It indicates that the pavement with the modified bitumen will have lesser deformation in the high temperature summer days. However, reduction of ductility particularly with higher proportion of PE would be a concern as reduction of ductility may risk pavement cracking. The plastomeric characteristic of plastic might be responsible for reduced ductility of the bitumen modified with higher proportion of LDPE. However, the increased tensile strength of the bituminous matrix modified with polymers would help to reduce the risk of cracking to a great extent. Jew, et al (1986) observation stated above regarding the attainment of increased service temperature range and resulting reduced low-temperature cracking of PE modified bituminous pavement is worth to mention here. Nevertheless, higher ratio of PP (i.e. PE: PP = 1:1) has given lower penetration and higher softening point i.e. higher resistance to deformation in high summer temperature and again comparatively higher Ductility i.e. less susceptible to cracking. Therefore, it can be concluded that the PP would be better than PE for use with bitumen in road pavement works. Accordingly higher proportion of PP may be used as bitumen modifier. However, a further study is necessary separately for LDPE and HDPE with or without PP in varying proportions. This will help us to exploit the potential of waste plastics to a higher scale for road works.

Table 2.4: Some Properties of 80/100 grade Bitumen with or without Polymers.

Properties	80/100 grade bitumen	8% by wt. LDPE:PP (3:1) in 80/100 grade bitumen	8% by wt. LDPE:PP (1:1) in 80/100 grade bitumen
Penetration, mm	80-100	43	37
Softening Point, °C	45-52	78	82.5
Ductility, cm	100	50	70

[Source: BTF, 2008]

Central Road Research Institute (CRRI), India carried out a detail laboratory study on the utilization of waste plastic bags in bituminous concrete mix in 2002. They used 60/70 grade bitumen and waste plastic bags. Waste plastic bags are produced both from HDPE and LDPE. The ratio of HDPE and LDPE used in the study is not mentioned in the report. The study found that the Optimum Bitumen Content (OBC) by weight of aggregates was same both in conventional mix (no plastic shreds) and in modified mix (with 8% plastic shreds). However, the Marshal Stability of the modified mix (1700 kg) was significantly higher than the conventional mix (1450 kg). Further study was carried out for retain stability test by soaking the samples in water bath at 60°C for 24 hours. The percentage retained stability obtained was 98% in case of modified mix and 88% in case of conventional mix. This shows that the modified mix with 8% waste plastic bags is stronger and it is less susceptible to moisture damage – a very important property required for the roads of Bangladesh. Study on Indirect Tensile Strength was also carried out for both the mixes at 25°C. The indirect tensile strengths found were 6.8 kg/sq cm and 9.0 kg/sq cm respectively for conventional and modified mixes. These values indicate that the modified mix has higher strength to retard cracking caused by shrinkage in winter and shear stress caused by heavy wheel load. Fatigue Life of the mixes was tested and it was found that test specimens ruptured at an average repetition of 17,554 and 8,650 for modified and conventional mixes respectively. This test shows that the modified mix has more than double fatigue life than the conventional mix, which is very important for Bangladesh with a growing overloading traffic. Rutting characteristics was studied using a German designed Hamburg Wheel Tracking Device (HWTD). It was found that for a post compaction 1000 nos. passes of the wheel 6mm and 8mm depression were occurred respectively in case of modified and conventional mixes. This is also important for major roads carrying stream of large vehicles and subject to rutting related depression and failure.

All the characteristic tests carried out by CRRI shows that the bitumen mix modified with 8% shredded plastic bags are significantly better than that with virgin bitumen only. However, 60/70 grade bitumen was used in CRRI study instead of 80/100 grade bitumen commonly used in Bangladesh. In 2003 Bofinger carried out a detail study about the premature cracking of Bangladesh roads and recommended the use of harder grade particularly 60/70 penetration grade bitumen in Bangladesh roads. The reduction of penetration value of 80/100 grade bitumen modified with recycled plastic is thus giving us harder grade bitumen with a prospect of better roads without additional costing for procuring virgin harder grade bitumen. We can, therefore, consider CRRI findings regarding the potential of waste plastics in road pavement along with the introduction of 60/70 grade.

2.6 Process of Blending

2.6.1 General

The blending of polymer with bitumen is a difficult task. Compatibility is the first and main problem that we must face when we trying to modify bituminous rheology by adding polymer to it. Blending depends on the compatibility (Baker, 1998) of polymer and bitumen to each other. Incompatible polymer cannot be blended with bitumen. Compatibility is the main considerable factor for the preparation of blend. There are three processes of blending. The processes are described in article and 2.7.

2.6.2 Compatibility

The issue of compatibility is confused in terms of the concept and its impact on binder performance properties. The compatibility of asphalt / polymer systems may be defined in several ways. It may be in terms of microscopic observation of the micro-morphology of the modified binder i.e. the structural arrangement of the polymer particles, chains or groups within the asphalt matrix. The compatible system has a homogeneous 'sponge-like' structure whereas the incompatible system has a coarse discontinuous structure.

It may be in terms of thermodynamic stability, i.e. whether the conformation of the polymer particles or chains are in a low energy state, i.e. whether there is a driving force to increase entropy. It may be in terms of practical storage stability, i.e. will it separate on standing. Or it may be based on whether a given property or set of properties are achieved and can be maintained for a suitable period of time (that is until the material has been applied). Some researchers measure compatibility as the difference between the softening point of the top half and bottom half of a modified binder. Phase separation or incompatibility can be demonstrated by a simple hot storage test in which a sample of the polymer modified bitumen is placed in a cylindrical container and stored and alleviated temperature, usually 150°C in an woven for up to 7 (Seven) days. At end of the storage period, the top and bottom of the sample are separated and tested. Incompatibility is usually assessed by the difference in softening point between the top and bottom samples - if the difference is less than °5 C the binder is considered to be storage stable.

However, a binder may be incompatible at one temperature and compatible at a slightly higher temperature. Thus the defined temperature is important, and this, together with time and vessel shape/size differs from researcher to researcher. It is therefore hard to extrapolate the compatibility findings of one researcher to another. The importance of compatibility is contentious as well, with some researchers claiming that incompatibility has a deleterious effect on binder properties. Others claim that incompatibility has no significant effect on the final modified binder properties, as long as no separation of the binder and polymer has occurred. In fact a polymer can be considered compatible with particular bitumen when the visible changes in the colloidal mixer of the bitumen do not arise. The compatibility of polymer with bitumen depends upon the type and grade of polymer system, its structure (linear, radial etc.), molecular weight and density. Linear and low-density polymer is more compatible with bitumen. The lesser the molecular weight the higher the compatibility (Baker, 1998). But polymers having too low molecular weight impart very low cohesion to the bitumen.

The composition of base bitumen has a tremendous effect on compatibility. Bitumen is a complex mix of different chemical compound with different molecular weight. The constituent of bitumen can be classified as asphaltenes (compound containing heavy carbon particles) and malthenes (paraffin, aromatic compound, resin etc.). Asphaltenes and malthenes play an important role in polymer modification of bitumen. But high asphaltene content is not desirable because bitumen containing high amount of asphaltene compound will loss compatibility especially when high percentage of polymers are desired to be added. Again too low content of asphaltenes will prevent proper compatibility. The aromatic content of malthenes also influences the homogeneous mixing of polymer and bitumen. In short, the success of blending of a polymer with particular bitumen will depend on the following three important factors.

- Chemical composition of bitumen.
- Composition, type or grade of polymer.
- Blending process

2.7 Method of Blending System

There are generally considered to be three basic processes which may utilize recycled plastic (Polymer)/Tyre Rubbers or Crumb Rubber modifier (CRM) in the production of different types of asphalt concrete pavements. These processes are known as the Dry Process, the Terminal Blend Process, and the Wet Process. A short definition of each process is presented below:

2.7.1 Dry Process

The dry process is suitable for blending the crumb rubber with aggregate and asphalt without using any special equipment required by other processes. Recycled rubber tyre is sized in a particular form. Generally a cubical, uniformly shaped cut CR particle with low surface area in size from 1/2-1/8 inches is normally used and is blended dry into the asphalt mix. The aggregate grading is gap graded to allow for space for the 3% of rubber that is added. The time at "reaction" temperature is limited by limiting mixing time and the rubber retains its integrity. The surface only interacts with the asphalt creating a durable bond. Shock absorbing pavement for children play ground is being built with rubber aggregate.

A new variation on this process has been recently trialled in Southern California in USA(www.rubberpavement.org).This uses only the finer rubber addition and maintains the aggregate grading as for the wet process. In this the solid rubber particles are conveyed into the pug mill during weigh up. The theory is that the rubber particles will partially digest and fill voids.

2.7.2 Terminal Blend Process

Terminal blend asphalt rubber is produced at a refinery or central blend plants and trucked to the job site. Such materials are relatively new and use synthetic polymers with lower percentages of crumb rubber than AR and significantly less rubber crumb than the wet process. The University of Calgary has reported some success with terminal blend trials and the U.S. Turner Fairbanks site reports chemically modified (stabilized) crumb rubber blends, which would fall into this category [www.tfhrc.gov/pubrbs/spring97/crum.htm].

2.7.3 Wet process

Wet process is the most common method of polymer modification of bitumen. It is also called the McDonald process. This process requires special equipment to blend polymer. The polymer/waste plastic is mixed and digested in the asphalt by either low or high shear mixing in the wet process. The rubber undergoes a specific interaction with the asphalt. This is often referred to as a reaction. It is rather a physiochemical reaction rather than simply a chemical one. The polymer/rubber swells in components of the asphalt to produce a composite.

The wet process is used mostly in Australia, South Africa and USA. There are three wet process (Hossain, 2006).They are **a)** Chemical reaction process, **b)** Gelatin process and **c)** Blending process.

Chemical Reaction Process: Polymer chemically reacts with bitumen and produces blend. The process is performed at the refinery. Obtained blend from this method has higher storage stability.

Gelatin Process: Here polymers do not react with bitumen. Polymer is dispersed in to the bitumen to form a two-phase homogeneous mixer.

Blending Process: This process may be called cooking process and suitable for scrap polymer and rubber. Polymer/rubber is cooked in the bitumen in this process. This method requires a blending/cooking system. Major parts of the blending equipment are a container, a mechanical stirrer with shear blade and controlled heating facilities. Bitumen is heated in the container to make it liquid. Then the polymer in particular form (powder, shredded, pellet, latex) is added to the bitumen and stirring is continued up to completion of blending. Required blending time and temperature and speed of stirrer depend on the type of polymer used.

The drawback with these systems is that mixing uniformly is difficult and often the result is significant segregation of waste plastic.

2.7.4 Factors Affecting Blending

The process of blending of compatible polymer with bitumen is affected by the following factors.

Blending Mechanism: The possible problems with modified bitumen are mainly in the storage of the bitumen, mixing temperatures, and the length of time the material is held at elevated temperatures before laying. The blending of bitumen and polymer is not an easy process because two complex materials are forced together to form a two-phase system. The polymer must disperse uniformly into bitumen. Hence it is required to provide high shear force during blending. The configuration of shear blade of the stirrer of blender and the speed of the stirrer determine the shear rate. The speed of the stirrer should not be less than 2500 rpm (Ibrahim, et al, 1998). However some polymer does not require high shear force such as EVA and LLDPE.

Blending Time: The duration of blending time depends on the blending temperature and applied shear rate and on the complexity of polymer system. Blending time should be kept minimum by adjusting blending temperature and applied shear rate. Too long blending time may cause the change of rheological properties of PMB.

Blending Temperature: Blending of polymer should be performed within a specified temperature range. It is an important factor. Without controlling the temperature it is not possible to prepare blend properly. The blending temperature mainly depends on the molecular weight of the polymer. Polymer of higher molecular weight requires higher blending temperature (Baker, 1998). Blending temperature of particular polymer is above its melting point. From the economic point of view and to diminish some change in asphalt or polymers, a temperature of the order of the 170-190 °C is generally satisfactory.

2.7.5 Storage Stability of Blend

The storage stability of the polymer/bitumen blend is a prime indicator of compatibility. Storage stability can be defined as the quality of blend for which it can be preserved for future use without physical and chemical change. It is an important factor to be considered to store prepared blend. Storage stability indicates successful blending and better compatibility of polymer with bitumen. In fact storage stability is a measure of compatibility.

The storage stability of PMB is necessary to store it for future use. Study on storage stability of PMB expresses that quick cooling of blend has least effect on storage stability, storage at room temperature has moderate effect and hot storage has adverse effect (Hossain, 2006) on stability of blend.

2.8 Some Study Results*:*

Although the application of polymer modified bitumen (PMB) in pavement construction in many countries of the world had been started long years ago, no remarkable study on PMB was performed yet in our country. A few students of BUET tried to study the properties of recycled rubber modified bitumen and RPE modified bitumen. But their research work was abandoned at the preliminary stage for want of proper procedure and information. (Islam, 2003) and (Hossain, 2006) who worked on PMB in M. Engineering Projects where they succeeded to blend pure polymer and scrap tyre respectively with bitumen as mentioned in the chapter 1. The following articles now represent some study results on PMB.

2.8.1 LDPE Modified Binder

Islam, (2003), previous researcher of the similar topic became successful at BUET to blend pure polymer (LDPE) with bitumen using a manually controlled blender prepared by him. The laboratory test results of LDPE modified binder performed by him is given in Table 2.5.

Table 2.5: Laboratory Test Results of Modified Binder -at Different LDPE Concentrations

LDPE Concentration	Penetration at 25°C (l/10mm)	Softening Point CO	Ductility at 27°C (cm)	Specific Gravity	Loss on Heating (%)	Viscosity (Centistokes)	Film Thickness (mm)
0	87	45	100	1.030	0.060	331	0.0481
2.5	65	48	94	1.025	0.065	630	0.0549
5	55	54	70	1.020	0.040	1117	0.0790
7.5	35	61	45	1.019	0.060	1572	0.0891
10	24	68	19	1.018	0.053	9494	0.1190

[Source: Islam, 2003]

2.8.2 CR Modified Binder

Hossain, (2006) studied on rheological properties of scrap tyre (Crumb Rubber) modified bitumen for paving mixes. He used electromechanically controlled blender for blending scrap tyre. Some laboratory test results found by him are presented in table 2.6:

Table 2.6: Laboratory Test Results of Modified binder -at Different Scrap Tyre Concentrations.

Scrap Tyre Concentration	Penetration at 25°C (l/10'"mm)	Softening Point CO	Ductility at 27°C (cm)	Specific Gravity	Loss on Heating (%)	Viscosity (Centistokes)	Film Thickness (mm)
0	89	49	100^{+}	1.030	0.060	364	0.0527
2.5	61	55	79	1.039	0.065	571	0.0684
5	50	58	59	1.044	0.040	707	0.808
7.5	32	64	29	1.054	0.060	1171	0.0961
10	22	69	16	1.060	0.053	-	0.1060

[Source: Hossain, 2006]

2.8.3 EVA Modified Binder

Panda, et al (1999) studied the engineering properties of Ethylene Vinyl Acetate (EVA) modified bituminous binder for paving mixes. Some properties of EVA modified binder and mixes are shown in Table 2.7 and in Table 2.8.

Table 2.7: Physical Properties of Binder at Different EVA Concentration

EVA Concentration	Grade of EVA	Penetration at 25° C (1/10 mm)	Softening Point (°C)	Ductility at 27° C (cm)	Specific Gravity
0	Bitumen	88	44	100+	1.032
2.5	1802	55	59	72	1.027
	2806	65	54	102	1.030
5	1802	45	68	43	1.022
	2806	51	61.5	75	1.020
7.5	1802	39	72	27	1.020
	2806	42	64	50	1.023
10	1802	35	74	18	1.015
	2806	39	66	35	1.016

[Source: Panda, et al, 1999]

Table 2.8: Marshal Properties at Optimum EVA Modified Binder Content

EVA Content in Binder (%)	Optimum Binder Content in Mix *(%)*	Marshall Stability (lb)	Flow value (1/100 inch)	Unit Weight (Ib/cft)	Air Voids (%)
0	5.50	2157	12.8	143	3.8
2.5	5.75	2641	13.8	143	4.0
5	6.00	3079	14.2	142	4.0
7.5	6.30	3180	15.0	141	4.0
10	6.60	3304	15.0	141	3.4

[Source: Panda, et al, 1999]

2.8.4 Rubber Modified Binder

The characteristics of rubberized bituminous mixes are studied by Kumar, et al (2001). They have used natural rubber latex, centrifuged latex and tyre dust as modifier. Their results of Marshall Test are presented in Table 2.9 and in Table 2.10.

Table 2.9: Marshall Properties of Centrifuged Latex Modified

Centrifuged LATEX(%)	Specific Gravity	Unit Weight (lb/cft)	Marshall Stability (lb)	Flow Value (1/100 inch)	Air Voids (%)	VMA (%)	VFB (%)
0	2.33	148	2544	9.1	4.0	16.62	74.94
1	2.337	147	2256	11.0	4.8	10.41	53.89
1.5	2.339	148	2625	10.6	4.7	10.38	54.72
2	2.341	148	2706	9.4	4.6	10.34	55.53
3	2.359	149	2670	10.2	3.8	9.62	60.48

[Source: Kumar, et al, 2001]

Table 2.10: Marshall Properties of Tyre Dust Modified Binder

Tyre Dust (%)	Specific Gravity	Unit Weight (lb/cft)	Marshall Stability (lb)	Flow Value (1/100 inch)	Air Voids (%)	VMA (%)	VFA (%)
0	2.33	148	2544	9.1	4.0	16.62	74.94
1	2.32	148	1775	6.3	5.58	11.22	50.27
5	2.34	149	3142	8,7	4.2	10.28	59.14
10	2.30	146	2243	7.5	5.08	11.72	56.66
15	2.27	144	1018	6.7	5.65	12.86	56.07

[Source: Kumar, et al, 2001]

2.8.5 RPE modified binder

The performances of reclaimed polyethylene(RPE) modified binder were also studied by Panda, et al (1997]. They use reclaimed polyethylene (shopping bag) to modify bitumen. The test result on binder indicates a noticeable improvement of rheological properties. Their test results on binder are presented in Table 2.11.

Table 2.11: Physical Properties of RPE Modified

RPE Content by % Weight of Bitumen	Penetration, 25°C (1/10th mm)	Softening Point (°C)	Ductility (cm)	Specific Gravity
0	88	44	100+	1.042
2.5	64	51	73	1.034
5	47	55	60	1.028
7.5	39	61	51	1.021
10	18	81	6	1.012

[Source: Panda, et al, 1997]

2.9 Polymer Modified Bitumen (PMB) Used in Different Countries

2.9.1 Natural rubber Latex Used in Singapore, UK, USA and South Africa

The first ever application of natural rubber latex in road construction took place in 1929 in Singapore. The great depression, war and slow recovery of global economy meant that it was another 20 years before researchers once again began to take an interest in Natural rubber latex in roads. In UK, USA and South Africa, organizations such as the NRPRA (Natural Rubber Producers Research Association, UK) in cooperation with the government road research organization's like TRL (Transport Research Laboratory, UK) began to study the effects of NRL modification on Asphalt durability in road surfaces. Early studies assessed use of Natural Rubber Latex and Natural Rubber Powder (unvulcanised and lightly vulcanised.)

