JIMMA UNIVERSITY

SCHOOL OF GRAUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL & ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

EXPERIMENTAL STUDY ON MODIFICATION OF BITUMEN USING WASTE PLASTIC FOR FLEXIBLE PAVEMENT

A Research Paper Submitted to School of Graduate Studies of Jimma Institute of Technology, in Partial Fulfillment of Requirements for Degree of Masters of Science in Civil Engineering (Highway Engineering)

BY

Andinet Bekele

June 2017

Jimma, Ethiopia

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June 2017

Jimma, Ethiopia

DECLARATION

I, the undersign declare that this thesis entitled by "Experimental Study on Modification of Bitumen Using Waste Plastic For Flexible Pavement" is my original work and has not been presented by any other person on an award of degree in this or other university and all sources of materials used for this thesis have been duly acknowledge.

Candidate: Andinet Bekele

Signature: ______________________ Date__________________

As masters research advisors, we hear by certify that we have read and evaluated this MSc research prepare under our guidance, by Andinet Bekele entitled by "Experimental Study on Modification of Bitumen Using Waste Plastic for Flexible Pavement"

We recommend that it can be submitted as fulfilling the MSc thesis requirement.

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ABSTRACT

The growth in varies type of industries together with population growth has resulted in enormous increase in production of varies type of waste plastic material and it is one of the major environmental concerns. On the other side, the road traffic and the traffic intensity is increasing; the load bearing capacities of the road should be improved. To deal with the problem, study on use of plastic waste as partial replacement to bitumen is considered in the present work. This paper will help to take care of both those aspects.

The main objective of this study was to evaluate laboratory performance of modified bitumen mix using waste plastic for flexible pavement to enhance asphalt mix properties. This research has determine the best method of adding polymer in asphalt mix. In this study four proportion (6,9,12 &15%) of waste plastic (PET and HDPE) were introduced in the asphalt mixture with a selected aggregate grading. Marshal mix design procedure was used, first to determine the Optimum Bitumen Content (OBC) and the OBC was 5.1% by weight of asphalt mix. Number of laboratory tests such as penetration, ductility, softening point, loss on heat and marshal stability test has been carried out by replacing some parts of the bitumen with plastic waste. The results show that there is an improvement on those properties when compared to normal bitumen.

The Marshal stability results reveals that the waste plastic (PET and HDPE) increases the stability values of the compacted mixes with increasing the waste plastic content in the bitumen up to 9% PET and 12% HDPE. The density of the compacted mixes slightly decreases with the increase of waste plastic contents in the bitumen.

It is expected that using the output of this research, provide an economical solution and minimize the frequency of rehabilitation work by improving the performance of asphalt. It is also expected to substantially reduce volume of environmentally hazardous plastic and environmental pollution.

Study recommends contractors and local authorities to confirm using waste plastic in asphalt mix with the proposed percentage (7% PET and 8% HDPE by OBC weight) to improved the performance of asphalt mix. Moreover, further studies are needed in various topics related to effective utilization and best incorporation techniques of waste materials.

Key Word: - *Marshal Stability, Modified Bitumen, Optimum Binder Content (OBC),Plastic Waste*

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ACRONYMS

AASHTO	Association of American State Highway and Transportation officials
AC	Asphalt Concrete
AAiT	Addis Ababa institute of Technology
ASTM	American Society for Testing and Materials
ERA	Ethiopian Roads Authority
ERCC	Ethiopian Road Construction Corporation
ETB	Ethiopian Birr
HDPE	High Density Polyethylene
HMA	Hot Mix Asphalt
JIT	Jimma Institute of Technology
LDPE	Low Density Polyethylene
MSW	Municipal solid wastes
OBC	Optimum Bitumen Content
PE	Poly Ethylene
PET	Polyethylene Terepthalate
PMB	Polymer Modified Bitumen
PP	Poly Propylene
PVC	Polyvinyl Chloride
SG	Specific Gravity
SPI	Society of the Plastics Industry
RB	Ring and Ball
TCDE	Transport Construction and Design Enterprise
VFB	Void Filled with Bitumen
VMA	Void in Mineral Aggregate

CHAPTER ONE

INTRODUCTION

1.1 Background

The management of solid waste is a growing problem in many urban areas in Africa today. One of the reasons for this is that during the recent decades urban areas in Africa have experienced a rapid urbanization due to rapid population growth and high rates of migration from rural areas. To give an indication of the situation, the urban population of the world is expected to double to more than five billion people in the next 35 years, with 90 percent of the growth taking place in developing countries (Medina 2002).

Plastics are commonly used substances which play an important role in almost every aspect of our lives. The widespread generation of plastics waste needs proper end-of-life management. The highest amount of plastics is found in containers and packaging (like bottles, packaging, cups and other), and they also are found in durables such as tires, building materials and furniture and disposable goods. (Plastic Common Wastes & Materials US EPA. 2013)

The highway engineers are thinking about the alternative solutions to cop up with 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).

In the construction of flexible pavements, bitumen plays the role of binding the aggregate together by coating over the aggregate. It also helps to improve the strength and life of road pavement. A common method to improve the quality of bitumen is by modifying the rheological properties of bitumen by blending with synthetic polymers like rubber and plastics. Use of plastic waste in the bitumen is similar to polymer modified bitumen. (FHWA; 1997)

In recent years, applications of plastic wastes have been considered in road construction with great interest in many developing countries. The use of these materials in road making is based on technical, economic, and ecological criteria. The durability of the roads laid out with plastic waste is much more compared with roads with asphalt with the ordinary mix. Roads laid with plastic waste mix are found to be better than the conventional ones. The binding property of plastic makes the road last longer besides giving added strength to withstand more loads. While a normal highway quality road lasts 4-5years it is claimed that plastic-bitumen roads can last up to 10 years. (Kurmadasu C. et. al., 2016)

Along with technical aspect, economical aspect is of course a huge driving force for the choice of technology. Different kinds of pavements have different demands on performance. From the economic aspect, it is not always better to achieve higher performance for a road. Only when the technology is cost-effective and people get the maximum benefits from it, then can it become popular. As for polymer modified bitumen, the cost is quite relevant with the dosage of the added polymer, while the polymer dosage usually has important influences on the final degree of polymer modified bitumen performance. So before constructing a road, the designers must know what the needed degree of performance for the road is and then decide to use polymer modified bitumen or not, and how much should be applied. Currently, most of the world consumption of bitumen is still base bitumen. (Zhu, J. et al., 2014)

Use of waste plastic in road construction with different method and approach is one of emerging advanced technology getting famous now days. Such technology solves not only the problem of management of municipal solid waste plastic but also it save environment pollution and bitumen cost. In most case utilization of plastic in flexible pavements has been done to increase the stability and durability of roads and reduce the cost of construction by replacing some percentage of bitumen with that of the waste plastic.

1.2 Statement of the Problem

The global production of plastic has continued to rise. Millions of tons of plastics were produced exponentially throughout the year. Recovery and recycling were practice but still it is not enough to consume all the plastic waste in the environment; such as landfill and water areas. In any part of the world the plastic produced or consumed per person is continued to rise together with the economy. (Gaelle G., 2015)

In Ethiopia, there are efforts in the reduction of plastic waste material in landfills. In addition to the harmful chemicals it adds to the environment such as bisphenol A, phthalates and antimony, it reduces the aesthetic value of the environment. (Abraha G. et. al., 2012). Inadequate municipal and industrial dry waste collection will result to unmanageable waste. Much amount of these waste products will end up in open dump, waterway and everywhere. At the end of the day, these will cause environmental and health problem (Tadesse Kuma, 2004)

The government is importing bituminous materials from Middle East and other African countries. The consumption of this bitumen is increasing as the government improves the road network. Replacing parts of this material will ease and minimize the consumption of bitumen. Plastic can be one of the waste products which can partially replace bitumen. The percentage of replacement and the increase of performance will be the aim of this research paper.