2.9.2 Crumb Rubber Used in Arizona, California and Los Angeles in USA

Charles H. McDonald, the material engineer of the City of Phoenix Arizona worked extensively with asphalt and rubber materials in the 1960s and 1970s and was instrumental in development of the "wet process" (also called the McDonald process) of producing asphalt rubber. He was the first to routinely use asphalt rubber in hot mix patching and surface treatments for repair and maintenance. Asphalt rubber chip seals served effectively as the City's primary pavement maintenance and preservation strategy for arterial roadways for nearly twenty years, until traffic volumes forced a change to thin AC overlays. Though the Arizona Department of Transportation (ADOT) and the City of Phoenix began using crumb rubber from scrap tyres in hot mix in the 1960's and 1970's, but more extensive use began in 1985 using open and gap graded mixes. Currently Arizona uses only the wet process. Their experience with crumb rubber in the dry process has been unsuccessful.

The Florida Department of Transportation (FDOT) began their use of crumb rubber in hot mix in 1988-1989. Their decision to begin use of crumb rubber was prompted by State legislative interest. However, FDOT took a very structured approach. Their main use is 5 % crumb rubber by total weight of binder in dense graded friction courses. These are placed in a 1inch (25mm) thickness to improve the resistance to rutting, particularly at intersections. On their freeways FDOT uses a Vi inch (15mm) thin layer of open graded friction coarse is containing 12 % crumb rubber (by weight of total binder). The crumb rubber is used to improve the durability of the hot mix. FDOT also has developed a wet process which uses about 5-10 % ultra fine crumb rubber in the hot mix (by weight of total binder). The crumb rubber is introduced into the asphalt just prior to the binder being introduced to the hot plant. There is no lengthy reaction time. FDOT does not use the dry process.

California's experience with crumb rubber began in the 1970's in chip seals or SAM's. The California Department of Transportation (Caltrans) began experimenting with crumb rubber in hot mix applications in 1978 and since then Caltrans has been a leader with hot mix usage and has had considerable experience with dense and gap graded mixes. Caltrans experience with the dry process has not been successful. Some field trials using the dry process continue, but the wet process has proved to be the most cost effective and it is predominant in California.

Los Angeles used rubber in bitumen first in 1970. In 1985 a street of this county was resurfaced with rubber-modified bitumen and no reflective crack was seen in these days. The use of rubberized asphalt concrete (RAC) greatly increased in Los Angeles from 1992. By using crumb rubber in road way pavement the county diverts scrap tyres from landfills, which was creating environmental hazard. A local road of the county of Sacramento was resurfaced with 1-1/2 inches rubberized bitumen in 1989. The Department of Public Works of this county constructed 210 lane miles RAC resurfacing using nearly one half millions scrap tyres. A noise study survey was conducted in the city of Thousand Oaks constructing rubberized roads and conventional road. The study result showed that rubberized road reduces noise above five dB (A). (Public Works Department, The City of Thousand Oaks, USA). Another efficient use of scrap rubber in the form aggregate has been started in this time in different state of USA and becomes popular to user. The use of rubber aggregate in the playground pavement for the children is most welcomed by the user since it is comfortable and shock absorbing. (Hossain, 2006)

2.9.3 Colsoft Used in UK and France

Colsoft, the low-noise asphalt from Colas Ltd. has undergone trials at the Transport Research Laboratory (TRL) in the UK. The test followed construction of a new noise assessment test area, which was completed by Colas. Colsoft is developed to reduce noise pollution in urban areas and alleviate environmental problems. Laid as thin asphalt layer using crumb rubber from recycled vehicle tyres (half a tyre to each m2) as part of a discontinuous graded aggregate, the product also incorporates the high performance SBS modified binder, Colflex. Recent tests in France showed that Colsoft's noise reduction and absorption properties give typical noise values of between 4 to 7 dB (A) lower than hot rolled asphalt (equivalent to a 50 % - 70 % reduction in traffic) and to generate lower noise than porous asphalt.

2.9.4 PMB Used in Other Countries

In recent years, the use of PMB has begun in other countries of the world. Greater Bangalore city also known as the Garden City of India because of its tree-lined avenues, well maintained roads, parks and botanical garden located in the heart of the city. A unique feature of Bangalore city is that it has more than 300 Km. roads made of waste plastic and BBMP plans to use plastic waste to asphalt on a road network of 1000 Km. covering greater Bangalore city.

K. K. Plastic Waste Management Pvt. Ltd., a Bangalore firm has developed the new technology of using waste plastic (plastic carry and shopping bags, tea cups, pet water bottles, ice cream cups, etc.). Waste plastics are melted and mixed with bitumen in certain proportions (8% to 10% by weight) for laying roads. These are utilized for making a compound for modifying bitumen used in the construction of roads. LDPE, HDPE and PP waste generated from household, industrial and agricultural packaging are mixed with bitumen for road construction, repair and maintenance work. The firm developed a polymer blend marketed as 'K. K. Polyblend' made out of littered plastic bags, PET bottles, and thin film grade plastics (BTF, 2008).

Shredded Waste Plastic in a tray held by worker (K K Waste Plastic Processing, Plant, Bangalore)

Shredded Waste Plastic in a tray held by worker (K K Waste Plastic Factory, Bangalore)

The temperature of major cities of Russia fluctuates between 40°C to 30°C. This wide range of temperature needs special attention for selecting the binder and the Russian successfully did it. Most of the city roads in Russia are smooth, waterproofing, crack sealing, skid resistant and durable. The achievement of this quality in pavement was possible by using PMB. Figure: 2.3 and 2.4 show the application of PMB in a high way of Moscow and Kualalampur Airport respectively. The E30 road runs through Great Britain, the Netherlands, Germany, Poland, Belarus and Russia needed repairing along 60 km stretch connecting Brest on the Polish/Belarus border with the Russian border. The region is subject to harsh winters and very hot summer, so the road pavement was constructed with KRATON polymer modified bitumen which could create a long lasting road surface able to withstand such temperature extremes, thus reducing long term maintenance costs. The construction company used granulated KRATON D-1101 polymer to provide modified bitumen with improved aging characteristics and superior all-round performance. Over 800 tons of the polymers were used to resurface the top layer of the high way and the work was completed in the summer of 1998. Experimental use of polymer in bitumen has been started in Portugal in order to find out a way of reducing pavement rehabilitation costs. A new road network to link with Lisbon and its airport was needed to construct to celebrate Expo 98, a 100-day festival. Local constructors used Caribit SP from Shell Bitumen (Portugal), bitumen modified with KRATON D-1101 polymer in the construction of tunnels and road surfaces for part of new road network. (Hossain, 2006)

Figure 2.3: Application of PMB in Moscow

Figure 2.4: PMB in Kualalampur Airport

2.10 Mix Design of Polymer Modified Binder

2.10.1 General

Mix design procedure for hot mix paving mixtures depend upon the aggregate gradation, maximum size of aggregate, wheel load and its frequencies and on the rheology of binder. Modified binder may need slight modified method of mix design. The mixing and compaction temperature may be different for PMB/RMB depending on the improvement of viscosity. Marshal mix design method for dense graded paving mixtures using rubber modified bituminous binder is shortly described in this article.

2.10.2 Method of Mix Design

Both Marshall and Hveem methods can be used for designing hot mixes with PMB. Mix design procedure will depend on the rheological properties i.e. viscosity, elasticity etc. of PMB. When low percentage of polymer /waste plastic is used unmodified mix design procedure can be followed. Higher amount of modifier (waste plastic or polymer) make significant changes in physical and mechanical properties of PMB. So that a modified mix designs method needs to be followed.

2.10.3 Aggregate Requirement

Aggregate should meet the same quality required for conventional bituminous pavement. For waste plastic content 5-10% (by weight) the aggregate gradation for dense graded mixes should be maintenance on the course side of the gradation band.

2.10.4 Binder Content

The binder content needs to increase as the waste plastic content in the binder increases. Approximately 25% more binder is required in case of RMB. (Hossain, 2006)

2.10.5 Specimen Mixing

The Polymer Modified Bitumen (PMB) should be heated using indirect source of heat. The recommended heating temperature for binder is 177±5°C and for aggregate is 150±3°C. Binder should be stirred to avoid local over heating. Mixing of the PMB and aggregate should be performed using standard mechanical mixer. Vigorous manual mixing may be acceptable also. Mixing should be performed immediately after the addition of binder to the aggregate. Maximum mixing time should not exceed two minutes. If complete coating of aggregate cannot be achieved within mixing time, one or more of the following parameters should be adjusted.

- The content of binder should be increased.
- Increase binder temperature to reduce viscosity.
- The rubber content in bitumen should be decreased.

2.10.6 Specimen Compaction:

Polymer bituminous mixture is more sensitive to temperature than conventional mixtures. The compacting temperature should be maintained carefully. The recommended compaction temperature can be between I35°C-150°C. Compacted specimen should be allowed to cool to ambient temperature prior to removal from the moulds.

2.10.7 Specimen Testing:

Standard procedures should be followed to test the specimens to evaluate stability, flow, and density and air voids result.

2.11 Construction Practice

2.11.1 General

Polymer Modified Bitumen (PMB) has a wide ranged application possibilities in construction of new pavement as well as in rehabilitation and maintenance of old pavement. All conventional bituminous works can be replaced by PMB. It may require slight modified mix design procedure if PMB posses higher viscosity than that of traditional binder. Some construction practices with PMB are: 1) Hot mix pavement, 2) Surface Treatment, 3) Crack and joint sealant (Hossain, 2006).

2.11.2 Hot Mix Pavement:

The main use of PMB/RMB is in hot mix pavement. Two widely used technologies for hot mix are Mc. Donald and Plus Ride technology. These two methods use Rubber Modified Bitumen (RMB) and Crumb Rubber (CR) and known as wet process and dry process respectively (Hossain, 2006). The technologies are described bellow.

Mc. Donald Technology:

Charles Mc. Donald (1964) a material engineer of Arizona develops this method of blending crumb rubber with bitumen and provides a modified mix design technique. According to his name this technology is known as Mc. Donald technology. It can be used in the dense graded, open graded and gap graded aggregate mixtures. The binder content depends on the aggregate gradation, rubber content in the binder and its rheological properties i.e. viscosity, elasticity and softening point. Higher binder content (up to 10% - 11%) is required for high viscous RMB. Higher RMB content creates thicker binder film around the aggregate and durable pavement is possible to obtain by proper compaction.

Plus Ride Technology:

It is a very recent technology of mix design. It does not follow the conventional Marshall and Hveem method of mix design. The process uses crumb rubber as rubber aggregate, which is incorporated in to a gap-graded aggregate prior to mixing with the bitumen. The coarse rubber particles act as elastic aggregate in the gap graded aggregate mix and produces a more flexible and ice-debonding pavement surface. The process recommends the maximum size of granulated rubber is less than ¼ inch and the targeted air void is 2 to 4 percent. As specified in the design the crumb rubber amount is about 3 percent by weight of the total mix. The binder content generally varies from 7.5% to 9%.

2.11.3 Surface Treatment

Most of the pavement failures initiate from the surface of pavement. So, surface treatment in road maintenance is very important. Treating surface with PMB, cracks and bleeding can be reduced as well as stripping can be minimized (Hussein, et al, 1999 and Hoque, 1996). Intrusion of water, which is a major cause of "pot holes", can be prevented by improving the impermeability of surface course. The type of surface treatment is dependable on extend of pavement failure. Road surface treated with modified asphalt can extend pavement life and reduce maintenance costs.

Slurry Surfacing:

Slurry surfacing is a mixture of graded aggregates, a polymer modified emulsion and additives. It is applied using a special paver mounted on a truck or self propelled Components are metered into a pug mill, mixed and spread on the surface. There are three type of slurry surfacing which are as flows:

- Slurry Seal
- Micro Surfacing
- Colored Slurry

Slurry Seal:

Slurry seals are used both as preventative and corrective maintenance treatments. It is applied on cracked pavement. Polymers can extend the performance of slurry in the context of adhesion and cohesion, abrasion resistance, bleeding resistance and durability. Slurry Seal consists of four materials, binder (emulsion), water, aggregate and set control agents or retarders. The thickness of slurry seal generally maintained between 1 to 1.5 inches. Its performance is affected by not only PMB but also quality (hardness, durability, resistance to polishing) and size of aggregate. According to Holleran and Ristic (1999), its lifetime is five to ten years. So it is powerful tools in crack preventive maintenance. The application of slurry seal is seen in Figure: 2.5

A rubberized slurry seal was applied in five local airports of Los Angeles, in 1990, where $\frac{1}{2}$ pound of crumb rubber was used in one gallon of emulsified bitumen. Fider graded and low percentage of aggregate was used to reduce the tendency for the propellers of Jet to lift the aggregate from the surface and damage the aircraft.

Figure 2.5: Applications of Slurry Seal

Micro Surfacing:

Micro surfacing is a thin surface, cold applied paving mixture composed of polymer-modified asphalt emulsion, 100 percent crushed aggregate, mineral filler, water, and other additives. A self propelled continuous loading machine or a truck mounted machine is used to proportion and mix the materials and apply the mixture to the pavement surface. Micro surfacing is used to retard ravelling and oxidation, fill ruts, reduce the intrusion of water, improve surface friction, and remove minor surface irregularities. In 1990 and 1991 Georgia Department of Transportation (GDOT) conducted an evaluation of micro surface mixes in test road. Two different micro surface mixes were used, containing different polymer modifier. Both the mixes showed little deterioration after two years.

Colored Slurry:

It is one kind of slurry seal used in pavement application. Colored slurry is an emulsion that contains polymer rejuvenating oil and bitumen. It is sprayed onto cracked surfaces and choked with sand or cinders. It penetrates and softens hardened bitumen. It can be used in cold conditions.

2.11.4 Crack and Joint Sealant

Crack Sealing is the placement of a mixture of a neat or modified binder, such as a PG64-22, mixed with polyester or polypropylene fibbers, into existing cracks in the pavement. Crack Sealing is used to minimize the intrusion of water into the pavement. By keeping water out of the pavement, erosion of the mix is kept to a minimum, deterioration of the crack is slowed, and less water is available to saturate the base materials. Rubberized bituminous binder is widely used as crack and joint sealant in maintenance work. In crack sealing application the RMB must have the property of less temperature susceptibility and high elasticity to resist cracks that induced in the pavement at low temperature. Additionally PMB should be flexible enough to keep pavement flexible at cold weather. High penetration grade bitumen with a high amount of crumb rubber can satisfy both the requirement. The choice of sealant for a particular location depends on many factors. The main factors are; type of pavement, type of crack and joint, shape and size of the crack or joint and degree of pavement distress (Hoque, 1996).

2.12 Where Bituminous Polymer Products should not be used:

Temperature affects placement and compaction of conventional mixtures, but is more critical when working with materials that have been modified to increase high temperature stiffness (such as asphalt rubber and polymer-modified performance based Asphalt, PBA) and are being placed in thin lifts. According to Caltrans (California Department of Transportation) Asphalt Rubber Usage Guide, Asphalt rubber paving materials should not be placed in the following conditions:

- During rainy weather.
- During cold weather with ambient or surface temperatures <13°C.

- Over pavements with severe cracks more than 12.5 mm wide where traffic and deflection data are not available.
- Areas where considerable handwork is required.
- Where haul distances between AC plant and job site are too long to maintain mixture temperature as required for placement and compaction.

2.13 Over View

The preceding articles presented a brief review of polymer modified bitumen. It has intended to present polymer modification as a viable cost effective technique of improving pavement performance. From the literature review it is found that in many countries, modified binders are being used in all paving and maintenance applications including hot mix, warm mix, cold mix, chip seals, hot and cold crack filling, patching, slurry seals and even airport pavement. They are being used extensively wherever extra performance and durability are desired. In consideration of improved stability, durability and elasticity, modified binders are gradually being replacing the conventional bituminous binder.

Literature review revealed that now-a-days many countries are exploiting the potential of polymer modification particularly to tackle pavement distresses due to extreme hot and cold temperature and in some counties to reduce their waste disposal problems. But little study document is found emphasizing its potential to reduce drainage induced pavement failure. This may be due to the fact that in developed countries this mode of pavement failure is not a serious problem. The later issue is very significant in Bangladesh, particularly in built-up areas, due to acute drainage problems coupled with extended monsoon period. As such, there is a strong need to study on the polymer (waste plastic) modified bituminous hinder and mixes in particular relation to its performance under submerged condition.

Based on the literature review presented in this chapter, the important observations emphasizing on blending process and technique, is summarized as following:

- Only thermoplastic polymers are suitable for modification of bitumen.

- It is possible to blend scrap tyres, tube, rubber, PET bottle, and waste polythene bags with bitumen.
- SBS (Styrene Butadiene Styrene), KRATON, POLYBILT are the commercially Produced polymers for the modification of bitumen,
- Blending depends on compatibility of polymer with bitumen and compatibility depends on the type of polymer and chemical composition of bitumen,
- Successful blending of polymer with bitumen depends on
    - Compatibility of polymer and bitumen (i.e. mixing)
    - Blending temperature
    - Blending time
    - Application of Shear force
- In the developed countries, specific blending plants are used for the mass production of polymer-modified binder.
- Conventional equipment and procedures is used for the mixing, lay down and compaction of polymer modified mixes.
- Marshall and Hveem mix design methods is used for designing hot mixes with waste plastic modified binder.
- Polymer (waste plastic) reduces temperature susceptibility, increases viscosity, imparts elasticity and improves other rheological properties of bitumen.

Chapter 3
Methodology

3.1 Introduction

Traditional bituminous materials are extensively used in road constructions particularly in flexible pavement. Its demand is increasing day by day. But it has some limitations regarding the performances which are evaluated by rheological properties. Binder modification by blending polymer to it is a major issue and continuous research in this area is aiming produce new binders with better rheological and mechanical properties, which allow the manufacturing and application of road bituminous mixes with performance. Waste plastic modified bituminous materials can bring real benefits to highway maintenance/construction, in terms of better and longer lasting roads, savings in total road life costing and improvement of environmental hazards. Waste plastic changes the properties of bitumen when it is blended with it and brings how much and what kind of changes in the geological behavior of bitumen, which is one of the main objectives of this investigation. To investigate this set of examinations of reference binder and waste plastic-modified binder is required. This chapter includes the planned experimental design, which is outlined in Art. 1.5. The design includes selection of blending technique, searching compatible waste plastic to blend, process of evaluation of polymer modified binder and mixes. This chapter also includes the procedure of tests and field demonstration which are performed.

The performances of compacted mixes depend not only on binder quality but also on mechanical and physical properties of constituent material. Besides binder, aggregate is the main constituent of paving mixes. A short description of the properties of aggregate that would be used in the experiment is also included in this chapter.

3.2 Method of Blending

There are mainly two methods of blending polymer with bitumen, the dry blending method and wet blending method. In the dry method polymer is mixed with heated aggregate whereas in the wet blending method, polymer is added to the hot bitumen prior to adding the resulting binder to the aggregate. The wet method is termed as "Cooking Method" (Hossain, 2006). The method requires a simple cooking device. The device comprises of a container, a stirrer and a heater. The stirrer should have shear blade to produce required shear force in the mixer during blending process. The shear force required to blend polymer with bitumen depends on the polymer types. Blending can be performed in three ways by using:

- Commercial automated blending system
- Laboratory milling machine
- Manual cooking device

3.2.1 Commercial Automated Blending System:

There are some chemical companies viz. VSS Asphalt (Bitumen) Technologies, ISS Asphalt Rubber, Heatec, Exxon etc. that supply polymer-bitumen blending system. Various types of polymers such as SBS, ground tyre rubber, natural rubber latex etc. can be blended with bitumen with this blender. It is useable at both asphalt terminals and hot mix asphalt plant. The blending system may be portable or stationary. Some commercially available blenders made by the various international companies are also discussed in this article.