1.3 Research Question

This research was conducted to answer the following questions.

- What are the physical and mechanical properties of waste plastic modified bitumen concrete mix?
- What is the effect of waste plastic on strength & stability characteristics of bitumen concrete mix?
- What is the optimum proportion of waste plastic to be added in bitumen mix in order to get the required Marshal value from the specification?
- What are the variation of the engineering properties of modified bitumen pavement and the normal asphalt concrete pavement?

1.4 Objectives

1.4.1 General Objective

- The main objective of this study was to evaluate laboratory performance of modified bitumen mix with waste plastic for flexible pavement using Marshal Test method.

1.4.2 Specific Objectives

The study was carried out to satisfy the following specific objectives:

- To determine the basic physical and mechanical properties of waste plastic modified bitumen concrete mix.
- To identify the effect of waste plastic on strength and stability of bitumen concrete mix.
- To quantify the optimum proportion of waste plastic to be added in bitumen mix in order to get the required marshal value.
- To compare the properties of modified bitumen pavement and the normal asphalt concrete pavement using Marshal Method.

1.5 Significance of Study

Plastics have a number of important properties which were used alone or together with other products to make a significance and expanding contribution for road construction needs. Therefore, the study has a beneficial purpose to the government and authorities to reuse of waste plastic which improve the solid waste disposal problem. The study were used as a bench mark information to those scholars who want to conduct future detailed studies on utilization of waste plastic for road construction and other related issues. These waste materials were possible to use in pavements, and this can reduce not only the cost of management of the increasing waste plastics but also reduce the cost on the use of bitumen. Also this study has contribution in creating employment opportunities.

1.6 Scope and Limitation of the Study

This study was conducted to explore the idea on the use of waste plastic in bituminous concrete. Laboratory investigation was carried out to find whether it is viable to use waste plastic for road construction as a partial replacement of bitumen in bituminous asphalt pavement.

The present study basically focused: -

- on the study of the effect on Marshall Stability of bituminous mix with the addition of waste plastic (HDPE and PET).
- on the reduction of the bitumen amount by addition of waste plastic (HDPE and PET) in bituminous mix.

The laboratory investigation on the bituminous mix was carried out as per the ASTM/AASHTO/ERA standard for road construction. The field application is out of the scope of work.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Over the past two decades, traffic volumes have increased, demanding from pavement engineers, stronger and long lasting pavements. New methods of pavement design are being developed to improve the performance of roads. New materials are being used to replace the old ones to improve the durability, strength, aesthetics and economy. One of the promising ways is to use plastics in bituminous road construction industry. (Bhageerathy K. P. et. al., 2014)

Plastic is a relatively cheap, durable and versatile material. Plastic products have brought benefits to society in terms of economic activity, jobs and quality of life. Plastics can even help reduce energy consumption and greenhouse gas emissions in many circumstances, even in some packaging applications when compared to the alternatives. Plastic waste also imposes negative environmental externalities. It is usually non-biodegradable and therefore can remain as waste in the environment for a very long time; it may pose risks to human health as well as the environment; and it can be difficult to reuse and/or recycle in practice. An issue of particular concern is that giant masses of plastic waste have been discovered in the North Atlantic and Pacific Oceans, the full environmental impacts of which are not yet fully understood but which cause severe damage to seabirds, marine mammals and fish.(European Commission (DG Environment), 2011)

2.1.1 Plastic Material

Plastic is an organic material manufactured from petroleum derivatives or naturally occurring. It is composed of one organic substance or more. It can be shaped into any form or shape as desired. It is either synthetic or naturally occurring, that may be shaped when soft and then hardened to retain the given shape. Plastic is a polymer. A polymer is a substance made of many repeating units. The word polymer comes from two Greek words: poly, meaning many, and meros, meaning parts or units. A polymer can be thought of as a chain in which each link is the “mer,” or *monomer* (single unit). The chain is made by joining, or *polymerizing*, at least 1,000 links together.(American Chemistry Council."History of Polymers and Plastics for Teachers.")

Plastic is the general term for a wide range of synthetic or semi synthetic polymerization products. They are composed of organic condensation or addition polymers and may contain other substances to improve performance or economics. There are few natural polymers generally considered to be "plastics". Plastics can be formed into objects or films or fibers. Their name is derived from the fact that many are malleable, having the property of plasticity. (L.A. Utracki. 1995)

2.1.2 Characteristics of Polymers

Polymers seem to have a limitless range of characteristics along with properties that allow them to be dyed in an endless array of colors. Their properties can be enhanced by additives. Being able to design or engineer polymers for specific applications makes plastics unique materials. Although each polymer has unique characteristics, most polymers have some general properties:

- They are resistant to chemicals.
- They are insulators of heat and electricity.
- They are light in mass and have varying degrees of strength.
- They can be processed in various ways to produce fibers, sheets, foams, or intricate molded parts. (González Uranga, 2008)

2.1.3 Classifications of Plastic

Plastics can be classified in many ways, but most commonly by their physical properties. Depending on their physical properties, may be classified as thermoplastic or thermosetting materials.

- Thermoplastic materials:-can be formed into desired shapes under heat and pressure and become solids on cooling. If they are subjected to the same conditions of heat and pressure, they can be remolded.
- Thermosetting materials:-which once shaped cannot be softened /remolded by the application of heat.

Table 2-1 Typical Thermoplastic and Thermosetting material

Thermoplastic	Thermosetting
Polyethylene Teryphthalate (PET)	Bakelite
Polypropylene (PP)	Epoxy
Polyvinyl Chloride (PVC)	Melamine
Polystyrene (PS)	Polyester
Low Density Polyethylene (LDPE)	Polyurethane
High Density Polyethylene (HDPE)	Urea – Formaldehyde

(Source: Central Pollution Control Board table /Source: IS 14535: 1998 & ICPE Newsletter, Vol. 6, Issue 2, Apr- Jan 2005.)

2.1.4 The Different Types of Thermoplastic

Polyethylene Terephthalate (PET):

Plastic marked with the Society of the Plastics Industry (SPI) code of 1 is made with polyethylene terephthalate, which is also known as PETE or PET. PETE-based containers sometimes absorb odors and flavors from foods and drinks that are stored inside of them. Items made from this plastic are commonly recycled. PET plastic is used to make many common household items like beverage bottles, medicine jars, peanut butter jars, combs, bean bags, and rope. (Material on Plastic Waste Management, 2012)

Figure 2- 1 Polyethylene terephthalate (PET)

High-density polyethylene (HDPL):

The SPI code of 2 identifies plastic made with high-density polyethylene, or HDPE. HDPE products are very safe and are not known to leach any chemicals into foods or drinks. (However, due to the risk of contamination from previously held substances, please note: it is never safe to reuse an HDPE bottle as a food or drink container if it did not originally contain food or drink!) HDPE products are commonly recycled. Items made from this plastic include containers for milk, motor oil, shampoos and conditioners, soap bottles, detergents, and bleaches. (Material on Plastic Waste Management, 2012)

Figure 2- 2 High Density Polyethylene (HDPE)

Polyvinyl chloride (PVC):

Harmful and toxic if used for long time. It is commonly abbreviated PVC and used in the manufacturing of plumping pipes, bathroom curtains, toys, and transparent plastic wraps for meat and cheese. It is widely used because of its cheap price, so it is considered the most dangerous type of plastic. (Material on Plastic Waste Management, 2012)

Figure 2- 3 Polyvinyl Chloride (PVC)

Low-Density Polyethylene (LDPL):

Plastic marked with an SPI code of 4 is made with low-density polyethylene, or LDPE. LDPE is not commonly recycled, but it is recyclable in certain areas. It tends to be both durable and flexible. It also is not known to release harmful chemicals into objects in contact with it, making it a safe choice for food storage. Plastic cling wrap, sandwich bags, squeezable bottles, and plastic grocery bags all are made from LDPE. (Material on Plastic Waste Management, 2012)

Figure 2- 4 Low Density Polyethylene (LDPE)

Polypropylene (PP): Consumers will find the SPI code of 5 on plastic items made with polypropylene, or PP. PP can be recycled but is not accepted for recycling as commonly as PETE or HDPE. This type of plastic is strong and can usually withstand higher temperatures. Among many other products, it is used to make plastic diapers, Tupperware, margarine containers, yogurt boxes, syrup bottles, prescription bottles, and some stadium cups. Plastic bottle caps often are made from PP as well. (Material on Plastic Waste Management, 2012)

Figure 2- 5 Polypropylene (PP)

Polystyrene (PS): Dangerous and unsafe, used for burger, hotdog and teacups packaging. It looks like the cork and was being used in the international fast food chains. It is still being used here in fast food and popular restaurants. This material has impact on the ozone layer because it is made of harmful Chloro Floro Carbon gas (CFC).