VSS Asphalt Technologies:

VSS Asphalt Technologies is an International Company involved in manufacturing of emulsions and equipments and supplying of raw materials. The PMB plant is made by VSS Asphalt Technologies is shown in the Figure: 3.1

Figure 3.1: A VSS asphalt rubber blending system in China.

Reed International Asphalt Rubber Blender:

Reed International has designed and built the latest in functional and efficient asphalt rubber blenders on road systems. A short description of this blender is given below:

Main elements of the system:

- Weigh Hopper
- Heater Blender
- Reaction Vessel

Weigh Hopper

The Weigh Hopper meters is a key piece of equipment, it allows free flow of crumb rubber to the blender, it ensures accurate dosing and lumps (agglomerated particles) are broken down before the blending tank. The weigh hopper weighs in the crumb and controls the batch size.

Heater/Blender:

The blender is the heart of the system, It's function is to combine the extender oil and the asphalt (bitumen) and to wet out the crumb rubber and disperse it to allow optimal reaction between the aromatic-naphthenic fractions of the asphalt and extender oil for optimum binder properties.

Steps of Blending:

- Super Heat the Asphalt to mixing temperature.
- Meter the Asphalt into the Mixing Chamber.
- Load the Crumb Rubber from the Hopper.
- Mix the Asphalt and Crumb Rubber.
- Pump the mixed Binder to the Reaction Vessel.

Reaction vessels:

The function of nurse trucks or reaction vessels is to ensure that the crumb is reacted to the correct extent in the finished binder. Heat plays a big role in this reaction. Too little heat and the reaction will take too long and too much and degradation of the rubber and or asphalt can occur. The Reed International reaction vessels feature the ability to control temperature and create an even and controlled reaction.

Steps:

- Receive the Asphalt Rubber Binder from the Heater-Blender.
- Raise the Temperature of the Binder.
- Agitate the Mixture to facilitate the reaction.
- Meter Binder to the Asphalt Plant for Hot Mix Projects.
- Load Binder into Spreader Trucks for Chip Seal Projects.
- Provide enough storage to allow for reaction time

Tosas High Speed Blender:

Tosas produces its own rubber granules, ensuring the correct grading of rubber crumbs. The technologically advanced, high-speed homogenous mix blenders allow the operator to digitally control the feeding of raw materials in precise proportions, guaranteeing a quality end product. Sophisticated distributor machines are equipped with special product stirring agitators to ensure that while in the sprayer, the product receives a uniform heat distribution, prevent the overheating of product in the immediate surrounding of the flue pipes.

3.2.2 Laboratory Milling Machine

This milling machine is used in the laboratory to blend polymer with bitumen for experimental purpose. It comprises a rotor to produce shear force, an electric heater and a container. Blending temperature and applied shear force can be controlled properly in this machine. Most of the compatible polymer including recycled polymer (scrap polymer, crumb rubber and polyethylene bags) can be blended in this machine.

3.2.3 Manual Cooking Device

It is a manual method of blending polymer with bitumen; it works in the same principle as that of a commercial blending system. In this device the required shear force is produced by means of manual stirring. Since it is difficult to control the blending temperature and produce the required shear force, all type of polymer cannot be blended in this process. Some selected polymers, which require low shear force can be blended in this device.

Advantages of manual cooking method:

- Low cost
- Easy to manufacture
- Easy to operate

Limitation of manual cooking method:

- Difficult to control temperature
- Cannot produce high shear force
- Produces smoke
- Suitable for small-scale production
- Deals with only LDPE

Laboratory Milling Machine would be used to blend Polymer (Waste Plastic) in this research because it is not possible to blend properly the recycled polymer with manual cooking devise and the milling machine (Mechanically Controlled Blender) was fabricated using locally available resources by previous researcher (Hossain, 2006) A number of trials would be made to find out the compatible waste plastic to modify bitumen.

3.3 Compatibility Test

In order to find a suitable modifier, compatibility test would be performed on several types of locally available recycled polymers viz. polythene bags and pet bottles. The objective of this compatibility test is to identify the appropriate waste plastic that can be used as a modifier of bitumen.

3.4 Process of Evaluation of Modified Binder and Mixes

In order to evaluate the properties of polymer-modified binder, a sample of virgin bitumen would be taken as reference binder. The reference binder would be modified by different proportion of the selected waste plastic. A comparative study would be performed on the reference binder and modified binder. The physical and rheological properties of both the reference and modified binders would be investigated by performing Specific gravity, Softening point, Penetration, Ductility, Viscosity and Loss on heating tests.

Besides, Marshall Test would be performed to evaluate the properties of mixes prepared with modified and unmodified binder. Several sets of Marshall Test specimen would be prepared at different proportion of binder in order to determine the effect of polymer modification of bitumen. The mix prepared with reference binder (virgin bitumen) would be consider as reference mixes and the properties of the mixes prepared with modified binder would be compared with that of reference mixes. In preparing the mixes, other factors such as the type of aggregate, gradation of aggregate, test procedures and specification would be strictly followed. A short description of the test is given in the following Article.

3.5 Tests on Binder

3.5.1 General

The tests that would be performed in order to evaluate the properties of binders (pure and modified) are Softening point, Specific gravity, Penetration, Ductility, Viscosity, Loss on heating etc. All of these tests would be carried out following the AASHTO/ASTM standard procedure. A brief description of these tests methods and their significance are presented here.

3.5.2 Penetration Test

The penetration test measures the consistency of binders. It is expressed as a distance in tenths of a millimeter that a standard needle vertically penetrates into a sample of the material under specified conditions of loading, time, and temperature. The higher value of penetration indicates softer consistency. To determine the penetration, sample should be melted properly and cooled and maintained specified temperature. The penetration is measured with Penetrometer (penetration apparatus) at standard temperature of 25ºC.

3.5.3 Ductility Test

Ductility is a measure of elasticity of bitumen. The ductility of paving asphalt is measured by the distance to which it will elongate before breaking or fracture when two ends of a briquet specimen are pulled apart at a specified speed and temperature.

3.5.4 Specific Gravity Test

The specific gravity of bituminous binder is the ratio of the mass of a given volume of the material at 25°C to that of an equal volume of water at the same temperature. The specific gravity of binder influences the bitumen absorption capacity of aggregate and also Marshal Criteria of mix design.

3.5.5 Viscosity Test

There are two types of viscosity, kinematic and absolute viscosities. Kinematic viscosity is the measure of resistance to flow of a liquid under gravity. ASTM D2170-85 (AASHTO T201) describes the determination of kinematic viscosity of liquid asphalt at 60°C and semi-solid asphalt at 135°C in the range from 6 to 100,000 centistokes. Absolute viscosity of bituminous material is measured following ASTM D2171 (AASHTO T202) designation. This method is applicable to bitumen with viscosities in the range from 0.036 to 200,000 poises.

Viscosity is one of the important terms to describe the properties of bitumen. The mixing and compacting temperature of hot asphalt paving mixes depends on viscosity of binder.

3.5.6 Softening Point Test

The softening point test is also the measure of consistency of binder. It is the temperature at which the binder changes its semi solid state to liquid state. Temperature susceptibility of binder can be evaluated by softening point test. Between two binders having the same penetration value, one will be less susceptible to temperature which has higher softening point. Samples of asphalts loaded with steel balls are confined in brass rings suspended in a beaker of water and glycerin or ethylene glycol at 25 mm (1 inch) above a metal plate. The liquid is then heated at a prescribed rate. As the asphalt softens, the balls and the asphalt gradually sink toward the plate. At the moment the asphalt touches the plate, the temperature of the water is determined, and this is designated as ring and ball (RB) softening point of asphalt.

3.5.7 Flash and Fire Point Test

The flash and fire point test is purely a safety test. It indicates the maximum temperature to which the materials can be safely heated. The flash point is the temperature at which a bituminous material, during heating will evolve vapours that will temporally ignite or flash when small frame is brought in contact with them. The fire point is the temperature at which the evolved vapours will ignite and continue to burn.

3.5.8 Loss on Heating Test

It is a measure of mass of oil and asphaltic compounds that are lost during the process of heating of binders. Higher amount of loss of materials is not desirable. Firstly 50.0 ± 0.5g of the sample is placed in a container, cooled to a room temperature and weighed to the nearest 0.01g. Then the container with the sample is placed in the woven maintaining temperature of 163º ± 1ºC for five hours. After heating, the sample is removed from the woven, cooled to a room temperature and weighed again. The loss on heating is calculated as follows:

% loss = [(A-B)/A´]* 100

Where, A = initial weight of the container plus sample

B = final weight of the container plus sample after heating

A´ = initial weight of the sample

3.6 Tests on Mixes

3.6.1 General

The purpose of performing tests on compacted mixes is to determine the mix properties that pavement at service condition. The standard Marshall Mix design method would be followed in the laboratory. A set of Marshall Test specimens would be prepared and tested. A volumetric analysis would also be performed on the test specimens.

3.6.2 Marshal Stability and Flow Test

For proper performance of a flexible asphaltic concrete pavement, it must be stable under loading. This stability is achieved in pavement design by compacting the mixes so that the aggregates distribute the load by point-to-point contract. The Marshall test and other tests for stability measure directly the performance of the asphaltic concrete under load. The performance of the pavement in service can thus be predicted. The Marshall test for asphalt paving mixtures may be used for laboratory design and field control of mixtures containing asphalt cement and aggregates not exceeding an inch in maximum size. Principal feature of the test is density-voids analysis and stability-flow tests on specimens of compacted asphalt paving mixtures. The Marshall test has been standardized and has been designated ASTM D 1559. The optimum asphalt content of the paving mix is determined and is usually that which yields optimum of adequate stability, maximum unit weight and median limits for percent air voids (usually for surface mix uses).

In Marshall Test, the maximum load at which test specimen fails is termed as stability. Pavement is desired to have higher stability and lower flow value, but not too much rigidity. Too much rigidity may be the cause of cracks in pavement. Pavement should have reasonable flexibility that also depends on the quality of binder.

3.6.3 Volumetric Analysis of Compacted Mixes:

Specific gravity, Density, air voids, void in the mineral aggregate, void filled with asphalt etc. of compacted mixes are known as the volumetric properties of paving mixes. The volumetric properties of compacted paving mixes provide some indication of pavement's performance in service condition. A volumetric analysis would be performed on the compacted paving mixes prepared with polymer modified bitumen and virgin bitumen.

3.6.3.1 Density Determination

Weigh the specimen in air and in clean water at a temperature of 77 ± 1.8°F. The difference between the two weights in grams gives the volume in cubic centimeters. The specific gravity of the specimen (density in Mg/m^3) is determined by dividing the weight of the specimen (in air) in grams by the volume in cubic centimeters. The density (in Ib/ft^3) is calculated by multiplying the specific gravity by 62.4. Two types of specific gravity - bulk specific gravity and maximum theoretical specific gravity would be determined. Specific gravity can be defined as the ratio of the weight of specimen in air to the weight of equal volume of water. The density of compacted mixes depends on the level of compaction if other parameters are kept constant.

3.6.3.2 Determination of Specific Gravity

The Bulk Specific Gravity (BSG) of each type of material must be measured so that volumes can be computed from the weights when necessary. The BSGs of the individual coarse aggregate fractions, the fine aggregate and mineral filler fractions are used to calculate the Bulk Specific Gravity (G_{sb}) of the total aggregate using the following formula:

$$G_{sb} = \frac{P_1 + P_2 \ldots\ldots\ldots\ldots P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \ldots\ldots\ldots \frac{P_n}{G_n}}$$

Where,

G_{sb} = Bulk specific gravity for the total aggregate

$P_1, P_2, \ldots\ldots\ldots\ldots P_n$ = Individual percentage by weight of aggregate

$G_1, G_2, \ldots\ldots\ldots\ldots G_n$ = Individual bulk specific gravity of aggregate

3.6.3.3 Effective Specific Gravity of Aggregate

When based on the Maximum Specific (G_{mm}) of a bituminous mixture, the Effective Specific Gravity of the aggregate, (Gse), includes all void spaces within the aggregate particles, except those that absorb bitumen, and is determined using:

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}}$$

Where,

G_{se} = Effective specific gravity of aggregate

G_{mm} = Maximum specific gravity of mixed materials (no air voids) and

$$G_{mm} = \frac{100}{\frac{P_s}{G_{se}} - \frac{P_b}{G_b}}$$

Where,

P_s = Aggregate content, percent by total weight of mixture

P_b = Bitumen content, percent by total weight of mixture

G_{se} = Effective specific gravity of aggregate

G_b = Specific gravity of bitumen

3.6.3.4 Effective Bitumen Content of the Mixes

The effective bitumen content does not include absorbed bitumen. It is calculated using:

$$P_{be} = P_b - \frac{P_{ba} P_s}{100}$$

Where,

P_{be} = Effective bitumen content, percent by total eight of mixture

P_b = Bitumen content, percent by total eight of mixture

P_{ba} = Absorbed bitumen, percent by total weight of aggregate

P_s = Aggregate content, percent by total weight of mixture

3.6.3.5 Air Void

The air spaces bitumen the coated aggregate of paving mixture is known as air void. It is a considerable factor in pavement performance. Too much air voids in paving mixture may cause stripping allowing water to stay in it. Air void of compacted mixes is determined using the following formula.

$$V_a = 100 \times (G_{mm} - G_{mb}) / G_{mm}$$

Where,

V_a = Air void in compacted mixture percentage of total volume

G_{mm} = Maximum specific gravity of paving mixture

G_{mb} = Bulk specific gravity of paving mixture

3.6.3.6 Void in the Mineral Aggregate

The void in the mineral aggregate (VMA) is defined by the intermolecular spaces between the aggregate particles in compacted paving mixtures that includes the air voids and the effective asphalt content. VMA is calculated on the basis of bulk specific gravity of the aggregate and is expressed as a percentage of the bulk volume of the compacted paving mixture. VMA should be sufficient to adhere bitumen to aggregate properly. VMA is measured as follows:

$$VMA = 100 - \frac{G_{mb} \times P_s}{G_{sb}}$$

Where,

VMA = Voids in mineral aggregate, percent of bulk volume.

G_{mb} = Bulk specific gravity of total aggregate

G_{sb} = Bulk specific gravity of compacted mixture

P_s = Aggregate content, percent by total weight of mixture

3.6.3.7 Void Filled with Asphalt

The void filled with asphalt (VFA) is defined as the percentage of the intermolecular void spaces between the aggregate particles that are filled with asphalt. It is measured as follows:

$$VFA = \frac{100 \times (VMA - V_a)}{VMA}$$

Where,

VFA = Voids filled with asphalt percent of VMA

VMA = Voids in mineral aggregate, percent of bulk volume

V_a = Air voids in compacted mixture, percent of total volume

3.7 Materials Properties

3.7.1 General

Flexible pavement consists of major two materials. These two materials are aggregate and binder. The performance of pavement is greatly influenced by binder. Generally bitumen is used as binder in pavement construction. The properties of Polymer (waste plastic) Modified Bitumen (PMB) would be studied in this research work. The research work would require virgin bitumen, waste plastic and aggregate as raw materials. In order to study only the effect of waste plastic on binder and mixes other ingredients are kept same throughout the whole experiment process. A short description of these ingredients and there characteristics are presented below.

3.7.2 Bitumen

Bitumen is a class of amorphous, solid, semi-solid or viscous, cementations substances, natural or manufactured, composed generally without limitation of high molecular weight hydrocarbons, as typically found in asphalts, tars, and pitches. Bituminous materials are typically derived from asphalt or coal tar, with asphalt found naturally or attainable as a by-product of crude oil refining, and coal tar and pitches.The compositional make up of coal, coal tar pitches, crude oils and natural asphalts vary depending upon the geological origin and/or geographical source. As a result, the physical characteristics of bituminous material, whether natural or manufactured, can differ markedly from another. The variety of bitumen gives it wide utility in the building and construction industry.

Bitumen holds the aggregate together in a bituminous pavement. The quality of bitumen depends on its crude source, refining process and chemical composition. The chemical composition affects the compatibility of bitumen with polymer. Bitumen is normally designated by "grade" though it does not indicate the overall qualities of bitumen. The characteristics of base bitumen affect the quality improvement of the modified bitumen. In this research 60/70 penetrations grade bitumen is used. The viscoelastic properties of virgin bitumen are shown in Table 3.1.

Table 3.1: Viscoelastic Properties of Virgin Bitumen

Properties of bitumen	**Specific Gravity**	**Softening Point (°C)**	**Penetration (1/10 mm, 25°C)**	**Ductility (cm)**	**Loss on Heating (%)**	**Flash Point (°C)**	**Fire Point (°C)**
Test method	AASHTO T228-93/ ASTM D 70-76	AASHTO T47-8/ ASTM D6-80	AASHTO T49-93 / ASTM D5-86	AASHTO T53-92/ ASTM D36-89	AASHTO T51-93/ ASTM D113-79	AASHTO T47-8/ ASTM D6-80	AASHTO T47-8/ ASTM D6-80
Test results	1.025	50	68	100^{+}	0.02	290	340

3.7.3 Polymer/Waste plastic

Polymers can be classified into two major class based on their responsive nature to heat: thermoplastic and thermo harden. The product of thermo harden polymer cannot be remolded. So this type of polymer cannot be used as modifier of bitumen. Thermoplastic polymers are recyclable. Polymers that will be used as modifier must be recyclable. In fact any thermoplastic polymer can be used as modifier of bitumen if it is compatible to bitumen. In this investigation, compatibility test is performed with waste plastic (waste polythene, PET bottle etc.) and finally waste polythene (LDPE) is selected as a modifier to prepare suitable blend of PMB to perform laboratory test considering the higher cost of waste PET bottle.

3.7.4 Aggregate

3.7.4.1 General

Aggregate is one of the prime ingredients of pavements construction and forms a major portion of the pavements structure. Aggregate are used in bituminous concrete, as granular base course, sub base course and surface course of the pavement construction. The physical properties (i.e. gradation) as well as mechanical properties (i.e. hardness, toughness, durability) of aggregate have great influence on the mix properties. The amount of aggregate required for each sample is that which will be sufficient to make compacted specimens 63.5 ± 1.27 mm high. This is normally approximately 1.2kg and should be confirmed by compacting a trial sample of 1.2kg of blended aggregate mixed at the estimated optimum bitumen content. If the height of the trial specimen falls outside the specified limits, the amount of aggregate used for the specimen should be adjusted according to the following equation:

Adjusted mass of aggregate=63.5*(mass of aggregate used)/specimen height (mm) obtained.

The method of mix design, binder content and procedure of mixing and compaction of mix depend on aggregate gradation to some extent. In this research, same aggregate with same gradation would be used for both mixes prepared with pure bitumen and polymer (waste plastic) modified bitumen in order to keep the behavior of aggregate constant in the mixes. The properties of coarse aggregate, fine aggregate and mineral filler are presented below.

3.7.4.2 Coarse Aggregate

Aggregate passing 25mm and retained #8 sieve is named as Course Aggregate which should be crushed stone, crushed gravel or crushed boulder. It occupies major part of the total volume of the mix. The behavior of bituminous mixes is highly affected by the gradation and quality of coarse aggregate. The value of Marshall Stability of the mix depends on the characteristics of coarse aggregate used. Hence, the selection of appropriate coarse aggregate of desired gradation is important. Moreover, it should be clean, tough, durable material free from vegetable matter, soft particles and other objectionable matter.

Mechanically crushed boulder would be used as coarse aggregate in the mix.
The boulder is available in Sylhet. The maximum size of coarse aggregate that would be used in the mix is 3/4(19 mm) inches and its specific gravity is 2.65.