Plastic marked with an SPI code of 6 is made with polystyrene, also known as PS and most commonly known as Styrofoam. PS can be recycled, but not efficiently; recycling it takes a lot of energy, which means that few places accept it. Disposable coffee cups, plastic food boxes, plastic cutlery, packing foam, and packing peanuts are made from PS. Recycled PS is used to make many different kinds of products, including insulation, license plate frames, and rulers. (Material on Plastic Waste Management, 2012)

Figure 2- 6 Polystyrene (PS)

Others: Such material does not come under any category of the abovementioned types of plastic. It can be mixture or compound of the six. The SPI code of 7 is used to designate miscellaneous types of plastic that are not defined by the other six codes. (*Giriftinoglu, 2007*)

2.1.5 Environmental Impact of Waste Plastic

Some environmentalists state that despite recycling efforts, millions of plastic bags and water bottles take decades or centuries to decompose. Plastics are used throughout the world for a broad number of applications. However, there are many environmental concerns associated with its use. The fact that plastic is durable means it degrades slowly. In addition, burning plastic can sometimes result in toxic fumes (Forbid et al., 2011). Aside from trying to eliminate waste plastic, its production is also costly to the environment. It takes large amounts of chemical pollutants to create plastic, as well as significant amounts of fossil fuels. Although Plastic activists argue that, plastic bags can be reused, all plastic materials find their way to landfills. Hence this is not a robust defense when it comes to the environment (Alston and Arnold et al., 2011).

Plastic bottles are a major part of the municipal waste. They have special importance due to their low density to volume ratio. Moreover, they are chemically stable since they are non-biodegradable materials (i.e. the biodegradation process is very slow). This means that plastic waste will be visible for months or years, and waste will sit in landfill sites for years without degrading. Therefore, plastic bottles can cause a serious environmental problem (Hall et al., 2005).

Today, the availability of the waste plastics is enormous, as the plastic materials have become part and parcel of daily life. If not recycled, their present disposal is either by land filling or by incineration. Both these processes have certain impact on the environment. (Bhageerathy K. P. et al., 2014)

2.2 Historical Perspective of Bitumen Modification

Bituminous binders are widely used in road paving and their viscoelastic properties are dependent on their chemical composition. Now-a-days, the steady increment in high traffic intensity in terms of commercial vehicles, and the significant variation in daily and seasonal temperature put us in a situation to think about some alternative ways for the improvement of the pavement characteristics and quality by applying some necessary modifications which shall satisfy both the strength as well as economical aspects. Bitumen can also be modified by adding different types of additives to achieve the present requirement. One of these additives is the polymers. (Monika Mohanty, 2013)

Bitumen polymer modification has a long history. Even before refined bitumen was produced, people began to modify natural bitumen and some patents were granted for natural rubber modification.

(Morgan ,P. et al., 1995) Synthetic polymers, however, were not widely used until after World War II ended. One well-known early example is neoprene (polychloroprene) latex, which began to be increasingly used for bitumen modification in North America from the 1950s Plastomers have a longer history of artificial synthesis than thermoplastic elastomers. Most of the currently popular plastomers began to be produced commercially before 1960 (L.A. Utracki. 1995).

Bitumen polymer modification was firstly used in the roofing industry, and then the paving industry.

In 1965, a tactic polypropylene (APP), which is a by-product of isotactic polypropylene(IPP) manufacturing, was firstly used to modify bitumen for roofing in Italy and the first commercial product was marketed in 1967 (Johnson. R.1987). However, it was not widely used until the early 1970s in Europe. As for the USA, it was in 1978 that Americans began to widely use modified bitumen in roofing. (Johnson, R. 1987)

Bitumen polymer modification for road construction is a field extensively covered by intellectual property. A patent, relating a bituminous composition with base bitumen and polyisobutylene, was granted as early as 1940 bituminous composition. During the 1970s, researchers proved that the addition of polymers, including plastomers and thermoplastic elastomers, could improve some properties of paving bitumen, such as reducing temperature sensitivity or increasing the resistance to permanent deformation (Rostler, F.S. et al. , 1972)

In 1978, Chaffin reported the potential storage stability problems of bitumen modified with elastomers, but they also wrote that their field test sections constructed in Texas in 1976 were performing well. In 1983, a binder for pavement wearing courses, which comprises PE modified bitumen, was reported by Denning et al. (Denning, J.H. Carswell, J., 1983) although it led to phase separation problems and higher manufacturing and compacting temperatures. In 1989, Reese reported the good resistance to ageing and cracking of PMB after a two-year field test in California, although they pointed out that further evaluations needed to be performed to be conclusive about the success of the modification.

By the early 1990s, increased interest in research of bitumen polymer modification was observed in many countries (Isacsson, X. Lu.1995). Researchers systematically investigated the mechanical properties, rheology, temperature sensitivity, morphology, thermal behavior, storage stability and ageing of different PMBs. Both the advantages and disadvantages of widely used PMBs were gradually found out. On the other hand, some drawbacks were proven, such as the thermal instability of some polymer modifiers and phase separation problems of some PMBs (Wardlaw, K.R., 1992).

In June 1998, a World Road Association International Symposium on polymer modification of bitumen was held in Rome, which gave an overview of the situation at that time and encouraged the publication of a report in 1999 (World Road Association,1999). Furthermore, attempts to remove PMB's drawbacks began from the 1990s. In 1996, Giavarini et al. claimed that PP modified bitumen could be stabilized by adding polyphosphoric acid (PPA) and they believed PPA could help to improve storage stability of PMB by changing the bitumen structure from Sol to gel. After 2000, investigations regarding PMB tended to be divided into two fields:

i. continuing to deeply investigate the mechanism of polymer modification and its failure and
ii. Attempting to overcome the disadvantages of some PMBs. The first field mainly focused on the microstructure, deformation, cracking, ageing and fatigue of PMB (Mouillet, et al ,2008)

Even now, there are still some academic debates in this field. For example, some researchers believe that bitumen has a heterogeneous colloid structure and PMB should be investigated as a multiphase (polymers/asphaltenes/maltenes) viscoelastic emulsion (Lesueur D.,2009),while some other researchers claim that bitumen is a homogeneous and continuous molecular solution based on their mutual solubility and polymers result in good effects on PMB by their partial solubility in bitumen (Redelius P. 2004),

Another example is some authors think asphaltenes are strongly polar components in bitumen and the polarity of polymer modifiers has a significant influence on their compatibility with bitumen and the final storage stability of the resulting PMBs [G. Polacco, J. Stastna, D. Biondi, L. Zanzotto.,2006 ; D.Lesueur.,2009]; but some others believe asphaltenes are typical non-polar molecules from a chemical point of view (Redelius P, 2009) As for the attempts to overcome disadvantages in 2000s, various ways were reported to remove PMB's drawbacks, including sulfur vulcanization (Wen G. et al. 2001), adding antioxidants

2.3 Previous Studies on Plastic Modification of Bitumen:

The results of previous studies showed that the using of waste plastic in asphalt mixture improve the engineering properties such as Marshall Stability, resistant to water (measure by retained stability) and resistant to crack propagation (indicated by indirect tensile strength of modified asphalt mixes).This approach of modification also produces better binding property for the bitumen mix and increase the road life (Chavan, 2013).

In recent years, research on the application of modified bitumen binders has reported lots of advantages. These advantages include improved bitumen resistance to rutting due to high viscosity, high softening point and better resilience, improved bitumen resistance to surface initiated cracks, the reduction of fatigue or reflection cracking, the reduction of temperature susceptibility, improved durability as well as the reduction in road pavement maintenance costs. A study on the thermal behaviour of polymers show that on heating at 130-160^{o}C, plastics such as Polyethylene (PE), Polypropylene (PP), and Polystyrene (PS) soften and exhibit good binding properties. As plastics are heated to a maximum temperature of 165^{o}C, there is no evolution of harmful gas. However, when heated above 270^{o}C, plastics get decomposed and above 750^{o}C, they get burnt to produce noxious gases (Amos, 2011).

Afroz et al (2012), in their research reveal that polymer modified bitumen shows improved rheological properties for highway construction. In the construction of flexible pavements, bitumen plays the role of binding the aggregates together by coating over the aggregates. The bitumen as a binder also helps to improve the strength and life of road pavements. But its resistance towards water is poor, whereas polymer modified bitumen has better resistance to temperature and water. (Zoorob & Suparma, 2000) reported the use of recycled plastics composed predominantly of low density polyethylene (LDPE) and polypropylene (PP) in conventional bituminous concrete mixtures with improved durability and fatigue life. Apurva & Chavan, (2013) in their research, showed that polymer-bitumen blend helps to have a better binding of bitumen with plastic coated aggregate due to increased bonding and increased area of contact between polymers and bitumen. The polymer coatings also reduce voids. This prevents the moisture absorption and oxidation of bitumen by entrapped air. This has resulted in reducing rutting, raveling and pothole formation.

Sreedevi & Salini, (2013) investigated pavement performance on roads surfaced using bituminous mixtures with coated aggregates and concluded that, the use of waste plastic for road construction can save the environment, increase the service life of roads, reduce the consumption of petroleum products and serve the society with additional income for those associated with it.

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

Murphy et al. (2001) examined the possibility of incorporating waste polymer into bitumen as a modifier, evaluated the performance of recycled modified bitumen and compare their properties with those of standard bitumen and polymer modified bitumen. They concluded polypropylenes are not useful in improving the properties of bitumen and displayed practical difficulties during mixing and testing, suggesting poor cohesion with bitumen.

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.

CHAPTER THREE

RESEARCH METHODOLOGY AND MATERIAL

3.1 Study Design

Experimental type of research was carried out to evaluate the properties of modified asphalt mix with HDPE and PET waste plastic with regards to suitability, economical and environmental based on ASTM, AASHTO and ERA standard. Qualitative study forwards impression of the findings whereas the quantitative study was used to describe the numerical aspects of the findings.

3.2 Source of Data

The data was collected from two sources, those primary data was collected from the laboratory investigation and secondary data was gathered from literatures review of previous studies on the subject matter, laboratory manuals and specification (ASTM, AASHTO and ERA).

3.3 Study variables

Dependent Variable:

- Plastic Modified bitumen

Independent Variable:

- Optimum Bitumen Content(OBC)
- Void Ratios
- Voids Filled with Bitumen (VFB)
- Void in Mineral Aggregate (VMA)
- Bulk Specific Gravity
- Marshal Stability
- Penetration Value
- Ductility Value
- Softening Point
- Optimum Plastic Content(OPC)

3.4 Sampling Procedure

Sampling of bitumen was undertaken as per ASTM standard in order to determine physical characteristics. Quartering method was used to obtain sample from aggregate. Harmful plastic waste were eliminated and clean water bottle waste plastic were used to reduce the effect of the content during the sampling procedure of this research.

3.5 Data Processing and Analysis

Processing and analysis of data carried out on this study was presented and explained using tables and graphs. Analysis was based on the outstanding and present specification suggested by ASTM, AASHTO and ERA.

3.6 Laboratory Test Procedure

This study is based on laboratory testing as the main procedure to achieve study objective. All the testing is conducted using equipment and devices available in the laboratories of AAiT and ERCC. Laboratory tests are divided into several stages, which begin with evaluation of the properties of used materials as aggregates, bitumen and waste plastics. Sieve analysis is carried out for each aggregate type to obtain the grading of aggregate sizes. After that, asphalt mixes with different bitumen contents are prepared and marshal test is conducted to obtain optimum bitumen content. The value of the optimum bitumen is used to prepare asphalt mixes modified with various percentages of waste plastic. Marshal Test was utilized to evaluate the properties of these modified mixes. Finally, laboratory tests results are obtained and analyzed.