3.7.4.3 Fine Aggregate

Fine aggregate (Passing #8 and retained #200) occupies the interspaces of coarse aggregate. It consists of natural sand, stone screenings or combination of both. It should also be composed of clean, hard durable particles, rough surfaced and angular, free from vegetable matter, soft particles, clay balls or other objectionable matter. Stone screenings would be used as fine aggregate. The screening is produced when stones are crushed with mechanical crusher. The specific gravity of the fine aggregate is 2.63.

3.7.4.4 Mineral Filler

Properties of bituminous materials depend not only upon the quality of binder and aggregates, but also upon the properties of the filler. Mineral filler consists of lime stone dust or similar rock dust, portland cement, hydrated lime, silica cement and other mineral matter. It is non-plastic and free from foreign and other objectionable material. Bituminous materials are influenced by such factors as the amount and mineral composition, the grading and shape of the grains, micro-coarseness and specific activity of the filler. Mineral filler fills the void in the aggregate and increases density of the compacted mixes. Percent void in the mineral aggregate can be controlled by the use of mineral filler. Fraction of aggregate passing #200 sieves is Mineral Filler. The specific gravity of mineral filler is 2.73.

3.7.4.5 Gradation of Aggregate

Gradation of the aggregate used in a given bituminous mix is obviously an important factor. Gradation is closely related to the workability and density. Open graded of aggregates has become out of date. Various engineering department and other large engineering organization, have recommended the uses of densely graded mixes. Aggregates which are well graded from course to fine are generally sough in high type bituminous paving mixes. The basic concept behind this statement is that well graded materials produce the densest and therefore the most stable and durable mixes requiring the minimum bitumen content for satisfactory result. The aggregate gradation, which is used in this research, is shown in Table 3.2. The same graded aggregate would be used for both mixes prepared with virgin bitumen and polymer (waste plastic) modified bitumen (PMB).

Table 3.2: Gradation of Combined Aggregate

Sieve Size	Range of Percent Finer by Weight	Average Percent Finer by Weight	% Retained	Type of Aggregate (%)
1"	100	100	0	Coarse Aggregate 64%, Fine Aggregate 31% & Mineral Filler 5%
3/4"	90-100	95	5	
3/8"	63-73	68	32	
No.4	45-55	50	50	
No.8	31-41	36	64	
No.50	7-17	12	88	
No.200	3-7	5	95	
Pan	0	0	100	

3.8 Field Demonstrations

Field demonstration is carried out with almost same gradation of aggregate and modified bitumen (optimum waste plastic content bitumen) after all laboratory works. In this case central Asphalt Plan of Dhaka City Corporation located at Dhalpur is used. During demonstration, waste plastic is manually blending in the bitumen boiler maintaining a constant temperature of 180 °C.

3.9 Overview

In this chapter different types of blender, methods of blending, compatibility test of polymer and evaluation of prepared blend and mixes, procedure of different laboratory tests have been discussed. For blending the recycled type polymer with bitumen, the mechanically controlled blending system is used for this research work. Two types of recycled polymers (Waste polythene and pet bottle) are primarily selected for compatibility test. Based on the compatibility test, one of the two polymers is selected to use as modifier of bitumen. This polymer is used to prepare the final blend on which tests would be performed. The production of blend, preparation and testing of samples and field demonstration are described in the next chapter.

Chapter 4

Sample Preparation, Testing and Field Demonstration

4.1 Introduction

The chapter includes description of blending devices, process of blending, compatibility test of waste plastic, selection of suitable waste plastic, test on binders and mixes. The tests that are performed on the binders are specific gravity, softening point, penetration, ductility, loss on heating etc. A brief description of these tests is also included in this chapter. Marshall Mix Design method is followed in order to determine the properties of mixes prepared with reference binder and modified binder. In this research work two different types of specimens namely (a) reference specimen using conventional bitumen and (b) modifier specimen using various proportion of waste plastic were prepared and necessary tests were performed. A field demonstration is also included using optimum waste plastic content modified binder as well as original binder in this chapter.

4.2 Blending Device

Mechanically and thermo statistically controlled bending device is used in this research work. The previous researcher (Hossain, 2006) prepared this blender for his research work. It consists of the following parts.

A drilled machine made in China has rotational speed 1400rpm-2700rpm. The stirrer create required shear force for blending purpose is placed in the teeth of the chuck of the drill machine at which the drill bit is normally attached for drilling purpose. A working table of the drill machine is used to support the heater and the container. The container is also covered with a lid holed at its centre through, which the stirrer is rotated. The stirrer can also be moved up and down vertically with the help of handle of the machine by the help of which drill bit is moved for drilling purpose. A speed controller is attached to the machine to control the rotational speed of the stirrer. A complete electrical setting runs the heater and thermostat controls the temperature. A panel box is used to hold the electrical arrangement and a stand with stable base is used to hold the panel box. An asbestos sheet is used between the top of the support and the heater so that the heat could not transfer to any other parts of the blender from the heater except the container. A square plane sheet made of brass is welded with the bottom circular edge of the cylindrical brass container and the container is placed to the contact of the heater, which is placed on the working table (the support of the container and heater). The container, the heater and the asbestos sheet are attached to the supporting plate with nut and bolt system so that overturning of the container could not be happened during vigorous stirring of mixture at the time of blending operation. The total arrangements of the blender are shown in the following photographs.

Figure 4.1: Electromechanically Controlled Blender

Figure 4.2: Checking of Blender before blending of Waste Plastic

4.3 Compatibility Test

It should be mentioned here that the incompatible polymer cannot be blended with bitumen. It is observed from previous researcher (Islam, 2003) that three pure forms of polymers such as EVA, PP and LDPE are compatible with the bitumen. In this research, the compatibility of waste polythene (LDPE) and PET bottle were tested. The waste polythene and PET bottle could be seen in the following Figure 4.3 and Figure 4.4 respectively.

Figure 4.3: Shredded Waste Polythene (LDPE)

Figure 4.4: Shredded Waste PET Bottle

4.4 Production of Blend

4.4.1 General

The previous researcher (Hossain, 2006) became successful to blend the recycled polymer like scrap tyre, with mechanically controlled blander. In this study waste plastic is used as modifier. Review of literature reveals that three factors affect the success of blending of polymer. The factors are blending temperature, blending time and shear force. The factors vary from polymer to polymer. Recycled polymer like waste plastic needs higher shear force and long blending time around 40 minutes. Blending time should be kept as less as possible, because too long blending time may change the rheology of modified binder (Hossain, 2006). It is observed that the low-density polymers require less shear force and complete blending is possible by using manual stirring. But the necessity of mechanically controlled blender for blending the recycled polymer (HDPE) is a mast because the mechanically controlled blender possesses higher shear force, which is essential to blend the waste plastic.

4.4.2 Preparation of Blend

Mechanical method (except field demonstration) of blending is used in this investigation. The method is described below.

4.4.2.1 Mechanical Method of Blending

The waste plastic (waste polythene/PET bottle) is collected in the shredded form from a business man who buys these from vangariwala/tokai. His factory is located at Kamrangir Char, Dhaka. The size of the modifier is below 5 mm. While preparing the modified binder, the electric heater is turn on. When temperature of the heater shows about 180^{o}c the required quantity of liquid bitumen, which is heated in another container is poured into the container attached to the heater. Then the blending machine is started at the rotational speed about 1200 rpm to rotate the stirrer fixed with the chuck of the machine and required quantity of waste plastic is added to the bitumen gradually. After addition of the waste plastic with bitumen the container is covered with lid properly and the stirrer is attached to the chuck again. Then the machine is started at a speed of 1500 rpm to rotate the stirrer and the rotating stirrer is moved up and down with the help of handle. After 40 to 60 minutes the machine is stopped. By this time it is seen that there formed a homogeneous mixture of binder and is poured into another pot from the container for the test on other practical proposes. It also found that once using the above procedure prepares the binder it can be stored for future use without any separation of the two components. Following the above blending procedure a total of four modified binder are prepared with 2.5%, 5.0%, 7.5% and 10% of polymer (waste plastic) and one binder with a 7.5% PET bottle. It is also seen that the higher percentage of waste plastic requires higher blending time. The following figures show the pure and modified binder.

a **b** **c**

Figure 4.5: a) Pure Bitumen, b) 7.5% Waste Plastic Modified Bitumen, c) 7.5% PET Bottle Modified Bitumen

4.5 Test Procedures

4.5.1 General

Seven conventional tests are performed on the six samples of binder (one pure and five modified) in order to analyze the effects of waste plastic in the bitumen. All of the tests are performed following the AASHTO/ASTM designation. In order to obtain representative results, all the tests are carried out as preciously as possible following the standards test procedures. In spite of this, due to some instrumental constraint or problems a few tests have shown inconsistent results.

4.5.2 Penetration

Test Method: AASHTO DESIGNATION T 49-93 (ASTM DESIGNATION D5-86).

Summary of the Method: The sample is melted and cooled under controlled condition. The penetration is measured with a Penetrometer by means of which a standard needle is applied to the sample under the specified condition.

Test Condition: The accuracy of the test result is dependent on closely controlled temperature condition. The test is performed at 25°C temperature. The test load and loading time are 100 gm and 5 seconds respectively.

4.5.3 Softening Point

Test Method: AASHTO DESIGNATION T 53-92 (ASTM DESIGNATION D36-89) (Ring and Ball method).

Summary of the Method: The sample is melted and thoroughly stirred to avoid incorporation of air bubbles and to ensure homogeneity in case of modified binder. Then the sample is poured into the ring which was rested on an amalgamated brass plate. After cooling for 1 hr, the excess material is cut off with a slightly heated knife.

Test Condition: The temperature of the freshly boiled distilled water in the glass vessel is maintained at 5°C for 15 minutes. The ring with sample is placed 2.54 cm above the bottom of the glass vessel. The rate of heating is 5°C per minute.

4.5.4 Flash and Fire Point

Test Method: AASHTO DESIGNATION T 48-91 (ASTM DESIGNATION D92-85) (Cleveland Open Cup Method)

Summary of the Method: The sample is heated pin an open cup and at intervals a small flame is applied near its surface. The flash point and fire point are recorded very carefully.

4.5.5 Ductility

Test Method: AASHTO DESIGNATION T 51-93(ASTM DESIGNATION D113-79).

Summary of the Method: The sample is melted, stirred and poured into the mold as per specification. After cooling to room temperature for 30-40 minute, the excess material is cut off with a slightly straight edged putty knife. The mold is then set in the testing apparatus and ductility is measured at standard test condition.

Test Condition: Test is performed at 25°C±0.5°C temperature, at pulling rate 5 cm/minute.

4.5.6 Specific Gravity

Test method: AASHTO DESIGNATION T 228-93 (ASTM DESIGNATION D70-76).

Summary of the Method: The sample is heated and stirred to be sufficiently fluid to pour. Then sample is poured into a clean, dry and warmed Pycnometer to the three-fourth of its capacity. The Pycnometer with its contents is allowed to cool to ambient temperature for a period not less than 40 minutes and is weighted. The rest portion of the Pycnometer is filled with distilled water at test temperature and weighted again. All weights are taken carefully.

Test Condition: Test is performed at 25/25°C condition

4.5.7 Loss on Heating

Test Method: AASHTO DESIGNATION T 47-83 (ASTM DESIGNATION D6-80).

Summary of the Method: 50±0.5 gm of the water free sample is taken in a container and cooled it to room temperature and weighed. The container with the sample is placed in the oven at a temperature of 163°C. The temperature of the oven is maintained at 163°C±1°C for 5 hrs.

Test Condition: The test is performed at 163°C for 5 hrs.

4.6 Mix Design

The concepts of the Marshall method of designing paving mixtures were formulated by Bruce Marshall, a former Bituminous Engineer of the Mississippi State Highway Department. The Marshall Test procedure has been standardized by the American Society for Testing and Materials (ASTM). The original Marshall method is applicable to the design and field control of hot mix asphalting paving mixtures containing aggregates with a maximum size of up to 25mm.A modified Marshall Method has been proposed for aggregates with maximum sizes up to 38 mm

Firstly aggregates are prepared and blended to make samples, which conform to a selected particle size distribution. Initially mix design samples are prepared with different of binder contents and are then subjected to a level of compaction which is related to the expected traffic, in terms of equivalent standard axles, to be carried in the design life of the HMA layer(s). The properties of the compacted samples are then determined. These properties include; bulk density, air voids, and stability and flow characteristics under load. In case of failure to meet the specified mix design criteria, the mix is reformulated and the tests are repeated until an acceptable design is established.

The method is empirical in nature. The standard shape of Marshall test specimen is cylindrical. The height of the sample is 64 mm (2.5 inch) and diameter is 102 mm (4 inch). In this experiment a total of 30 (6x5=30) specimens are prepared following the specified procedure of heating, mixing and compacting the asphalt-aggregate mixtures. Two different types of specimen namely (a) reference specimen using original bitumen and (b) modified specimen using varying proportion of waste plastic blended bitumen were prepared for testing.

4.6.1 Preparation of Test Specimens

4.6.1.1 Determination of Expected Design Binder Content

The "expected design" binder content can be determined from experiences, computational formula or by performing the centrifuge kerosene equivalency and oil soak tests in the Hveem procedure. Another quick method to arrive at a starting point is to use the dust-to-asphalt ratio guideline. The expected design binder content, in percent by total weight of mix, could then be estimated to be approximately equivalent to the percentage of aggregate in the final gradation passing the 75 pm (No.200) sieve. In this test the computational formula was used to estimate the expected design asphalt content.

$$P = 0.035a + 0.045b + Kc + F$$

Where:

P = approximate asphalt content of mix, percent by weight of mix

a = percent of mineral aggregate retained on 2.36 mm (No. 8) sieve

b= percent of mineral aggregate passing the 2.36 mm (No. 8) sieve and retained on the 75 µm (No.200) sieve

c = percent of mineral aggregate passing 75 µm (No. 200) sieve

K = 0.15 for 11-15 percent passing 75 pm (No. 200) sieve; 0.18 for 6-10 percent passing 75 pm (No.200) sieve ; 0.20 for 5 percent or less passing 75 pm (No.200) sieve
F = 0 to 2.0 percent, based on absorption of light or heavy aggregate. In the absence of other data, a value of 0.7 is suggested.

The gradation of combine aggregates indicates, a = 64%, b 31%, c = 5%. Using K = 0.2 and F = 0.7, the calculated expected design asphalt content is 5.18. Using 0.5% increment of binder content the specimen are prepared with 4.0%, 4.5%, 5.0%, 5.5% and 6.0% of binder. Around 1155 gm of aggregate is required for preparing one specimen.

4.6.1.2 Number of Specimens

The Marshall method recommends three specimens for each combination of aggregate and binder content. In this study, one specimen for each combination of aggregate and binder content is prepared (Total 5X6=30 Nos. specimens) to minimize the laboratory work. During sample preparation and testing the specification of the mix design method is strictly and carefully followed in order to get representative results. Though one specimen for each combination of aggregate and binder content is tested, the results found to be very consistent.

4.6.1.3 Mixing and Compaction Temperature:

Mixing and compaction temperature depend on viscosity of binder. In this experiment mixing and compaction are carried out at 160°C ± 5°C and 145°C ± 3°C respectively.

4.6.1.4 Preparation of Mould and Hammer

The mould assembly and the face of the compaction hammer are cleaned thoroughly. They are heated in a water bath to a temperature between 95°C and 150°C. Filter paper is used in the bottom of the mould before the mixture is placed in the mould.

4.6.1.5 Preparation of Mixture

A half-litter container of bitumen is heated in an oven to the ideal mixing temperature (160°C ± 5°C). Mixing is done in a mechanical mixer with a bowl capacity of approximately 4 litters. The mixing bowl, mechanical stirrers and any other implements used in the mixing procedure are pre-heated to the mixing temperature. The heated aggregate sample is placed in the mixing bowl and thoroughly mixed using a trowel. A crater is formed in the centre of the mixed aggregate into which the required weight of bitumen is poured. Mixture is then produced with a uniform distribution of bitumen by using the mechanical mixer. Mixing of aggregate and binder is shown in Figure 4.6.

Figure 4.6: Mixing is being done with Mechanical Mixer

4.6.1.6 Packing the Mould

The entire batch is placed in the prepared mould. Filter papers are used in the bottom of the mould. The mixture is spaded vigorously with a heated spatula for 15 times around the perimeter and 10 times over the interior. The surface is smoothened to a slightly rounded shape. The temperature of the mixture immediately prior to compaction is maintained within the compaction temperature ($145^0C \pm 3^0C$).

4.6.1.7 Compaction of Specimen

Another paper disc is placed on the top surface of the mix. The mould, base plate and filling collar along with the specimen are transferred to the Marshall Compaction apparatus and the sample is compacted by 50 blows with the compaction hammer. After compaction, the mould assembly is removed and dismantled so that the mould can be reversed. The equipment is reassembled and the same number of blows is applied to the reversed specimen. The mould assembly is then placed on a bench where the base plate, filling collar and paper discs are removed. The mould and the specimen are allowed to cool in air to a temperature at which there will be no deformation of the specimen during extraction by using an extrusion jack. The compacted briquette is labelled and allowed to cool to room temperature ready for testing the following day.

The whole procedure is then done on the remaining specimens. Removing of specimen after compaction could be seen in Figure 4.7.

Figure 4.7: Specimen is being removed after Compaction

4.6.2 Testing of Specimens

4.6.2.1 General

The Marshall tests were conducted on compacted specimens to find stability and flow values of different mixes. For volumetric analysis of compacted specimens, it was necessary to know the bulk and maximum specific gravity of the mixes. The maximum specific gravity of each specimen is determined after the completion of stability and flow test. Figure 4.8 shows the assembly of prepared specimens.

Figure 4.8: Assemblies of Specimens for Testing

4.6.2.2 Determination of bulk specific gravity

After the specimens are removed from the moulds, they are allowed to cool to room temperature. The bulk specific gravity of the compacted specimen is determined according to the ASTM D 1188 method of testing.

4.6.2.3 Stability and Flow Test

After the determination of bulk specific gravity, the specimens were immersed in a water bath at 60°C±1^0C for 30 minutes. The inside surface of the testing head was cleaned using water bath temperature between 21.1°C and 37.8°C. The guide rod was lubricated with oil and "zero" setting was checked in the flow meter and proving ring dial gauge. Ensuring the testing apparatus ready, the test specimen was removed from the water bath and the surface of specimen was dried carefully with a cloth. Then the specimen is placed in lower testing head and cantered. The upper testing head was fitted in to position and the complete assembly was cantered in loading device. Flow meter was placed over marked guide rod and again "zero" was checked. Load was applied to the specimen at constant rate of deformation (2 inch per minute) until failure occurred. The point of failure was defined as the maximum load. The total force required to produce failure was marked as Marshall Stability. When load began to decrease, the reading of flow meter was recorded. This was the reading of flow for the specimen. The flow value is expressed as 1/100 inch. The entire procedure for both stability and flow measurement were completed within 30 seconds. Testing of Marshall Specimen can be seen in Fig: 4.9

Figure 4.9: Marshall Test Arrangements

4.6.2.4 Determination of Maximum Specific Gravity

To determine the maximum specific gravity, one mixture was prepared with same aggregate and 5% binder content for each modified binder and pure binder. The mixture was weighed in air. Then it was placed in a container and water was poured to submerge the sample sufficiently and vacuum pressure was applied to remove void from the mixes. Then the weight of the sample was taken in water. Maximum specific gravity is determined to calculate the air void of the mixes.

4.6.2.5 Density and Void Analysis

After completion of stability and flow test, a density and void analysis was made for each series of test specimens. The unit weight of each specimen is determined multiplying the bulk specific gravity by the density of water (62.4 pcf). The effective specific gravity of total aggregates was calculated from the maximum specific gravity. The effective and bulk specific gravity of the total aggregates, the bulk specific gravity of the compacted mixes, the specific gravity of binder and the maximum specific gravity of the mixes are used to calculate percent absorbed binder content by weight of aggregate, percent air void (Va), percent void filled with binder (VFA) and percent voids in mineral aggregate (VMA).

4.7 Field Demonstration

Considering all laboratory data a field demonstration was performed with the optimum percent (7.5%) of waste plastic modified binder. The demonstration was done with the help of a contractor engaged for road maintenance works in Dhaka City Corporation. Firstly, a 100 metre long road segment was selected for surfacing. The total width of the road was 15 metre of which 50% was done with modified binder and remaining 50% with conventional bitumen. The road was one- way traffic system and hence the traffic intensity on the both segments was assumed to be same. For proper comparison, other specifications were kept unchanged for both types of binder. Other information was as follows:

- Name of road: Folder Street, Wari, Dhaka
- Location: 21, Folder Street (Near Hotel Super)
- Thickness of Carpeting = 50mm
- Type of Bitumen: 60/70 grade.
- Type of Modifier: Waste Polythene
- Cost of Waste Polythene: Tk.35 per kg

- Gradation of aggregate: ¾ inch down 40%, ½ inch down 35%, Sand 15%, Dust 10%
- Source of waste plastic = Lalbag.
- Date of Construction 21.11.2008.

The contractor was convinced to use waste plastic instead of bitumen as the price of waste plastic was slightly less than that of bitumen. The central asphalt plant of Dhaka City Corporation was used for the job (Figure 4.10). The bitumen boiler requires minimum 4.2 ton of bitumen to run the plant; hence the quantity of the waste plastic was 315 kg. The huge of waste plastic was collected in shredded from Lalbagh, Dhaka and blended manually with the help of a stirrer (Fig: 4.11 shows a shredding machine locally fabricated and Fig: 4.12 shows the manual blending technique). For homogeneous mixing of waste plastic the blending temperature was kept 170^0C during whole blending time of 1.20 hours. After proper blending of waste plastic carpeting works was done with this modified binder on previously selected road segment and the segment was marked for data collection in future. A sample of modified as well as pure bitumen was collected for laboratory test.

Figure 4.10: Central Asphalt Plant of Dhaka City

Figure 4.11: Locally Fabricated Shredding Machine

Corporation

Figure 4.12: Waste plastic is being manually

blended at Bitumen Boiler.

Chapter 5

Results and Discussions

5.1 Introduction

The main objectives of the project work are to i) determine the engineering and rheological properties of waste plastic modified binder ii) analyze the effect of waste plastic modified bitumen on road quality and iii) assess the field performance of waste plastic blended bituminous pavement section. In this project, waste plastic is used as modifier. For the assessment of quality improvement and comparison of reference binder (Virgin bitumen) with polymer modified bitumen, Penetration, Ductility, Softening point, Flash & Fire point, Specific gravity, Loss on heating tests are carried out on both virgin bitumen (VB) and polymer modified bitumen (PMB). Marshall tests are also performed on the compacted paving mixes prepared with reference bitumen and polymer modified bitumen. It is mentioned here that waste plastic has been used as a modifier for preparing all the test samples of modified binder. After completing all laboratory works, a field demonstration was done on a 100-meter X 7.5 meter road section with modified binder as well as adjoining same area with original binders to assess the performances. Then field data like potholes, depression, crack, rutting, ravelling etc. were collected at the end of every two month for $1\frac{1}{2}$ (one and half) year duration. This chapter contains all the results of these tests and field data in tabular & graphical forms, analysis and comparison of results and discussion on them.

5.2 Binder Test Result

5.2.1 General

Seven conventional tests are performed on the binders. Some important properties of binder such as temperature susceptibility, consistency, adhesive quality, etc. are assessed from these test results.

5.2.2 Penetration Test Result

In general the penetration is used to measure the consistency of semisolid and solid bituminous materials. It is used to classify semisolid bituminous materials into standard consistency grade. Since grade does not signify quality, the penetration test has no relation to quality of binder. It is an empirical test. The results of penetration test on unmodified bitumen and modified bitumen are shown in Table 5.1. The table also shows the penetration of residue from loss on heating test.

A plot of penetration versus waste plastic content is shown in the Figure 5.1. From the Figure 5.1, it can be noticed that the value of penetration decreases almost uniformly in case of both before and after LOH test. This means that waste plastic increases the consistency in a way of stiffness of bitumen.

The bituminous binder provides cohesion or tensile strength in the bituminous paving mixtures. Generally, higher values of penetration are preferable for bitumen to use in tropical countries to prevent bleeding in pavement. On the other hand, in the field bitumen gradually hardens due to aging or oxidation process and penetration value decreases with time. This characteristic of binder causes bleeding to new pavement and cracking to aged pavement. The waste plastic -modified binder may be the solution of this problem. Since waste plastic is a non-biodegradable substance, initially its presence in the binder decreases the penetration of modified bitumen but it has the potential to retards the time dependent hardening process or further decrease of penetration of binder. Thus, it enhances the performance of pavement.

Table 5.1. The Results of Penetration Test on Pure and Waste Plastic Modified Bitumen

Test Method	Waste Plastic Content (%)	Penetration (1/10 mm)	Penetration of Residue from LOH Test (1/10 mm)
AASHTO T49-93 ASTM D5-86	0.0 (Pure Bitumen)	68	62
	2.5	59	23
	5.0	39	17
	7.5	20	13
	10.0	18	10
	*7.5	46	44

* PET Bottle.

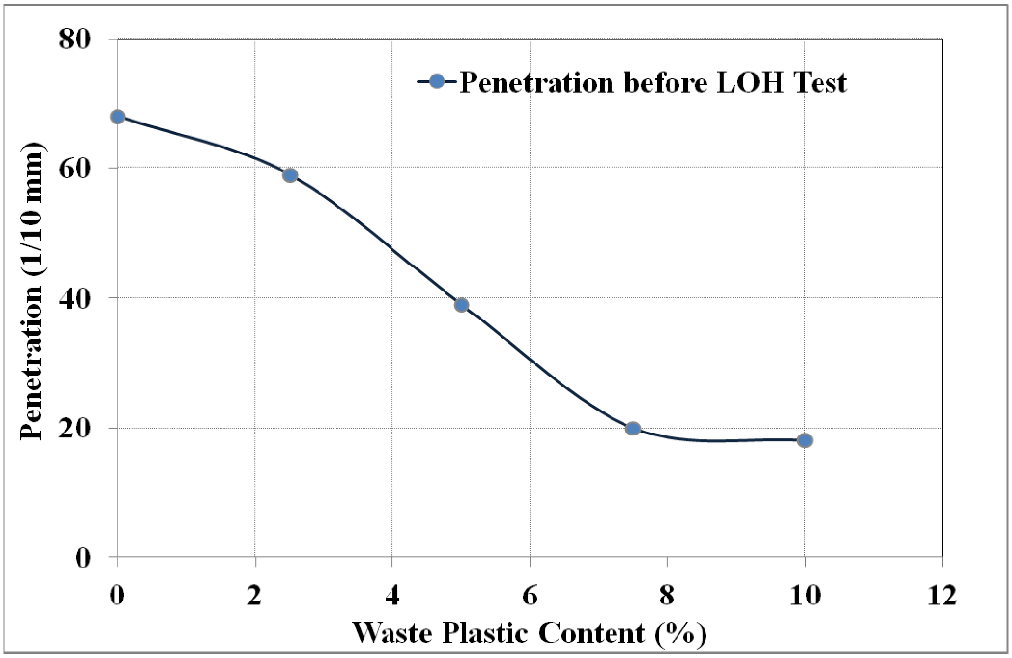

Figure 5.1: Variation of Penetration with Waste Plastic Content

5.2.3 Ductility Test Result

Table 5.2 and Figure 5.2 represent the ductility test results. The results indicate that ductility sharply decreases with the increase of waste plastic content in binder. The ductility of original bitumen was 100+ cm. This value of ductility is decreased to 14 for 10% of waste plastic content. Resulting loss of ductility with this waste plastic content is more than 86% as compared to the reference bitumen with ductility value of 100+ cm. This implies that use of waste plastic as a modifier has significant effect on the ductility property of the pure bitumen. From the Figure 5.2 it can also easily be seen that the change of ductility value with waste plastic content is not linear. The rate of change of ductility property increases with waste plastic content.

Table 5.2. The Results of Ductility Test on Pure and Waste Plastic Modified Bitumen:

Test Method	Waste Plastic Content (%)	Ductility (cm)
AASHTO T51-93 ASTM D113-79	0.0 (Pure Bitumen)	100+
	2.5	30
	5.0	27
	7.5	17
	10.0	14
	*7.5	39

* PET Bottle.

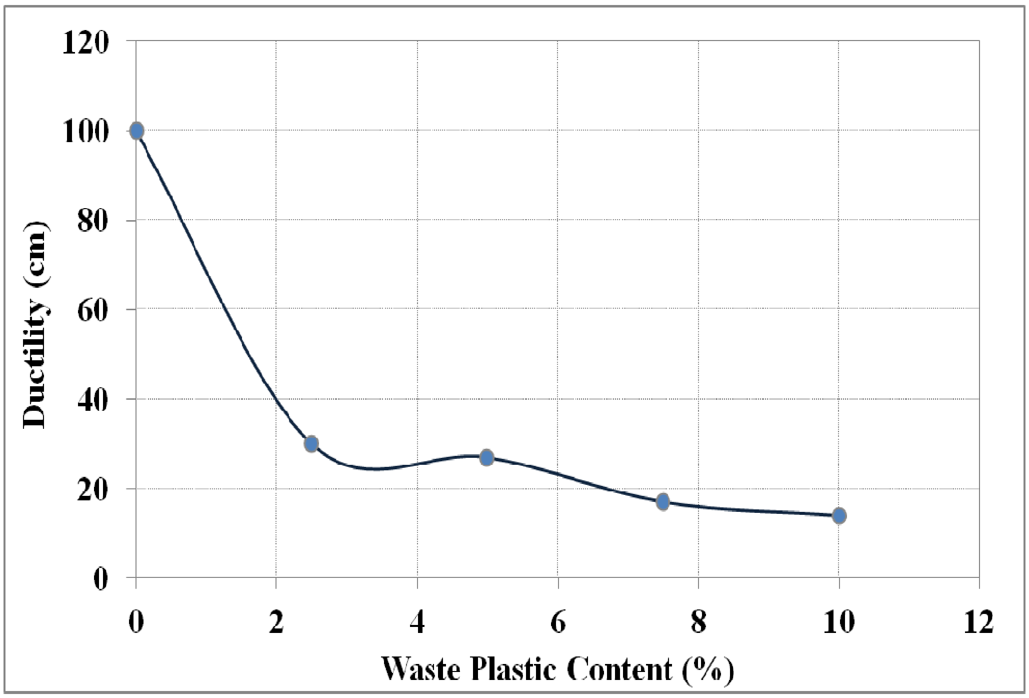

Figure 5.2: Variation of Ductility with Waste Plastic Content

Ductility is the measure of internal cohesion of the binder, which imparts cementing property in bituminous mixes. It is generally thought that bituminous materials with high ductility value have good binding properties. But bituminous materials with high ductility could perform differently. Initial ductility alone does not indicate whether the binder will perform better in service period or not. Generally, ductility of bitumen decreases with time and the rate of decrease are not same for all types of binders. Using waste plastic with bitumen can decelerate the rate of change of ductility value, though waste plastic initially reduces the original ductility of bitumen. As too much reduction of ductility may cause the binder unfit as pavement material, selection of maximum waste plastic content may be limited by the ductility value of modified binder. It is also learned from the literature review that in one hand polymer decreases ductility on the other hand it increases elasticity (flow) of the binder. In this consideration modified binder with lower ductility value could be used safely in the bituminous mixes.

5.2.4 Softening Point Test Results

The softening point test results are presented in Table 5.3 and Figure 5.3. Softening point is a measure of temperature at which binder changes from semi-solid to liquid state under the weight of a standard steel ball. It is not a measure of melting point. Actually softening point test is performed to measure the binder temperature susceptibility. From the Figure 5.3, it can be seen that softening point increases to 70°C from 50°C in case of 10 percent waste plastic content. As polymer content increases consistency of the binder, higher temperature will be required to make the modified binder soft. From the Table 5.3 it can be calculated that addition of 10% waste plastic with the virgin binder, softening point has increased by about 40%. It indicates that temperature susceptibility of binder significantly decreases with waste plastic content. This improvement of binder property will reduce the pavement-bleeding and segregation problem during hot season, which is one of the important modes of pavement distresses in tropical countries like Bangladesh. Hence this improved property of binder is very desirable to our country.

Table 5.3. The Results of Softening Point on Pure and Waste Plastic Modified Bitumen

Test Method	Waste Plastic Content (%)	Softening Point (°C)
AASHTO T53-92 ASTM D36-89	0.0 (Pure Bitumen)	50
	2.5	51
	5.0	60
	7.5	68
	10.0	70
	*7.5	56

* PET Bottle.

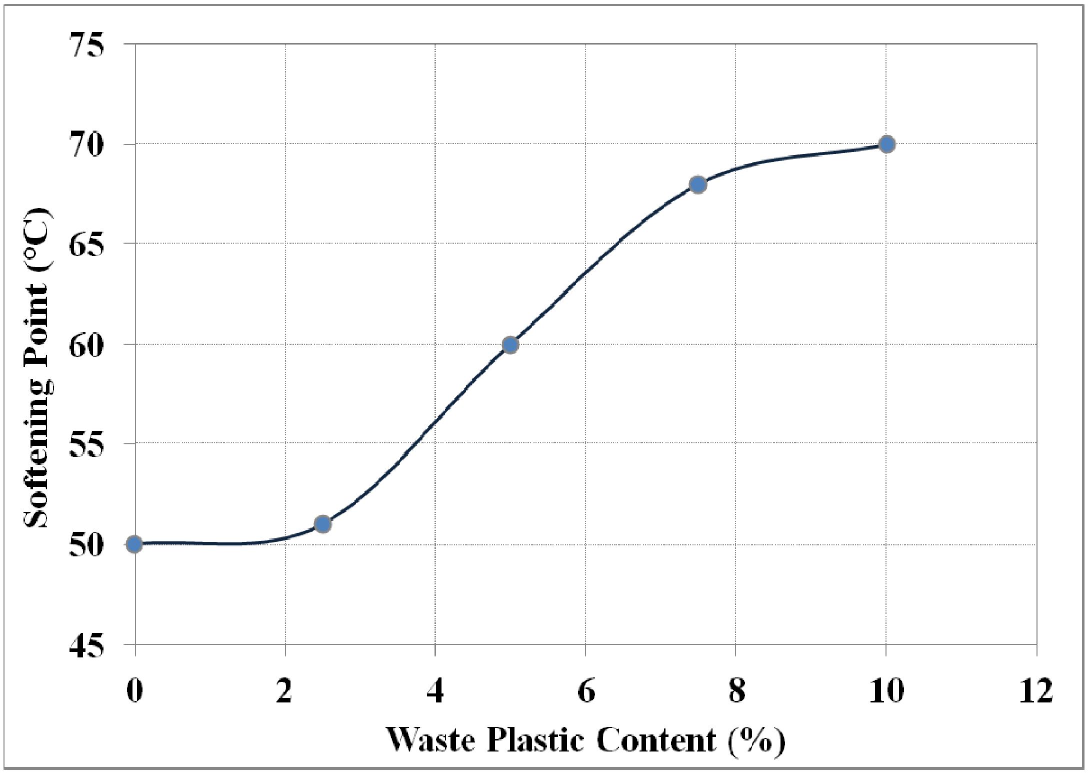

Figure 5.3: Variation of Softening Point with Waste Plastic Content.

5.2.5 The Effect of Waste Plastic in Ductility, Penetration and Softening points:

The effect of waste plastic on ductility, penetration and softening points are presented in the combined Figure 5.4. The results of penetration, ductility and softening point tests show that the stiffness of the binder increases whereas the temperature susceptibility decreases with addition of increasing quantity of waste plastic.

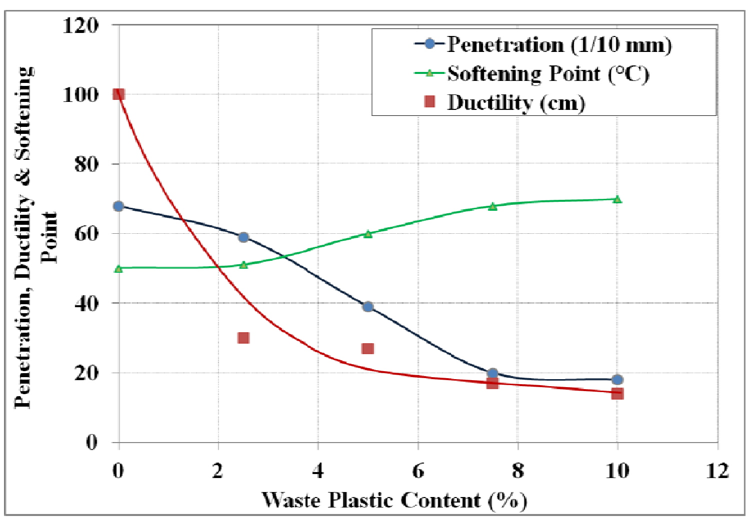

Figure 5.4: Variation of Penetration, Ductility and Softening Point with Waste Plastic Content in Bitumen.

5.2.6 Specific Gravity Test Results

The results of specific gravity test are shown in Table 5.4 and Figure 5.5 From the Table and Figure, it is seen that specific gravity of modified bitumen decreases with the increase of waste plastic content in bitumen. The specific gravity of virgin bitumen was 1.025. For 10% waste plastic content, this value has decreased to 1.010. It may be happened that the specific gravity of waste plastic (LDPE) is less than that of bitumen.

Table 5.4. The Results of Specific Gravity Test on Pure and Waste Plastic Modified Bitumen:

Test Method	Waste Plastic Content (%)	Specific Gravity
AASHTO T228-93 ASTM D70-76	0.0 (Pure Bitumen)	1.025
	2.5	1.020
	5.0	1.017
	7.5	1.014
	10.0	1.010
	*7.5	1.030

* PET Bottle.

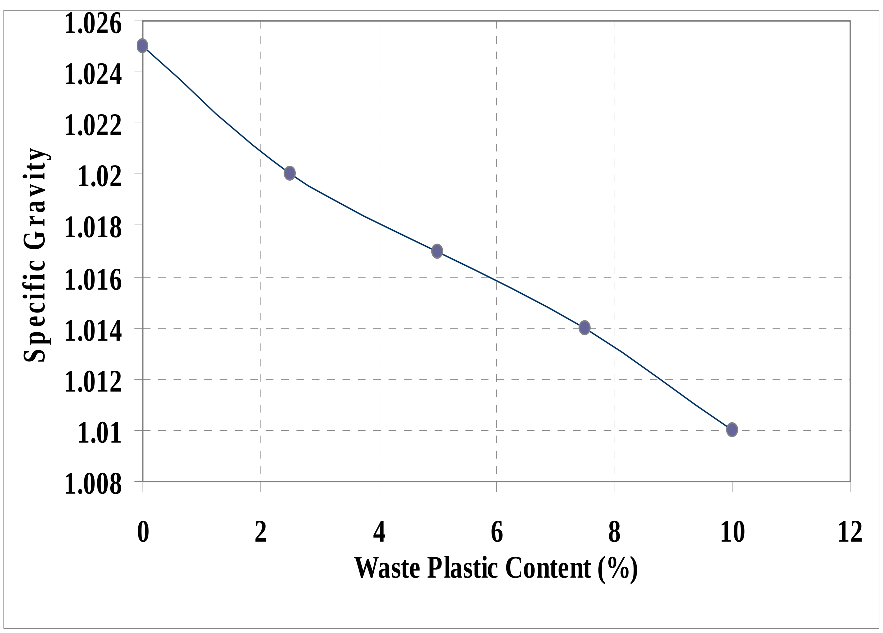

Figure 5.5: Variation of Specific Gravity with Waste Plastic Content.