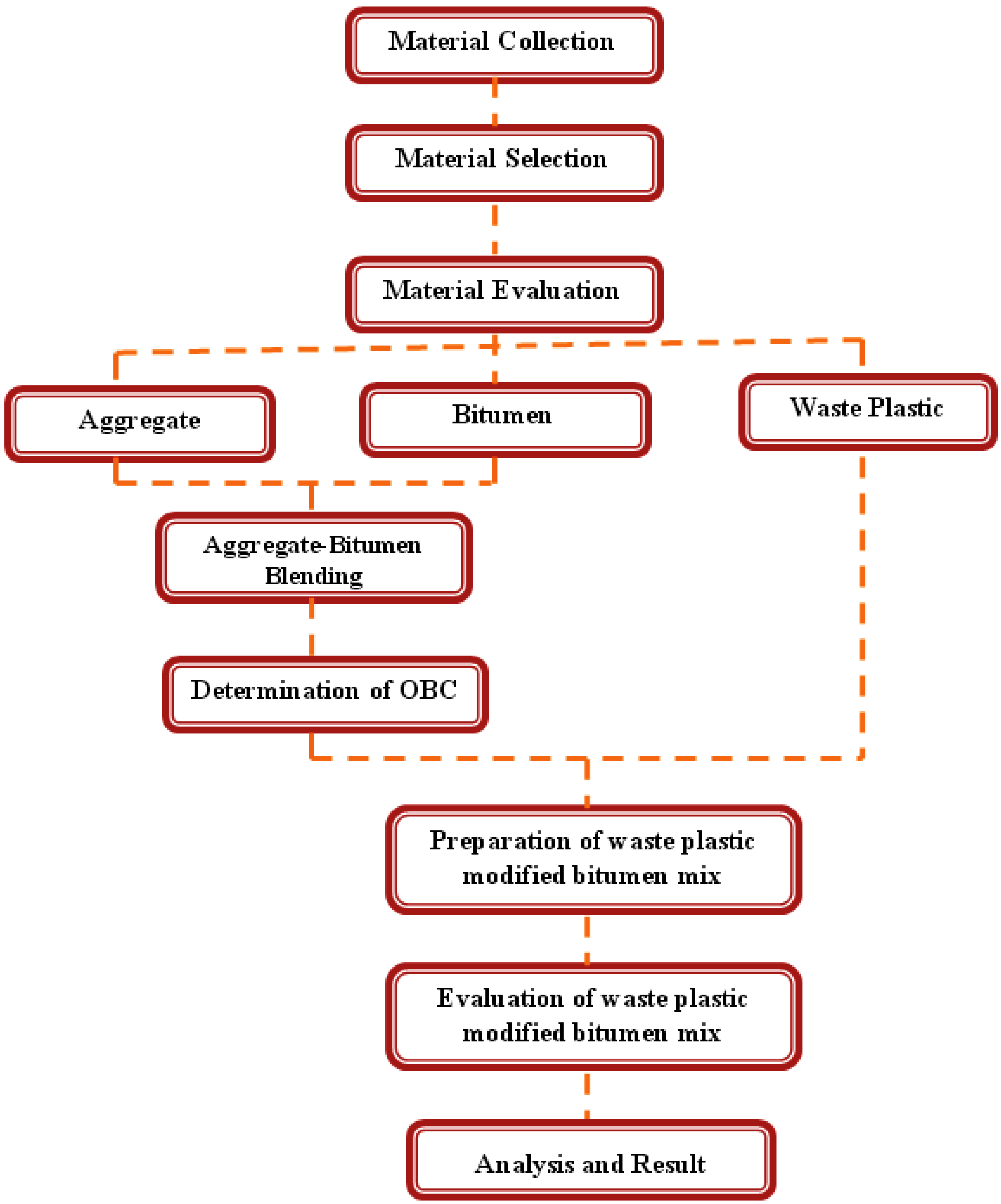

Figure 3- 1 Flow chart of Laboratory testing procedure

3.7 Materials Selection

Selection of material for conventional material is very important because, various material properties can influence the performance of the mix. While selecting the materials, engineering considerations which follow the specification were applied to ensure reliable result.

The materials selected for this study were collected from different sources, i.e. aggregate from Geom Luigi Varnero Impresa construction crusher quarry site and bitumen grade of 85/100 from Transport Construction and Design Enterprise (TCDE).

The materials used are as follows:-

Aggregates

Coarse aggregates

The aggregates retained on 4.75 mm sieve are called as coarse aggregates. Coarse aggregate should be screened crushed rock, angular in shape, free from dust particles, clay, vegetations and organic matters which offer compressive and shear strength and shows good interlocking properties. In present study, stone chips are used as coarse aggregate with specific gravity 2.75.

Fine aggregates

Fine aggregate should be clean screened quarry dusts and should be free from clay, loam, vegetation or organic matter. Fine aggregates, consisting of stone crusher dusts with fractions passing 4.75mm and retained on 0.075mm IS sieve. It fills the voids in the coarse aggregate and stiffens the binder. In this study, fine crushed stones are used as fine aggregate.

Mineral Filler

Aggregate passing through 0.075 mm IS sieve is called as filler. It fills the voids, stiffens the binder and offers permeability. In this study, stone dust are used as filler which consists of very fine, inert mineral matter that is added to the hot mix asphalt to increase the density and enhance strength of the mixture.

Bituminous Binder

Bitumen holds the aggregate together in a bituminous pavement. The quality of bitumen depends on its crude source, refining process and chemical composition. The characteristics of base bitumen affect the quality improvement of the modified bitumen. In this research 85/100 penetrations grade bitumen is used.

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 waste plastic polythenethe (PET) and high density polythene (HDPE) are selected as a modifier.

Table 3- 1 Amount of Used Raw Materials

Plastic Type	%of Plastic	Specimen	Weight of Plastic in gram	Weight of Bitumen in gram	Weight of Aggregate in gram
No Plastic	0	A	0	61.2	1200
		B	0	61.2	1200
		C	0	61.2	1200
PET	6	A	3.67	57.53	1200
		B	3.67	57.53	1200
		C	3.67	57.53	1200
	9	A	5.51	55.69	1200
		B	5.51	55.69	1200
		C	5.51	55.69	1200
	12	A	7.34	53.86	1200
		B	7.34	53.86	1200
		C	7.34	53.86	1200
	15	A	9.18	52.02	1200
		B	9.18	52.02	1200
		C	9.18	52.02	1200
Total			**77.10**	**840.90**	
HDPE	6	A	3.67	57.53	1200
		B	3.67	57.53	1200
		C	3.67	57.53	1200
	9	A	5.51	55.69	1200
		B	5.51	55.69	1200
		C	5.51	55.69	1200
	12	A	7.34	53.86	1200
		B	7.34	53.86	1200
		C	7.34	53.86	1200
	15	A	9.18	52.02	1200
		B	9.18	52.02	1200
		C	9.18	52.02	1200
Total			**77.10**	**840.90**	

3.8 Preparation of Modified Asphalt Mix

There are many different methods for utilization of waste polymer materials in asphalt mix. In this study dry process method was used for the asphalt mix in order to attain the objective of the study. After obtaining OBC, samples were prepared to evaluate the effect of adding waste plastic to asphalt mixture samples by considering four proportions (6%, 9%, 12% and 15%) by the weight of OBC.

The procedure of incorporating waste plastic in asphalt mix can be summarized as follows:

a. Waste plastic have to be grinded then sieved to have a granular size not more 4.75mm.

b. Requisite amount of grinded waste plastic is mixed with course aggregates. Waste plastic and course aggregates mix is heated at (180^{o}C-190^{o}C). The heating temperature and duration of aggregates were chosen based on many experimental trials to be hot enough to melt waste plastic that it would stick to the aggregate surfaces and leave textured surface with good adhesion between coated aggregates.

c. Fine aggregates are heated at the same temperature for the same period as in part (b) but in separated pan. Experimental trials show that it's better to separate fine aggregates from mix in part (b) when heating because they would form an insulating layer coating melted plastic which may weaken adhesion between course aggregates and melted plastics.

d. Requisite amount of bitumen is heated until it reaches 150^{o}C.

e. Waste plastic and course aggregates are mixed with fine aggregates followed by addition of hot bitumen at OBC. All ingredients are mixed vigorously to form a homogeneous asphalt mixture.

f. After preparing modified asphalt mix, specimens are prepared, compacted, and tested according to standard Marshal Method designated as ASTM D 1559-89.

(Roberts et al., 1996):

CHAPTER FOUR

RESULTS AND DISCUSSIONS

Results of laboratory work were obtained and analyzed to achieve the study objectives which include studying the effect of adding different percentages of waste plastic on the Marshal properties of asphalt mix and identify the optimum percent of waste plastic to be added to hot mix asphalt in order to modify bitumen binder.

The laboratory work results are presented in three stages. First, the results of gradation of blending aggregates is determine to obtain asphalt binder course gradation curve. Second stage, Marshal Test is carried out with different percentages of bitumen which are (4.5, 5.0, 5.5 and 6.0%) and the results are analyzed in order to obtain the optimum bitumen content (OBC). After obtaining OBC, the following step is used to study the effect of adding different percentages of waste plastic on asphalt mix properties which are 6,9,12 & 15% by the weight of OBC. Marshal test results for modified asphalt mixes are analyzed and finally the optimum waste plastic modifier content is obtained.

All of the tests are performed following the ASTM/AASHTO/ERA designation. In order to obtain representative results, all the tests are carried out as preciously as possible following the standards test procedures. Due to some instrumental constraint or problems a few tests may shown inconsistent results.

4.1 Material Property Test Result

4.1.1 Aggregate Gradation

The aggregates used in the research were subjected to various tests in order to assess their physical characteristics and suitability in the road construction. Asphalt mix requires the combination of fine and course aggregates, having different gradations, to produce an aggregate blend that meets gradation specifications for a particular asphalt mix. The final proportion of each aggregate material in asphalt binder course is shown in Figure 4.1. The proposed aggregates gradation curve is found to be satisfying ASTM 3515 specification for asphalt binder course gradation.