5.2.7 Loss on Heating Test Results

The test measures the loss of volatile substances of bitumen due to heating. The results of loss on heating test are shown in Table 5.5. This test requires very sensitive balance to weigh the material. But due to unavailability of sensitive balance in the laboratory there may be some error in the results. From the results presented in the Table 5.6 no definitive effect of waste plastic on loss of heating of modified binder could be inferred. The tests results show that additional waste plastic to bitumen the loss volatile substance due to heating is insignificant. The loss of material for reference bitumen is 0.02% and that for 7.5% waste plastic modified bitumen is found to be 0.04%. This may occur due to lack of accuracy of the balance. Variation of loss on heating with waste plastic content in bitumen is graphically presented in Figure 5.6.

Table 5.5. The Results of Loss on Heating Test on Pure and Waste Plastic Modified Bitumen.

Test Method	Waste Plastic Content (%)	Loss on Heating (%)
AASHTO T47-83 ASTM D6-86	0.0 (Pure Bitumen)	0.02
	2.5	0.02
	5.0	0.04
	7.5	0.04
	10.0	0.02
	*7.5	0.02

* PET Bottle.

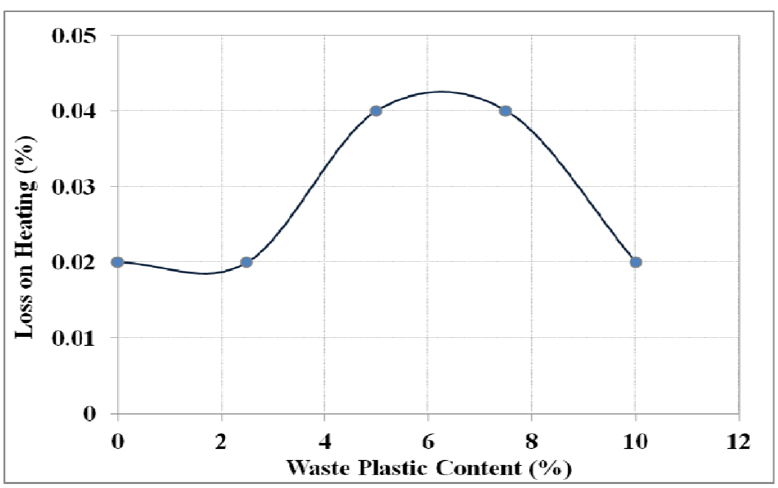

Figure 5.6: Variation of Loss on Heating with Waste Plastic Content.

5.2.8 Flash and Fire Point Test Results

The flash and fire point test is purely safety test. The test results are presented pin the table 5.6. The results show that both flash and fire points increase with the increase of waste plastic content up to an optimum value of 7.5%.The higher values of flash and fire point due to addition of waste plastic are encouraging regarding safety issue.

Table 5.6. The Results of Flash and Fire Point test on Pure and Waste Plastic Modified Bitumen.

Test Method	Waste Plastic Content (%)	Flash Point (^oC)	Fire Point (^oC)
AASHTO T 48 – 91 ASTM D 92 – 85	0.0 (Pure Bitumen)	290	340
	2.5	295	340
	5.0	325	350
	7.5	335	350
	10.0	295	310
	*7.5	320	350

* PET Bottle

5.3 Comparison of the Test Results of Mechanically Blended Binder with those of Manually Blended Binder.

Observing all the test results presented in the following table 5.7 it can be clearly said that there is no significant effect on the properties of binder whether the waste plastic is blended mechanically or manually. It is also noticed that the penetration of manually blended binder is found to be higher which is desirable.

Table 5.7. Comparison of the Test Results of Mechanically Blended Binder with those of Manually Blended Binder

Polymer content (%)	Penetration at 25°C (1/10mm)		Softening Point (°C)		Specific Gravity		Ductility at 27°C (cm)		Loss on Heating (%)		Flash Point (°C)		Fire Point (°C)	
Waste Plastic is used	*a	*b	*a	*b	*a	*b	*a	*b	*a	*b	*a	*b	*a	*b
7.5	20	37	68	52	1.014	1.017	17	19	0.04	Nil	335	335	350	350

*a = Mechanically Blended Binder; *b = Manually Blended Binder.

5.4 Comparison of the Test Results with Study of Previous Researchers

5.4.1 Comparison of the Test Results with those of the Previous Researcher (Islam, 2003)

Table 5.8 shows the different laboratory test results of this study and that of the previous researcher (Islam, 2003). The test results reveal that there is no significant variation between test results of virgin polymer modified bitumen and that of waste plastic modified bitumen regarding the test of penetration, ductility, specific gravity, loss on heating and softening point.

Table 5.8. Comparison of Test Results with those of Previous Researcher (Islam, 2003)

Polymer content (%)	Penetration at 25°C (1/10 mm)		Softening Point (°C)		Specific Gravity		Ductility at 27°C (cm)		Loss on Heating (%)	
Waste plastic is used in this study and virgin LDPE is used in the study of Islam	Results of this Study	Results of Islam	Results of this Study	Results of Islam	Results of this Study	Results of Islam	Results of this Study	Results of Islam	Results of this Study	Results of Islam
0.0	68	87	50	45	1.025	1.030	100^{+}	100	0.02	0.060
2.5	59	65	51	48	1.020	1.025	30	94	0.02	0.065
5.0	39	55	60	54	1.017	1.020	27	70	0.04	0.040
7.5	20	35	68	61	1.014	1.019	17	45	0.04	0.060
10	18	24	70	68	1.010	1.018	14	19	0.02	0.053

5.4.2 Comparison of the Test Results with those of Indian Researcher (Panda et al, 1997)

Some test results of this study and the same test results of Panda, et al (1997) are shown in Table: 5.9. The results of the tests performed by two different researchers do not show any remarkable variation.

Table 5.9. Comparison of the Test Results with those of Previous Researcher (Panda, et al, 1997)

Polymer content (%)	Penetration at 25°C (1/10mm)		Softening Point (°C)		Specific Gravity		Ductility at 27°C (cm)		Loss on Heating (%)	
Waste Plastic is used in this study and Polythene is used in the study of Panda et al	Results of this Study	Results of Panda et al	Results of this Study	Results of Panda et al	Results of this Study	Results of Panda et al	Results of this Study	Results of Panda et al	Results of this Study	Results of Panda et al
0.0	68	88	50	44	1.025	1.042	100^+	100^+	0.02	-
2.5	59	64	51	51	1.020	1.034	30	73	0.02	-
5.0	39	47	60	55	1.017	1.028	27	60	0.04	-
7.5	20	39	68	61	1.014	1.021	17	51	0.04	-
10	18	18	70	81	1.010	1.012	14	6	0.02	-

5.4.3 Comparison of this Study Results with those of Previous Researcher (Hossain, 2006)

The results of common tests performed with different modifier are shown in the Table 5.10. Though different penetration grade of bitumen is used in this study, the trend of change of test results like softening point, penetration, ductility, loss on heating is consistent except specific gravity.

Table 5.10. Comparison of the Test Results with those of Previous Researcher (Hossain, 2006)

Polymer content (%)	**Penetration at 25°C (1/10 mm)**		**Softening Point (°C)**		**Specific Gravity**		**Ductility at 27°C (cm)**		**Loss on Heating (%)**	
Waste Plastic is used in this study and waste tyre is used in the study of Hossain	Results of this Study	Results of Hossain	Results of this Study	Results of Hossain	Results of this Study	Results of Hossain	Results of this Study	Results of Hossain	Results of this Study	Results of Hossain
0.0	68	89	50	49	1.025	1.030	100^{+}	100	0.02	0.060
2.5	59	61	51	55	1.020	1.039	30	79	0.02	0.009
5.0	39	50	60	58	1.017	1.044	27	59	0.04	0.007
7.5	20	32	68	64	1.014	1.054	17	29	0.04	0.005
10	18	22	70	69	1.010	1.060	14	16	0.02	0.004

5.5 Marshall Test Results

5.5.1 General

In order to assess the performance of pure and waste plastic blended bitumen, a comparative analysis is presented here. For the performance evaluation of modified mixes, all the parameters of Marshall Test are used as a measure of index. Besides Marshall Stability and Flow tests, volumetric analysis of the test specimens is also given here. Raw data of Marshall Test and related calculations are included in the Appendix at the end of this report.

5.5.2 Marshall Stability

Table 5.11 and Figure 5.7 represent the stability test results. The Figure 5.7 shows the stability versus binder content curves. It can be seen from the Figure, the trend of stability curves for the mixes with modified binders is almost similar to that of mixes with pure bitumen. It is also seen from the figure that the stability for all mixes increases up to an optimum percent of binder content. The upward trend of six consecutive curves clearly indicates that the stability increases with the increment of waste plastic content (up to 7.5%) in bitumen. From the Table 5.11, the maximum stabilities for binders containing 0.0, 2.5, 5.0, 7.5 and 10.0 percent waste plastic are found to be 1970 lb, 2070 lb, 2304 lb, 2420 lb and 2325 lb respectively.

Further calculation of percent improvement of stability value revealed that due to use of 7.5% waste plastic in the binder, the stability has increased in the order of 28%. This finding indicates that high strength bituminous mixes could be produced by using waste plastic up to optimum level of 7.5% without changing other ingredients. This extra strength can provide more longevity of the flexible paved roads. In this consideration it is very important for our country.

Table 5.11. Marshall Stability Values for Mixes with Pure and Waste Plastic Modified Bitumen

Binder Content (%)	Marshall Stability (lb)					
	Pure Bitumen	2.5% Waste Plastic	5.0% Waste Plastic	7.5% Waste Plastic		10% Waste Plastic
4.0	1056	1450	1920	1776	*2189	1104
4.5	1018	1651	2083	1780	*1758	1614
5.0	1479	1877	1814	2339	*2160	1944
5.5	1970	2070	2304	2420	*2250	2325
6.0	1820	1464	2208	1907	*2232	2186

* Result of PET Bottle

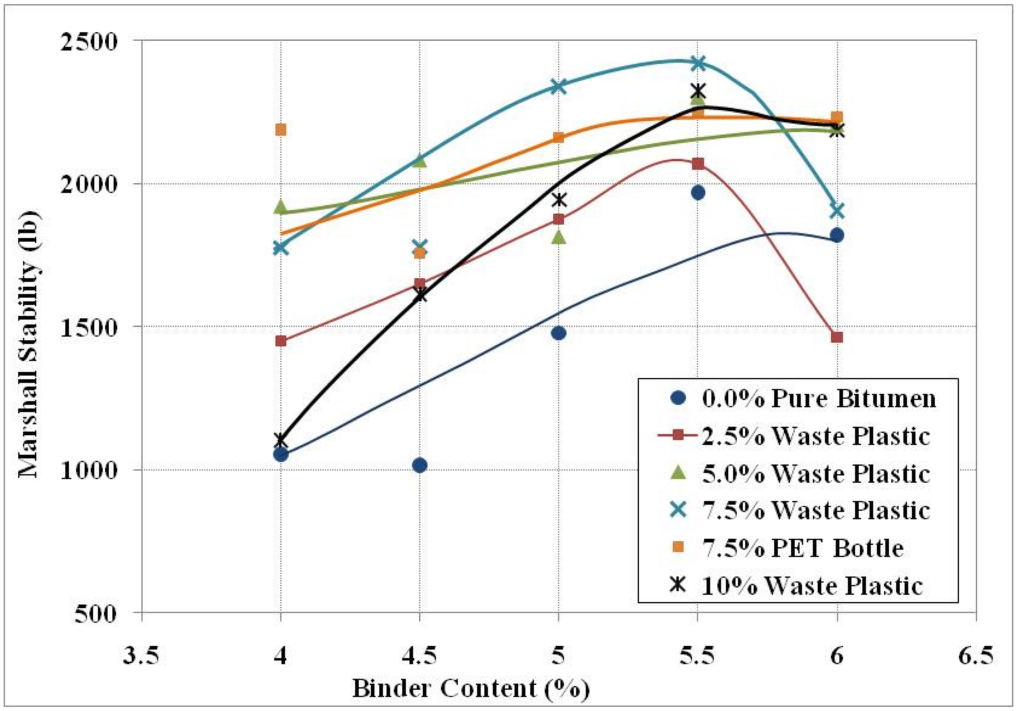

Figure 5.7: Variation of Marshall Stability Value for Mixes with Pure and Waste Plastic Modified Bitumen

5.5.3 Flow Value

The maximum deformation at which a Marshall specimen fails is termed as the flow value. It is a measure of deformation. Higher flow value of bituminous pavement indicates lower rigidity. The variation of Marshall Flow values with binder content is presented in Table 5.12 and Figure 5.8.From the results it can be observed that for all the binder contents the flow values increase with the increase of waste plastic content up to an optimum level (7.5%).

So, it can be said that modifier could not be used in any proportion to modify binder. Other research results (Shell Chemicals) also reveal that though due to application of polymer in bitumen increases the flow values but at the same time it significantly improves the elastic property of the modified binder. This implies that bituminous mixes with polymer modified binder would not create any functional problem as long as other Marshall Mix design criteria are satisfied.

Table 5.12. Marshall Flow Values for Mixes with Pure and Waste Plastic Modified Bitumen

Binder Content (%)	Flow Value (1/10 mm)					
	Pure Bitumen	2.5% Waste Plastic	5.0% Waste Plastic	7.5% Waste Plastic		10% Waste Plastic
4.0	10.5	12.0	14.0	14.5	*11.5	14.5
4.5	12.0	16.0	19.0	21.5	*17.5	11.0
5.0	11.0	17.5	15.0	19.0	*19.5	14.2
5.5	15.5	18.5	18.5	21.5	*19.5	15.0
6.0	11.5	16.8	14.4	22.5	*18.5	16.5

* Result of PET Bottle

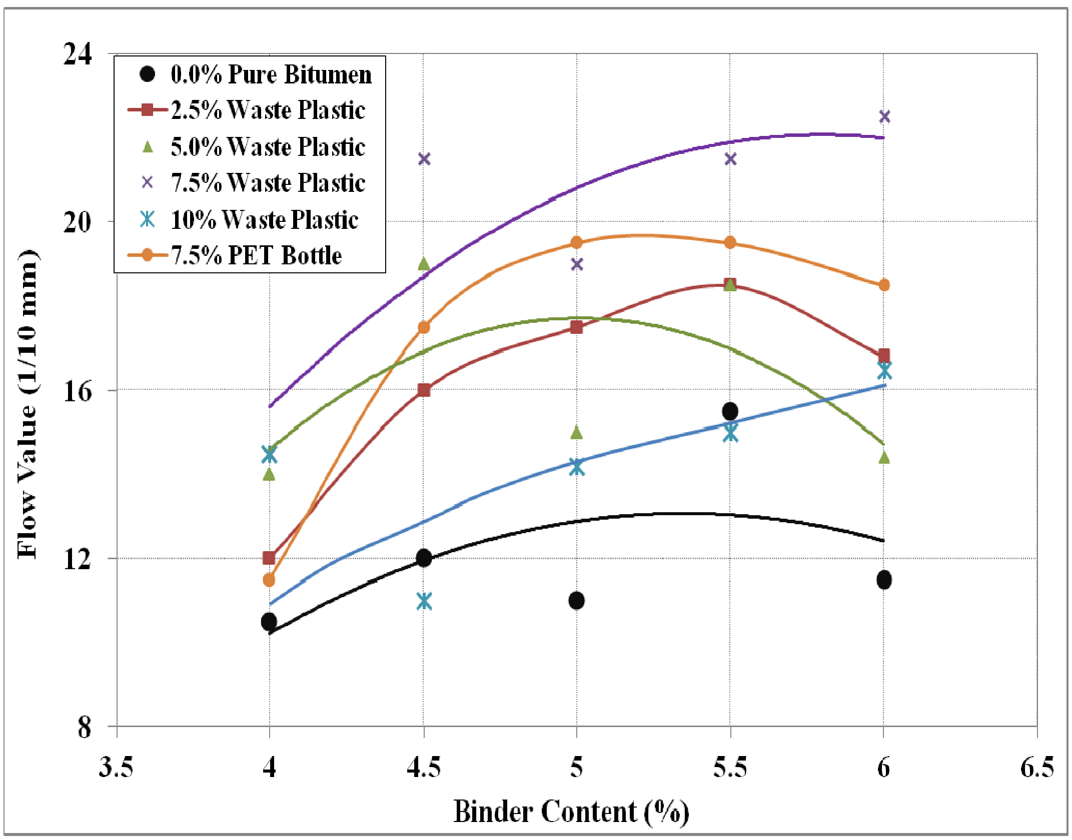

Figure 5.8: Variation of Marshall Flow Value for Mixes with Pure and Waste Plastic Modified Bitumen

5.5.4 Density

The results of density analysis are presented in Table 5.13 and Figure 5.9.By observing the results it can be seen that the density of compacted mixes slightly decrease with the increase of waste plastic content in bitumen. This may happen due to the fact that the specific gravity of waste plastic blended bitumen is slightly less than that of pure bitumen. From the test results it can be also said that the impact of binder modification is not significant. For all the mixes the maximum unit weight is obtained at 6 percent binder content and the shape of curves for all mixes with modified bitumen are similar to that of pure bitumen.