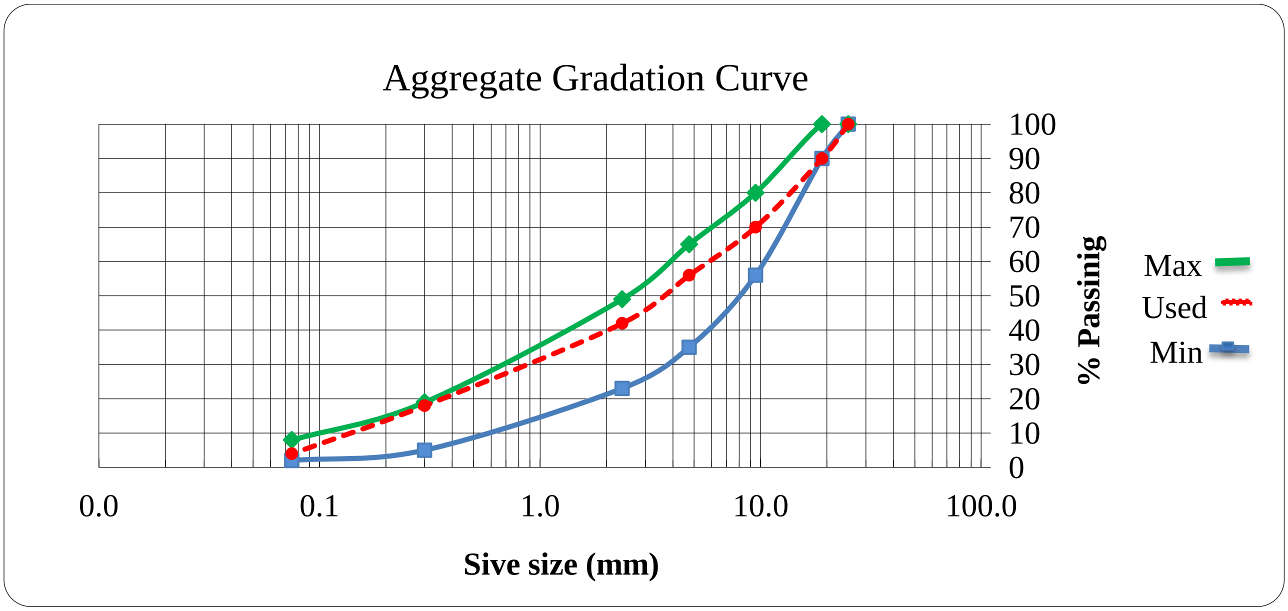

Figure 4- 1 Gradation of Aggregate mix with ASTM 3515 Specification Range

This graph shows the aggregate gradation curve of used aggregate (fine and coarse) which satisfy the ASTM 3515 specification for asphalt mix.

4.1.2 Bitumen Property Test

In order to evaluate bitumen properties, numbers of laboratory tests were performed (such as penetration value, ductility, softening point, loss on heat and specific gravity).

Bitumen 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 as per test specification of ASTM D5-95

Table 4-1 Penetration Test Result of Bitumen (mm)

Trial	Sample 1			Sample 2		
	A	B	C	A	B	C
Initial (0.1mm)	0	0	0	0	0	0
Final(0.1mm)	96	98	95	94	94	97
Penetration Value(0.1mm)	96	98	95	94	94	97
Each trial Average	96.33			95.00		
Sample Average	95.67					

Bitumen 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. Used test Specification ASTMD 113-86

Table 4-2 Ductility Test Result

Sample	Ductility(cm)
A	117
B	113
C	116
Average Value	115.3

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 (ethylene glycol) at 25mm 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 .Test Specification ASTMD 36-2002

Table 4-3. Softening Point Test Result

Sample	Softening Point (^{o}C)
A	49
B	48.6
Average	48.8

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.

Test specification: ASTMD D70

Table 4-4. Specific Gravity Test Results

Weight of sample (gm)	30
Weight of Pycnometer + water at 25.C (gm)	1684.36
Weight of Pycnometer + water at 25.C + Sample (gm)	1684.92

$$\textbf{Specific Gravity (S.G)} = \frac{\textbf{Wt of Sample in air}}{\textbf{Wt of in air} - \textbf{Wt in Water}}$$

Equation 4- 1

$$\text{SG} = \frac{30}{(1684.36+30)-1684.92} = 1.02g/cm^3$$

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 oven, cooled to a room temperature and weighed again. The loss on heating is calculated as follows:-

% loss = [(A-B)/A´]* 100

Equation 4- 2

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

Table 4- 5. Summary of Bitumen Properties Result with Specification

Test Type	Specification	Results	ASTM specifications limits
Penetration (0.01 mm)	ASTM D5-06	95.67	85-100 (85/100 binder grade)
Ductility (cm)	ASTM D113-86	115.3	Min 100
Softening point (°C)	ASTMD36-2002	48.8	(45 – 52)
Loss on Heating Test (%)	ASTM D92-90	0.03	Max 0.5
Specific gravity (g/cm^3)	ASTMD D70	1.02	0.97-1.06

4.1.3 Waste Plastic

The plastic waste used in this study was derived from the different types and sizes of bottles which are used to contain liquid products such as mineral water and cooking oil. Those plastics are free from dust and toxic and they are waste which were collected from households, hotels, and cafeteria and so on. They were washed and cleaned by putting them in hot water for 2-3hours. They were then dried.

The dried plastic was cut into tiny pieces of size not greater than 4.75mm. This is because when the plastic is to be added with bitumen and aggregate it is to be ensured that the mixing will be proper. The smaller the size of the plastic, the more is the chance of good mixing.

Figure 4- 2 Used Shredded Plastic Waste

4.2Marshal Test to Determine Optimum Bitumen Content (OBC)

Marshal Mix Design method was used to determine the optimum bitumen content and evaluate the stability of the mixtures in the laboratory. According to standard 75-blow Marshal design method designated as (ASTM D 1559-89) a number of 12 samples each of 1200gm in weight were prepared using four different bitumen contents (from 4.5 - 6% with 0.5 % incremental). Three samples were used to prepare asphalt mixture with specific bitumen content to have an average value of maximum Marshal Stability, maximum bulk density and median percent of air voids. (AASHTO R-12)

Figure 4- 3 Marshal Specimens with different bitumen content

Marshall Properties of the asphalt mix such as stability, flow, density, air voids in total mix, and voids filled with bitumen (VFB) percentage are obtained for various bitumen contents. The following parameters are analyzed to obtain optimum bitumen content.:

- Stability vs. Bitumen Content;
- Flow vs. Bitumen Content;
- Bulk Specific Gravity vs. bitumen Content;
- Air voids (Va) vs. Bitumen Content;
- Voids Filled with Bitumen (VFB) vs. Bitumen Content

The optimum bitumen content (OBC) for proposed mix is the average of three values of bitumen content (Jendia, 2000), which include:

a) Bitumen content at the highest stability $(\% m_b)_{Stability}$
b) Bitumen content at the highest value of bulk density $(\% m_b)_{bulk\ density}$
c) Bitumen content at the median of allowed percentages of air voids (Va = 3-5%) $(\% m_b)_{Va}$

Marshal graphs are utilized to obtain these three values. (Jendia, 2000)

$$\text{Optimum bitumen content (OBC) \%} = \frac{(\%\text{Mb})_{\text{Stability}} + (\%\text{Mb})_{\text{bulk density}} + (\%\text{Mb})_{\text{Va}}}{3}$$

Equation 4- 3

Properties of the asphalt mix using optimum bitumen content such as stability, flow, Va, bulk density and VMA are obtained and checked against specifications range.

4.3 Effect of Waste Plastic on Bitumen Property

Unmodified and waste plastic modified bitumen 85/100 was tested for the following properties and the obtained result is summarized in Table 4.8 and Table 4.9. Wet process of mixing procedure was adopted for waste plastic bitumen mix property test and waste plastic of 6%, 9%, 12% and 15% by weight of optimum bitumen content were mixed and mixture was blended for an hour and the temperature was maintained 180-190^{0}C, empirical test like penetration, softening, ductility and loss on heat were performed for modified bitumen and the process was repeated for all various percentage of quantities.

4.3.1 Effect of Waste Plastic on Penetration

The effect of waste plastic (both PET and HDPE) on penetration is shown in Fig. 4.4. There is general trend of decreasing penetration value with increase in plastic concentration in bitumen.

This is good in one sense since it might improve the rutting resistance of the mix.

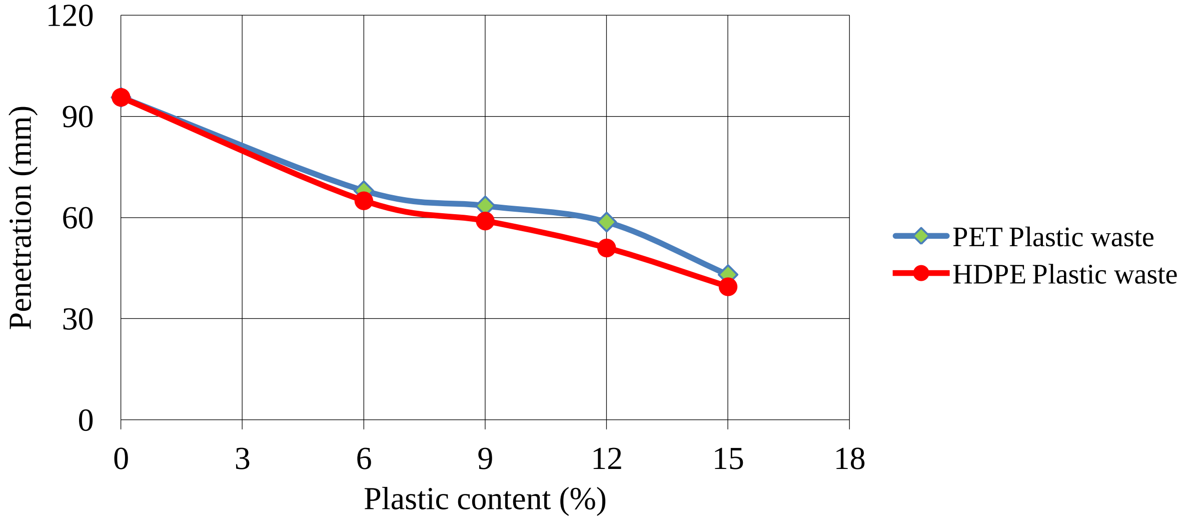

Figure 4- 4 Penetration Value of PMB with different % plastic content

Figure 4-4 shows that, the variation of penetration value with the various percentages of bitumen modified PET and HDPE decreases with the addition of both plastic. This means that the addition of plastic waste makes the modified bitumen harder and more consistent. This is good in one sense since it might improve the rutting resistance of the mix, but on the other hand this may affect flexibility. Punith, V.S (2010) in similar study identified that penetration decrease in value by plastic content increase. This increment of plastic should be consider the optimum level of flexibility, it shouldn't affect the flexibility the matrial.

4.3.2 Effect of Waste Plastic on Softening Point

Softening Point is a measure of temperature susceptibility and a measure of flow of bitumen in service. The test was performed in accordance with ASTM D36. It is a form of consistency test that determines the melting point of bitumen and is used for control in refining operation. The test for determining softening point is called Ball-and-ring / Softening point test.

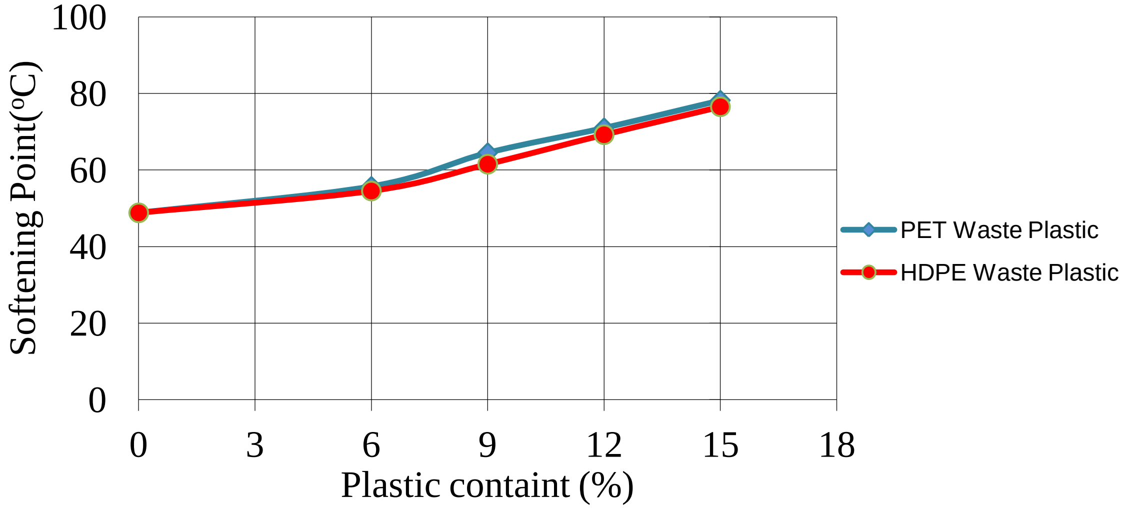

Figure 4- 5 Softening Point of PMB with different % plastic content

As plastic content increases consistency of the binder, higher temperature will be required to make the modified binder soft. It can be calculated that addition of 12% waste plastic with the virgin binder, softening point has increased by about 28% (HDPE) and 24%(PET) of modified bitumen . It indicates that temperature susceptibility of binder significantly decreases with waste plastic content.

In a similar study Punith, V.S; (2010) identified that softening point increase and penetration decrease in value by plastic content increase.

4.3.3 Effect of Waste Plastic on Ductility

The Ductility test is an empirical test which measures the cohesive strength of bitumen and its ability to stretch. The test was conducted as per ASTM D113

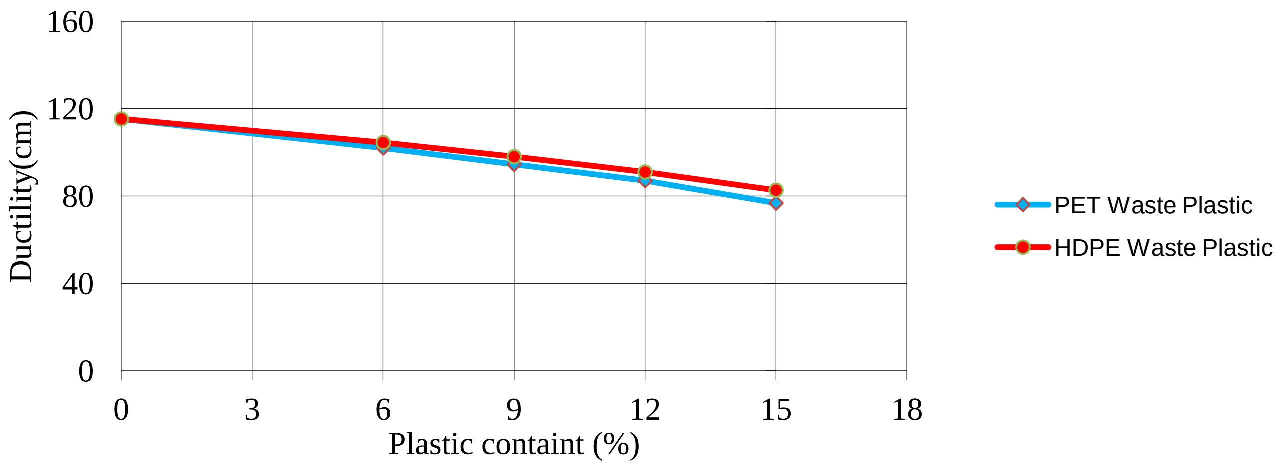

Figure 4- 6 Ductility Value of PMB with different %of plastic content

The result indicate that ductility sharply decrease with the increase of waste plastic content in both type of plastic 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. (Justo et al ; 2002)