Table 5.13. Unit weight Results for Mixes with Pure and Waste Plastic Modified Bitumen

Binder Content (%)	Unit Weight (lb/cft)					
	Pure Bitumen	2.5% Waste Plastic	5.0% Waste Plastic	7.5% Waste Plastic		10% Waste Plastic
4.0	142.90	140.4	137.90	137.90	*140.4	138.53
4.5	143.52	142.90	138.53	139.15	*140.4	139.15
5.0	144.14	144.77	141.02	141.02	*141.65	140.4
5.5	146.01	145.40	142.90	142.27	*140.4	140.4
6.0	147.26	147.26	144.14	142.90	*148.51	141.02

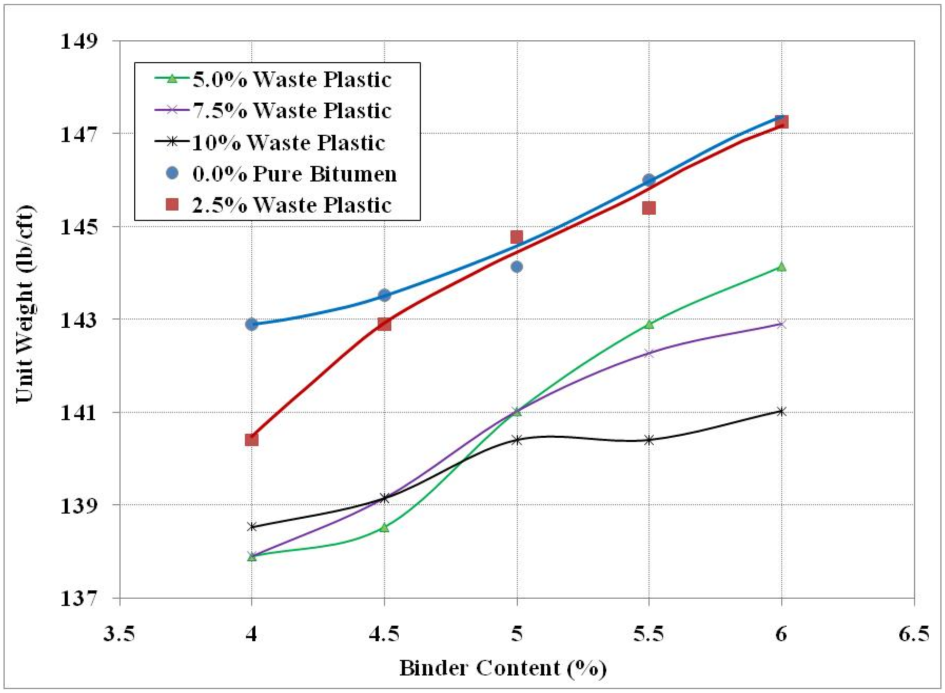

Figure 5.9: Variation of Unit Weight for Mixes with Pure and Waste Plastic Modified Bitumen

5.5.5 Air Void (Va)

The amount of air voids present in the mix is a very important design criterion. There should be sufficient air voids in the pavement mix so that binder can coat the aggregate properly and at the same time it would not create bleeding problem at elevated temperature. But too much or too less air voids should not exist in the compacted mix. Because in this case rutting, brittleness, premature cracking, ravelling or stripping may occur in the pavement. The results of air void analysis are presented in Table 5.14 and Figure 5.10. By observing the results it can be said that the variation of air voids due to change of waste plastic content in bitumen is not substantial. From close observation of the Table 5.14, it can be revealed that air voids slightly increase with increasing concentration of polymer in the mixes but not linear. From the Figure it can also be observed that the general shape of the curves for modified binders is very similar to that of virgin bitumen.

Table 5.14. Air Voids (V_a) Results for Mixes with Pure and Waste Plastic Modified Bitumen:

Binder Content (%)	Air Void (%)					
	Pure Bitumen	2.5% Waste Plastic	5.0% Waste Plastic	7.5% Waste Plastic		10% Waste Plastic
4.0	6.53	8.54	10.89	10.16	*9.64	10.84
4.5	5.35	6.15	9.76	8.98	*9.27	10.08
5.0	4.15	4.13	7.76	7.0	*7.72	8.54
5.5	2.5	2.92	5.76	5.39	*5.74	7.79
6.0	0.84	1.26	4.15	4.18	*1.65	6.61

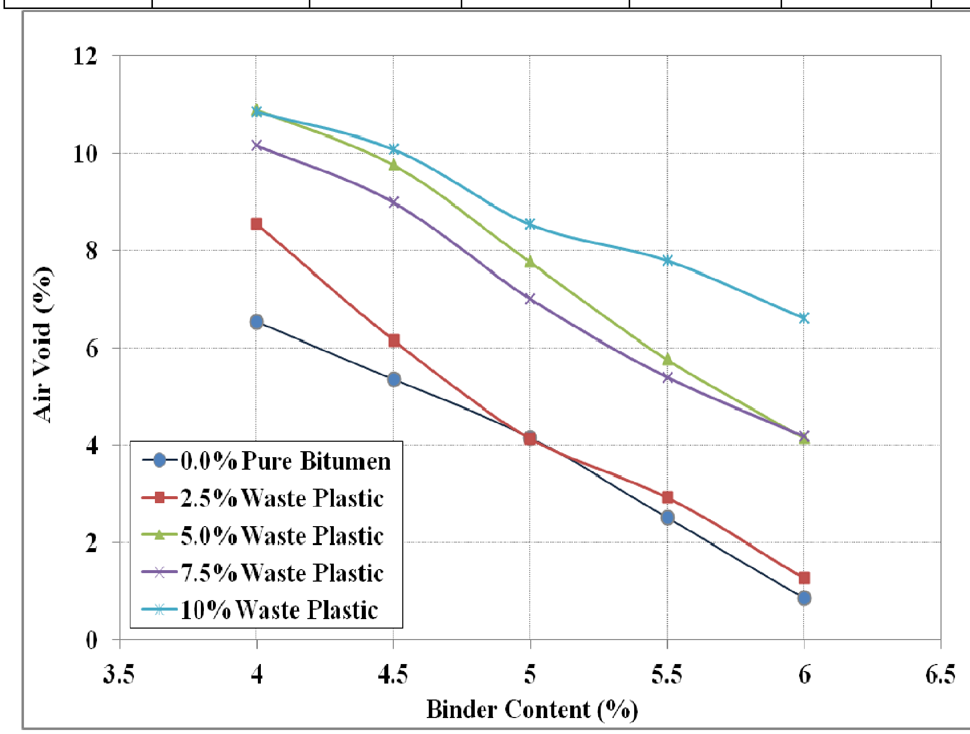

Figure 5.10: Variation of Air Voids (V_a) for Mixes with Pure and Waste Plastic Modified Bitumen

5.5.6 Void in Mineral Aggregate (VMA)

In many cases, the most difficult mix design property to achieve is a minimum amount of voids in the mineral aggregate. The goal is to furnish enough space for the binder so it can provide adequate adhesion to bind the aggregate particles without bleeding when temperatures rise and the binder expands. Normally, the curve exhibits a flattened U – shaped, decreasing to a minimum value and then increasing with binder content. The results of VMA analysis are shown in Table 5.15 and Figure 5.11. It can be seen that the VMA value increases with the increase in waste plastic content which is a good sign for flexible pavement. More over the VMA results against 7.5% waste plastic are satisfactory considering the Marshall Mix Design criteria.

Table 5.15. VMA Results for Mixes with Pure and Waste Plastic Modified Bitumen:

Binder Content (%)	VMA (%)					
	Pure Bitumen	2.5% Waste Plastic	5.0% Waste Plastic	7.5% Waste Plastic		10% Waste Plastic
4.0	17.04	18.49	19.93	19.93	*18.49	19.58
4.5	17.11	17.47	20	19.64	*18.91	19.63
5.0	17.19	16.83	18.98	18.98	*18.62	19.33
5.5	16.55	16.91	18.33	18.69	*17.98	19.76
6.0	16.29	16.29	18.06	18.77	*15.58	19.83

* Result of PET Bottle

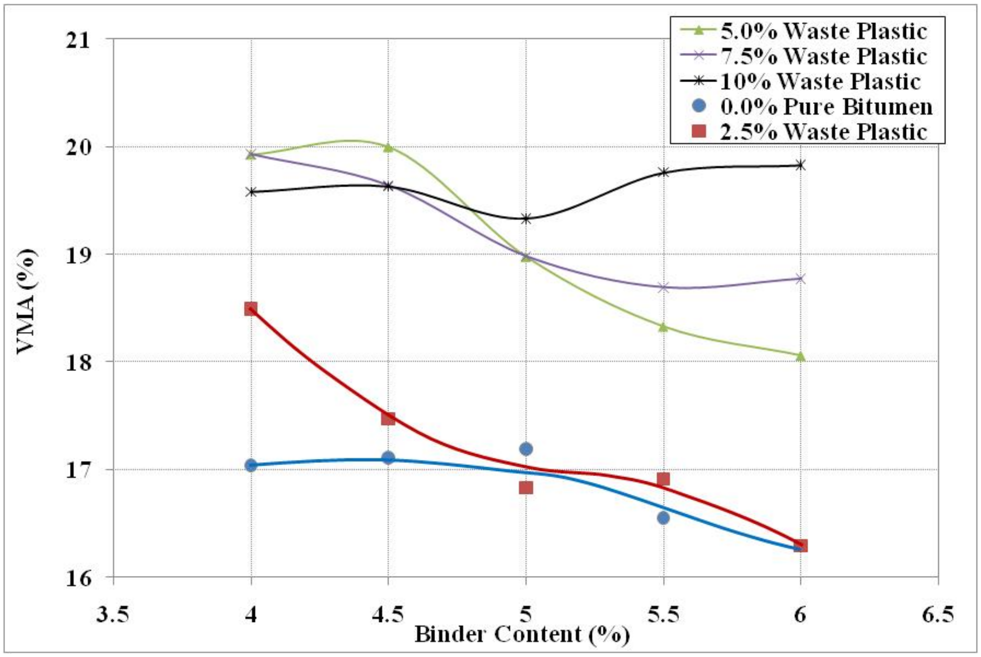

Figure 5.6: Variation of VMA for Mixes with Pure and Waste Plastic Modified Bitumen

5.5.7 Void Filled with Asphalt (VFA)

VFA (Void Filled with Asphalt), VMA (Void in Mineral Aggregate) and Va (Air Void) are closely interrelated and only two of the values are necessary to solve the other. VFA criteria help prevent the design of mixes with marginally acceptable VMA. The objective of the VFA analysis is to limit maximum levels of VMA and substantially maximum levels of binder content. VFA also restricts the allowable air void content in compacted mixes. Table 5.16 and Figure 5.12 show the VFA analysis results. From the results, it is seen that the value of VFA slightly decreases in case of waste plastic-modified bitumen as compared to pure bitumen and the nature of the curves for modified bitumen is very similar to that of pure bitumen. From the point of Marshall mix design criteria VFA for 7.5% waste plastic content is best suited.

Table 5.16. VFA Results for Mixes with Pure and Waste Plastic Modified Bitumen

Binder Content (%)	VFA (%)					
	Pure Bitumen	2.5% Waste Plastic	5.0% Waste Plastic	7.5% Waste Plastic		10% Waste Plastic
4.0	61.68	53.81	45.36	49.02	*47.86	44.64
4.5	68.73	64.80	51.24	55.10	*50.98	48.65
5.0	75.86	75.46	59.11	63.12	*58.54	55.82
5.5	84.89	82.73	68.58	70.59	*71.41	60.57
6.0	94.84	92.27	77.02	76.78	*89.41	66.67

* Result of PET Bottle

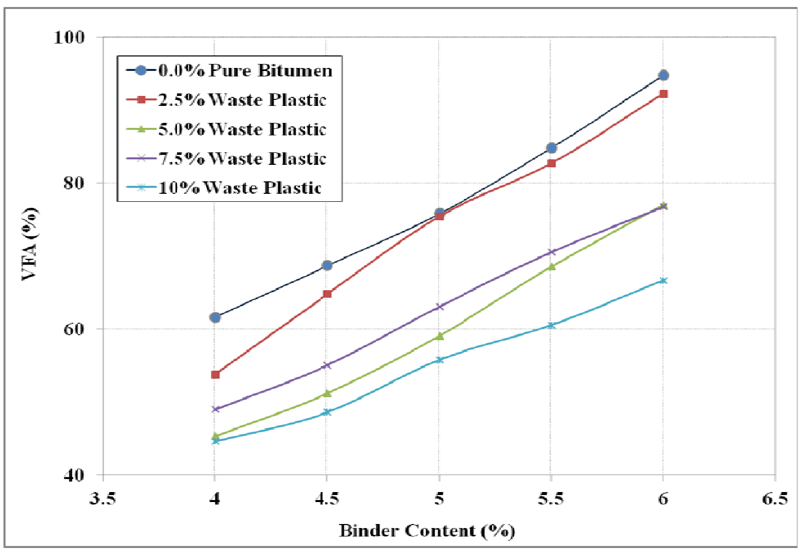

Figure 5.12: Variation of VFA for Mixes with Pure and Waste Plastic Modified Bitumen

Table 5.17. Comparison of Marshall Test Results of Mixes with Mechanically Blended Binder and Manually Blended Binder.

Binder Content (%)	Waste Plastic Content (%)	Stability (lb)		Flow (1/10mm)		Unit Weight (lb/cft)		Va (%)		VMA (%)		VFA (%)	
		*a	*b	*a	*b	*a	*b	*a	*b	*a	*b	*a	*b
4.0	7.5	1776	2168	14.5	14.0	137.90	141.64	10.16	8.47	19.93	17.77	49.02	52.24
4.5	7.5	1780	2189	21.5	11.0	139.15	144.14	8.98	6.10	19.66	16.75	55.10	63.58
5.0	7.5	2339	2280	19.5	13.0	141.02	145.39	7.0	4.51	18.98	16.47	63.12	72.62
5.5	7.5	2420	2891	21.5	13.0	142.27	147.26	5.39	2.48	18.69	15.84	70.59	86.30
6.0	7.5	1907	2231	22.5	16.0	142.90	149.14	4.18	0.83	18.77	15.22	76.78	94.58

***a = Mixes with Mechanically Blended Binder; *b = Mixes with Manually Blended Binder**

5.6 Field Performance of Waste Plastic Road

After field demonstration data were collected at the end of every two months to assess the performance which are presented in the Table 5.18. It can be seen from the Table 5.18 that pavement condition of normal road started deterioration after 10 months of construction whereas waste plastic road started after 14 months. At the end of 18 months of it is found that about 60% less crack is developed on waste plastic road than that of normal road. It is also observed that 9.3% of normal road and 3.88% of waste plastic road are deteriorated respectively after 18 months of construction. It should be mentioned here that for proper comparison, data should have been collected for minimum two years, but due to commencement of construction works of Jatrabari-Gulistan Flyover it was not possible.

Table 5.18. Field Observations Regarding Performance of Normal and Waste Plastic Modified Bituminous Carpeting:

Date of data collection	Parameter	Pure bituminous road segment	Waste plastic modified bituminous road segment	Comments
20.01.2009 (After 2 months of construction)	*Surface Appearance	Good	Good	
	Cracks (sqm)	-	-	
	Depression (sqm)	-	-	
	Ravelling (sqm)	-	-	
	Potholes (sqm)	-	-	
	Edge broken (sqm)	-	-	
20.03.2009 (After 4 months of construction)	*Surface Appearance	Good	Good	
	Cracks (sqm)	-	-	
	Depression (sqm)	-	-	
	Ravelling (sqm)	-	-	
	Potholes (sqm)	-	-	
	Edge broken (sqm)	-	-	
20.05.2009 (After 6 months of construction)	*Surface Appearance	Good	Good	
	Cracks (sqm)	-	-	
	Depression (sqm)	-	-	
	Ravelling (sqm)	-	-	
	Potholes (sqm)	-	-	

Date of data collection	**Parameter**	**Pure bituminous road segment**	**Waste plastic modified bituminous road segment**	**Comments**
	Edge broken (sqm)	-	-	
20.07.2009 (After 8 months of construction)	*Surface Appearance	Good	Good	
	Cracks (sqm)	-	-	
	Depression (sqm)	-	-	
	Ravelling (sqm)	-	-	
	Potholes (sqm)	-	-	
	Edge broken (sqm)	-	-	
20.09.2009 (After 10 months of construction)	*Surface Appearance	Fair	Good	Crack developed over the speed braker
	Cracks (sqm)	2.0	-	
	Depression (sqm)	-	-	
	Ravelling (sqm)	-	-	
	Potholes (sqm)	-	-	
	Edge broken (sqm)	-	-	
20.11.2009 (After 12 months of construction)	*Surface Appearance	Fair	Good	Crack & ravelling developed over the speed braker
	Cracks (sqm)	8.0	-	
	Depression (sqm)	-	-	
	Ravelling (sqm)	10.0	-	
	Potholes (sqm)	-	-	
	Edge broken (sqm)	0.1	-	
20.01.2010 (After 14 months of construction)	*Surface Appearance	Fair	Good	
	Cracks (sqm)	13.0	4.0	
	Depression (sqm)	-	-	
	Ravelling (sqm)	12.0	-	
	Potholes (sqm)	-	-	
	Edge broken (sqm)	0.12	-	
20.03.2010 (After 16 months of construction)	*Surface Appearance	Poor	Good	
	Cracks (sqm)	16.0	9.0	
	Depression (sqm)	-	-	
	Ravelling (sqm)	17.0	5.0	
	Potholes (sqm)	0.045	-	
	Edge broken (sqm)	0.25	-	

Date of data collection	Parameter	Pure bituminous road segment	Waste plastic modified bituminous road segment	Comments
20.05.2010 (After 18 months of construction)	*Surface Appearance	Poor	Fair	
	Cracks (sqm)	50.0	20.0	
	Depression (sqm)	-	-	
	Ravelling (sqm)	19.1	9.0	
	Potholes (sqm)	0.5	-	
	Edge broken (sqm)	0.15	0.1	

*Surface Appearance: 1) Good- Dense texture; 2) Fair-Some stripping; 3) Poor- Rough

5.7 Overview

This chapter has presented the analysis of experimental as well as field demonstration results. The tests that were performed for the evaluation of waste plastic modified binder and mixtures are very conventional. Test results indicate very encouraging sign. From the test results, it can be concluded that adding waste plastic with bitumen improves the inherent weakness of the traditional bitumen. It also improves consistency, temperature susceptibility, stiffness and other rheological properties of bitumen. These findings are very significant particularly for our country where pavement requires frequent maintenance. It is also evident from field performance results that higher longevity bituminous road is possible using waste plastic. Summary of findings in study is given in the next chapter.

Chapter 6
Conclusion and Recommendation

6.1 Introduction

The main objective of this study was to find out compatible waste plastic to blend with bitumen and assess the performance of waste plastic blended bituminous road.

According to other objectives of the research, the modified binder was investigated through extensive laboratory experimentation. A comparative analysis of waste plastic-modified bitumen and virgin bitumen regarding rheological properties were carried out. Bituminous mixes prepared with this modified binder and pure bitumen was also tested to compare Marshall Stability, Flow and other properties of these two types of mixes according to Marshall Method of mix design. Besides, a field demonstration was carried out on the two adjoining segments of Folder Street, Wari, Dhaka of DCC with the modified and pure binders respectively to compare the performances of the road segments. The summary of the test results, field performance data and other important findings are presented in the following articles.

6.2 Conclusion on Experimental Results

6.2.1 Polymer blending and its compatibility

The success of blending of any type of polymer with bitumen depends on their compatibility and affinity to mix with one another. An incompatible polymer cannot be blended with bitumen. From the point of compatibility of waste plastic, findings of this research are summarized below:

- Blending of bitumen with waste plastic (LDPE) can be easily done with the mechanically controlled blender. Blending is also possible with manual blending device.
- It is observed that long blending time (40-60 minutes) and high blending temperature (180° - 210°) is required for blending of waste plastic.
- It is found that for the blending of waste polymer with bitumen, the mechanically controlled blender is suitable.

- During preparation of the modified binder in the laboratory, no objectionable forms of gases are noticed from the heated polymer.
- It is also observed that no physical property change in the prepared blend stored for future.
- During field demonstration a huge quantity of waste plastic (LDPE) was readily (in the shredded form) available. Hence there is no scarcity of waste polymer in the market.

It is also proved that blending of a huge quantity of waste plastic (315 kg) is possible at a time in a Central Asphalt Plant by using manual stirring device but mechanically controlled blender is suitable.

6.2.2 Rheological properties of waste plastic modified binder

The rheological properties of binders (pure bitumen and modified bitumen) were evaluated by such tests as penetration, ductility, softening point, flash and fire point, specific gravity etc. The following conclusions can be drawn by analyzing the test results on the binders:

- The penetration of the waste plastic modified binder decreases with the increase of waste plastic content in bitumen. It is observed that addition of 7.5% waste plastic in bitumen results in decrease of penetration by more than 70% as compared to that of pure bitumen.
- The ductility of the waste plastic r modified binder sharply decreases with the increase of addition of waste plastic in bitumen. The observation from experimental investigation is that the value of ductility decreases by more than 83% in case of 7.5% waste plastic content in bitumen as compared to that of pure bitumen.
- The softening point increases with the increase of the plastic in the bitumen. Softening point increases by about 36% in case of 7.5% waste plastic content as compared to that of virgin bitumen.
- Loss on heating and specific gravity modified binder are almost equal to that of pure bitumen.

6.2.3 Characteristics of waste plastic modified bituminous mixes

The necessary tests on compacted mixes prepared with conventional bitumen and waste plastic modified bitumen were performed. The tests on the mixes reveal that:

- The stabilities of the compacted mixes increase significantly with the increase of the waste plastic content in bitumen up to 7.5% and then decreasing pattern for 10% waste plastic content. So, optimum waste plastic content can be taken as 7.5%.
- From the stability test of Marshall Specimens it is found that 7.5% waste plastic in the binder increases Marshall Stability by about 19% against 5.5% binder content. This implies that high strength bituminous mixes can be made by adding 7.5% waste plastic without changing any other mix ingredient.
- The flow values obtained in the Marshall tests show increasing pattern with the increase of waste plastic content up to 7.5% in the mix. The effect of waste plastic on density, air void (V_a), void in mineral aggregate (VMA) and void filled with asphalt (VFA) is found to be not substantial.
- From close observations of Marshall Characteristic's curves (viz. Stability Vs Binder Content, Flow Vs Binder Content, Unit Weight Vs Binder Content, %Va Vs Binder Content, %VMA Vs Binder Content and %VMA Vs Binder Content) for modified binder, it is found that the patterns and shapes are very similar to that of mixes with pure bitumen. This implies that the optimum quantity of modified binder could be determined following the same procedure of Marshall Mix Design and criteria.

6.3 General Conclusions

The use of west plastic modified binder has not yet started in Bangladesh. The fruitful research works conducted on it in the country are few. The results of this research together with that of previous researches are found to be encouraging for the future researchers who are interested to work in this field. In consideration of frequent submergence problems, high summer temperature and poor pavement construction practice and above all environmental hazards due to waste plastic in Bangladesh, the use of waste plastic in road construction may bring economical benefits in the following ways:

- In general excess binder content causes bleeding problems especially at high temperature, whereas any deficient amount of binder may cause cracking, loss of aggregates, pot holes problems etc. In Bangladesh due to manual mixing, it is very difficult to control the temperature and optimum amount of bitumen in the mix. In this regard polymer (waste plastic) modified binder could be a better solution due to its low ductility, high softening point and enhanced elastic properties.
- As the modified binder increases strength of compacted mix by a big margin, cost saving could be achieved in pavement construction and maintenance.
- Since waste plastic modified bituminous binder has the potential to make pavement long lasting, to reduce construction cost and maintenance frequency, it holds a huge potential and a great prospect in prevailing weather conditions and road construction practices in Bangladesh.
- Drainage problem is a big issue in urban area and waste plastic is mainly responsible for water lobbing. So use of waste plastic with bitumen in road construction may be a better solution.
- The unit cost of waste plastic is about 30% less than that of pure bitumen. Hence the use of waste plastic (7.5% by weight of bitumen) with bitumen may be economically viable for road construction and maintenance work.

6.4 Limitation of the Research

The main objective of the research was to incorporate waste plastic with bitumen with the aim of producing high performance binder and partly solving the undesirable stockpiling of non-biodegradable waste plastic. A thermostatically and mechanically controlled blending system was desirable for blending the waste plastic, but blending was done manually in case of field demonstration.

More over for proper comparison of performances between normal road and waste plastic road minimum duration of data collection should be 2 years, but due to construction of another infrastructure (Jatrabari-Gulistan Flyover Project) both the road segments were damaged.

Besides, due to lack of laboratory facilities, viscosity test for bitumen mixed with waste plastic could not be performed. And also due to same reasons, some important tests regarding the study topic such as Film Thickness, Elastic Recovery, Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer (BBR) tests could was not performed.

6.5 Recommendations

The study findings show that use of waste plastics as modifier to the bituminous surfacing of the conventional road pavement in Bangladesh would improve the performance of Bangladesh road network significantly. The following are the recommendations.

1. Government agencies like RHD, LGED, and City Corporations should come up with at least one comprehensive project of processing waste plastics and constructing roads using the waste plastic modified bituminous mix.
2. The models of collection of plastic wastes by the Bangalore City Corporation may be followed by City Corporations of Bangladesh. Private sector may be involved in the collection process.
3. Initiatives need to be taken to improve the locally fabricated equipment and machinery for shredding and blending of waste plastics. The private sector should be encouraged and involved. Government may provide necessary financial incentives.
4. To ensure the use of specified waste plastics in road works with proper specification road agencies along with academic institutions should develop Standard Test Procedures and set up laboratory facilities to do the specified tests.
5. Professional and academic training should be given to different appropriate levels in the implementing chain – Engineers, Technicians, Foreman and up to field level Labourers with regard to the new technology.

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APPENDIX

Table-A1: Raw Marshall Data and Calculated Results ((Mechanically Blended Binder)

Waste Plastic Content (%)	Binder Content (%)	S.G. of Binder (G_b)	Mass in air (gm)	Mass in water (gm)	Mass, SSD in air (gm)	Bulk Volume (cc)	Bulk S.G of Specimen (G_{mb})	Maximum S.G of Mix (G_{mm})	Effective S.G of Specimen (G_{se})	Unit Weight (lb/cft)	%Air voids (V_a)	% VMA	% VFA
0.0%	4.0	1.025	1204.1	683.4	1208.9	525.5	2.29	2.45	2.60	142.90	6.53	17.04	61.68
	4.5	1.025	1206.8	692.5	1217.3	524.8	2.30	2.43	2.60	143.52	5.35	17.11	68.73
	5.0	1.025	1201.3	691.5	1211.5	520.0	2.31	2.41	2.60	144.14	4.15	17.19	75.86
	5.5	1.025	1210.5	696.1	1212.4	516.30	2.34	2.40	2.60	146.01	2.5	16.55	84.89
	6.0	1.025	1220.09	708.7	1226.03	517.33	2.36	2.38	2.60	147.26	0.84	16.29	94.84
2.5%	4.0	1.020	1202.8	674.3	1208.0	533.7	2.25	2.46	2.61	140.4	8.54	18.49	53.81
	4.5	1.020	1210.0	684.9	1213.0	528.1	2.29	2.44	2.61	142.90	6.15	17.47	64.80
	5.0	1.020	1213.4	694.2	1217.1	522.9	2.32	2.42	2.61	144.77	4.13	16.83	75.46
	5.5	1.020	1216.6	697.9	1219.6	521.7	2.33	2.40	2.61	145.40	2.92	16.91	82.73
	6.0	2.020	1217.1	704.4	1220.0	515.6	2.36	2.39	2.61	147.26	1.26	16.29	92.27
5.0%	4.0	1.017	1183.8	656.7	1191.5	534.8	2.21	2.48	2.64	137.90	10.89	19.93	45.36
	4.5	1.017	1196.4	664.7	1204.0	539.30	2.20	2.46	2.64	138.53	9.76	20.0	51.20
	5.0	1.017	1220.6	687.3	1227.9	540.6	2.26	2.45	2.64	141.02	7.76	18.98	59.11
	5.5	1.017	1218.9	694.7	1227.2	532.5	2.29	2.43	2.64	142.90	5.76	18.33	68.58
	6.0	1.017	1221.4	698.6	1228.1	529.50	2.31	2.41	2.64	144.14	4.15	18.06	77.02
7.5%	4.0	1.014	1193.5	661.7	1199.9	538.2	2.21	2.46	2.62	137.90	10.16	19.93	49.02
	4.5	1.014	1234.4	692.4	1244.0	551.6	2.23	2.45	2.62	139.15	8.98	20.0	55.10
	5.0	1.014	1221.01	685.4	1225.7	540.3	2.26	2.43	2.62	141.02	7.0	18.98	63.12
	5.5	1.014	1229.9	694.0	1232.5	538.5	2.28	2.41	2.62	142.27	5.39	18.33	70.59
	6.0	1.014	1217.9	690.5	1222.4	531.5	2.29	2.39	2.62	142.90	4.18	18.0	76.78

Continued

Table-A1: Raw Marshall Data and Calculated Results (Mechanically Blended Binder)

Waste Plastic Content (%)	**Binder Content** (%)	**S.G. of** Binder (G_b)	**Mass in a**ir (gm)	**Mass** in water(gm)	**Sat** Surface in air(gm)	**Bulk** Volume (cc)	**Bulk** S.G of Specimen(Gmb)	**Maximum** S.G of Mix(G_{mm})	**Effective** S.G Of Specimen (Gse)	**Unit** Weight (lb/cft)	"A,**air** Voids (V_a)	% VMA	% VFA
10.0%	**4.0**	**1.01**	**1179.7**	**669.5**	**1201.5**	**532.0**	**2.22**	**2.50**	**2.65**	**138.53**	**11.20**	**19.58**	42.80
	4.5	**1.01**	**1213.0**	**680.0**	**1223.0**	**543.0**	**2.23**	**2.48**	**2.65**	**139.15**	**10.08**	**19.63**	**48.65**
	5.0	**1.01**	**1204.2**	**687.7**	**1222.8**	**535.1**	**2.25**	**2.46**	**2.65**	**140.4**	**8.54**	**19.33**	**55.82**
	5.5	**1.01**	**1216.1**	**688.6**	**1229.2**	**540.6**	**2.25**	**2.44**	**2.65**	**140.4**	**19.76**	**60.58**	**1.04**
	6.0	**1.01**	**1215.4**	**692.9**	**1229.0**	**536.1**	**2.26**	**2.42**	**2.65**	**141.02**	**6.61**	**19.83**	**66.67**
*7.5%	**4.0**	**1.03**	**1207.8**	**690.9**	**1227.5**	**536.6**	**2.25**	**2.49**	**2.65**	**140.4**	**9.64**	**18.49**	**47.86**
	4.5	**1.03**	**1204.2**	**683.8**	**1219.7**	**535.9**	**2.25**	**2.48**	**2.65**	**140.4**	**9.27**	**18.91**	**50.98**
	5.0	**1.03**	**1205.9**	**686.6**	**1217.4**	**530.8**	**2.27**	**2.46**	**2.65**	**141.65**	**7.72**	**18.62**	**58.54**
	5.5	**1.03**	**1210.8**	**689.6**	**1216.9**	**527.3**	**2.30**	**2.44**	**2.65**	**140.4**	**5.74**	**17.98**	**71.41**
	6.0	**1.03**	**1225.7**	**716.7**	**1231.1**	**514.6**	**2.38**	**2.42**	**2.65**	**148.51**	**1.65**	**15.58**	**89.41**

*PET Bottle.

Table-A2: Raw Marshall Data and Calculated Results (Manually Blended Binder)

Waste Plastic Content (%)	**Binder Content** (%)	**S.G. of** Binder (G_b)	**Mass in air** (gm)	**Mass** In water (gm)	**Mass, SSD** in air (gm)	**Bulk Volume** (cc)	**Bulk S.G of Specimen** (G_{mb})	**Maximum S.G of Mix** (G_{mm})	**Effective** S.G Of **Specimen** (G_{se})	**Unit Weight** (lb/cft)	%**Air** Voids (V_a)	% VMA	% VFA
0.0%	**4.0**	**1.020**	**1083.9**	**620.6**	**1089.10**	**468.5**	**2.31**	**2.47**	**2.62**	**144.14**	**6.48**	**16.32**	**60.29**
	4.5	**1.020**	**1091.5**	**634.4**	**1095.40**	**461.0**	**2.36**	**2.45**	**2.62**	**147.26**	**5.71**	**14.95**	**61.81**
	5.0	**1.020**	**1104.3**	**643.4**	**1105.70**	**462.3**	**2.38**	**2.43**	**2.62**	**148.51**	**2.10**	**14.70**	**85.71**
	5.5	**1.020**	**1096.0**	**643.2**	**1097.00**	**453.8**	**2.41**	**2.42**	**2.62**	**150.38**	**0.41**	**14.05**	**97.08**
	6.0	**1.020**	**1104.2**	**646.1**	**1104.90**	**458.8**	**2.40**	**2.41**	**2.62**	**149.76**	**0.41**	**14.86**	**97.24**
7.5%	**4.0**	**1.017**	**1083.4**	**613.0**	**1090.60**	**477.6**	**2.27**	**2.48**	**2.63**	**141.64**	**8.47**	**17.77**	**52.24**
	4.5	**1.017**	**1088.6**	**621.6**	**1093.60**	**472.0**	**2.31**	**2.46**	**2.63**	**144.14**	**6.10**	**16.75**	**63.58**
	5.0	**1.017**	**1099.2**	**631.8**	**1102.60**	**470.8**	**2.33**	**2.44**	**2.63**	**145.39**	**4.51**	**16.47**	**72.62**
	5.5	**1.017**	**1106.2**	**641.1**	**1110.30**	**469.2**	**2.36**	**2.42**	**2.63**	**147.26**	**2.48**	**15.84**	**86.30**
	6.0	**1.017**	**1113.7**	**648.9**	**1115.20**	**446.3**	**2.39**	**2.41**	**2.63**	**149.14**	**0.83**	**15.22**	**94.50**

Table-A3: Raw Marshall Data and Calculated Results (Mechanically Blended Binder)

Waste Plastic Content (%)	Binder Content (%)	Specimen Height in (mm)	Specimen Volume in (cc)	Correction Factor	Providing Dial reading	Marshall Stability (lb)	Corrected Stability (lb)	Flow Value (1/100 inch)
0.0%	4.0	63.00	525.5	0.96	203	1100	1056	10.5
	4.5	63.5	524.8	0.96	195	1060	1018	12.0
	5.0	65.0	520.0	1.0	265	1470	1470	11.0
	5.5	64.5	517.33	1.0	345	1970	1970	15.5
	6.0	64.0	516.3	1.0	319	1820	1820	11.5
2.5%	4.0	65.5	533.70	0.96	272	1510	1450	12.0
	4.5	64.3	528.10	0.96	294	1720	1651	16.0
	5.0	64.2	522.9	0.96	343	1955	1877	17.5
	5.5	63.3	521.70	1.0	363	2070	2070	18.5
	6.0	64.3	525.60	0.96	278	1925	1464	16.8
5.0%	4.0	66.0	534.80	0.96	350	2000	1920	14.0
	4.5	67.3	539.30	0.93	388	2240	2083	19.0
	5.0	68.0	540.60	0.93	347	1950	1814	15.0
	5.5	65.6	529.50	0.96	425	2400	2304	18.5
	6.0	66.60	*532.50*	*0.96*	*345*	*2300*	*2208*	*14.4*
7.5%	4.0	67.0	538.20	0.93	335	1910	1776	14.5
	4.5	67.6	551.6	0.89	350	2000	1780	21.5
	5.0	66.3	540.3	0.93	435	2515	2339	19.0
	5.5	65.6	531.5	0.96	436	2520	2420	21.5
	6.0	65.6	538.5	0.93	362	2050	1907	22.5
10.0%	4.0	68.6	532.0	0.96	212	1150	1104	14.5
	4.5	69.0	543.0	0.93	305	1735	1614	11.0
	5.0	68.3	535.1	0.96	355	2025	1944	14.2
	5.5	69.0	540.6	0.93	432	2500	2325	15.0
	6.0	68.3	536.1	0.93	408	2350	2186	16.5
*7.5%	4.0	68.0	534.6	0.96	395	2280	2189	11.5
	4.5	66.3	535.9	0.93	330	1890	1758	17.5
	5.0	65.3	530.8	0.96	390	2250	2160	19.5
	5.5	64.6	*514.60*	*1.0*	*390*	*2250*	*2250*	*19.5*
	6.0	64.6	537.30	0.93	412	2400	2232	18.5

* PET Bottle

Table-A4: Raw Marshall Data and Calculated Results (Manually Blended Binder)

Waste Plastic Content (%)	Binder Content (%)	Specimen Height in (mm)	Specimen Volume in (cc)	Correction Factor	Providing Dial reading	Marshall Stability (lb)	Corrected Stability (lb)	Flow Value (1/100 inch)
0.0%	4.0	58.40	468.50	1.19	280	1572	1871	11.5
	4.5	58.10	461.00	1.19	295	1710	2035	11.0
	5.0	58.70	462.30	1.19	318	1840	2189	11.0
	5.5	5836	453.80	1.25	340	1932	2415	13.5
	6.0	58.20	458.80	1.19	312	1764	2099	12.0
7.5%	4.0	59.50	477.60	1.14	335	1902	2168	14.0
	4.5	59.60	472.00	1.14	338	1920	2189	11.0
	5.0	58.90	470.80	1.14	350	2000	2280	13.0
	5.5	59.40	469.20	1.19	423	2430	2891	13.0
	6.0	58.70	466.30	1.19	330	1875	2231	16.0

Table A5: Marshall Mix Design Criteria

Marshall Method Mix Criteria[1]	Light Traffic Surface Base		Medium Traffic Surface Base		Heavy Traffic Surface Base	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Compaction (blows)	35		50		75	
Stability (lb)	750	-	1200	-	1800	-
Flow (0.01 inch)	8	18	8	16	8	14
Air Void (%)	3	5	3	5	3	5
Voids Filled with Asphalt (%)	70	80	65	78	65	75
Voids in Mineral Aggregates (%)	See Table A6					

NOTES

1. All criteria, not just stability value alone, must be considered in designing an asphalt paving mix. Hot mix asphalt bases that do not meet these criteria when tested at 60^0C (140^0F) are satisfactory if they meet the criteria when tested at 38^0C (100^0F) and are placed 100mm (4 inches) or more below the surface. This recommendation applies only to regions having a range of climatic conditions similar to those prevailing throughout most of the United States. A different lower test temperature may be considered in regions having more extreme climatic conditions.
2. Traffic classifications
   - Light- Traffic conditions resulting in a Design EAL $<10^4$
   - Medium- Traffic conditions resulting in a Design EAL between 10^4 and 10^6
   - Heavy- Traffic conditions resulting in a Design EAL $>10^6$
3. Laboratory compaction efforts should closely approach the maximum density obtained in the pavement under traffic.
4. The flow value refers to the point where the load begins to decrease.
5. The portion of asphalt cement lost by absorption into the aggregate particles must be allowed for when calculating percent air voids.
6. Percent void in the mineral aggregate is to be calculated on the basis of the ASTM bulk specific gravity for the aggregate.

Table A6: Minimum Percent Void in Mineral Aggregate (VMA)

Nominal Maximum Particle Size[1.2]		Design Air Voids, Percent		
		3.0	4.0	5.0
(mm)	(inch)	Minimum VMA, Percent[3]		
1.18	No. 16	21.5	22.5	23.5
2.36	No. 8	19.0	20.0	21.0
4.75	No. 4	16.0	17.0	18.0
9.5	3/8	14.0	15.0	16.0
12.5	½	13.0	14.0	15.0
19.0	¾	12.0	13.0	14.0
25.0	1.0	11.0	12.0	13.0
37.5	1.5	10.0	11.0	12.0
50	2.0	9.5	10.5	11.5
63	2.5	9.0	10.0	11.0

1. Standard specification for Wire Cloth Sieves for Testing Purposes. ASTM E11 (AASHTO M92)
2. The nominal maximum particle size is one size larger than the first sieve to retain more than 10 percent.
3. Interpolate minimum voids in the mineral aggregate (VMA) for design air void values between those listed.