4.3.4 Effect of Waste Plastic on Loss on Heating

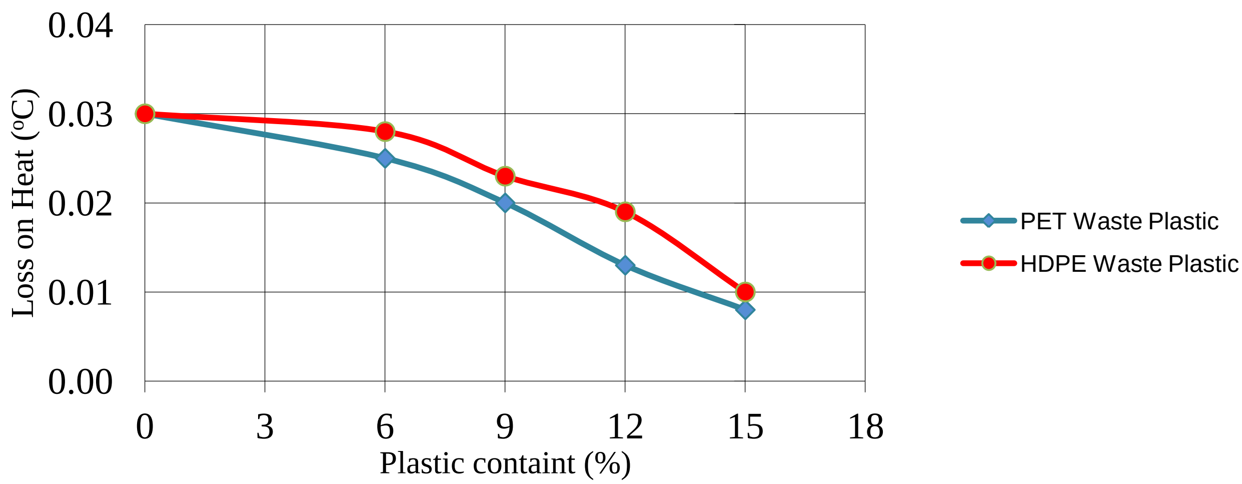

Figure 4-7 Loss on Heat Result

Table 4 - 6. Summary of HDPE Plastic Modified Bitumen Physical Property Result

Bitumen Characteristic	Test Method	Unit	Waste Plastic Content					Specification	
			0%	HDPE					
				6%	9%	12%	15%	Min	Max
Penetration at 25 °C, 100g, 5s	ASTM D5	mm	95.6	72	61.5	52	43.1	85	100
Softening Point	ASTM D36	°C	48.8	53.5	59	65	76.5	45	52
Ductility at 25 °C	ASTM D113	cm	115.3	104.5	98	91	82.7	100	-
Loss on heating	ASTM D6	°C	0.03	0.028	0.026	0.021	0.010	-	0.05
Specific Gravity at 25 °C	ASTM D71	%	1.02	1.015	1.013	1.01	0.99	1.001	1.05

Table 4 -7 Summary of PET Plastic Modified Bitumen Physical Property Result

Bitumen Characteristic	Test Method	Unit	Waste Plastic Content					Specification	
			0%	PET					
				6%	9%	12%	15%		
Penetration at 25 °C, 100g, 5s	ASTM D5	mm	95.6	78	69	59.5	43.1	85	100
Softening Point	ASTM D36	°C	48.8	58.7	63.5	68	78.2	45	52
Ductility at 25 °C	ASTM D113	cm	115.3	102	94.5	87	76.8	100	-
Loss on heating	ASTM D6	°C	0.03	0.025	0.02	0.013	0.008	-	0.05
Specific Gravity at 25 °C	ASTM D71	%	1.02	1.033	1.041	1.05	1.063	1.001	1.05

4.4-Effect of Waste Plastic on Marshal Properties of Bituminous Mixtures

4.4.1-Marshal Stability and Flow Test

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. 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. The Marshall tests were conducted on compacted specimens to find stability and flow values of different mixes.

Table 4- 8 Mechanical Properties of Normal Asphalt mix

S.No.	Bitumen% (By total weight)	Stability (Kg)	Flow (mm)	ρA(g/cm^3)	V_a(%)	V_b (%)	VMA (%)	VFB (%)
1	5.1	800	2.71	2.40	2.4%	11.85%	14.26%	83%
2	5.1	935	3.50	2.43	3.0%	11.78%	14.78%	80%
3	5.1	991	3.35	2.45	3.8%	11.69%	15.47%	76%
Aveg	5.1	901	3.19	2.42	3.1%	11.77%	14.84%	79%

4.4.2-Effect of Plastic on Marshal Stability

Stability is the maximum load required to produce failure of the specimen when load is applied at constant rate 50 mm/min. In Figure (4.6) stability of asphalt mix increases as the plastic content increase till it reaches the peak at plastic bitumen content 9% for PET plastic and then it started to decline gradually but HDPE modified mix stability increase till it reaches to 12%

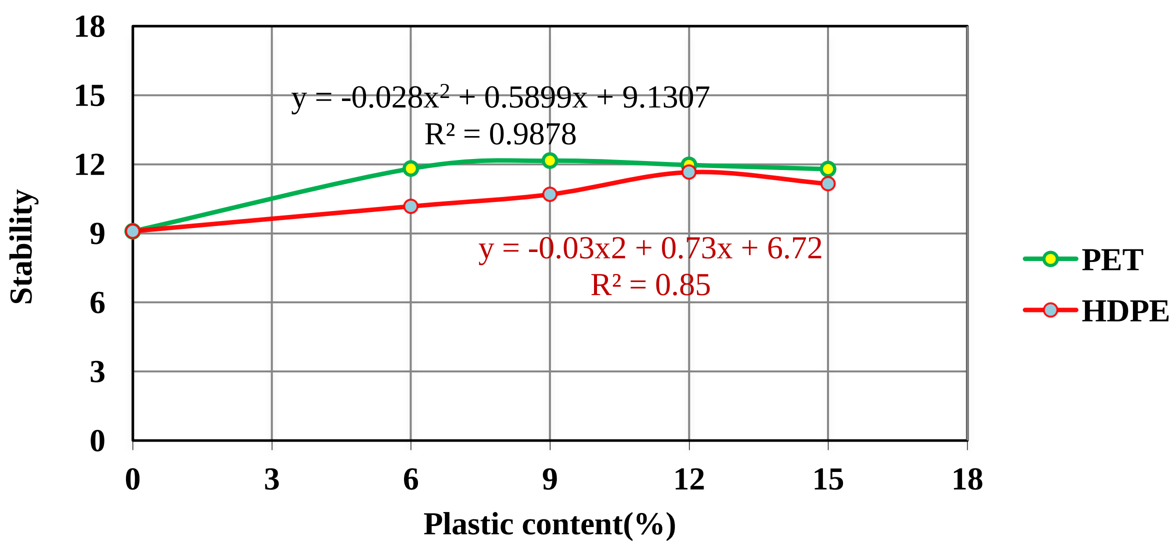

Figure 4- 8 Stability Vs Plastic Content Graph

In a similar study Mohammad T. Awwad et al (2007),he recommended proportion of the HDPE modifier should 12% by the weight of bitumen content. It is found to increase the stability.

4.4.3-Effect of Plastic on Flow

Flow is the total amount of deformation which occurs at maximum load. In Figure (4.9) Flow results for different plastic contents are represented. In both plastic flow of asphalt mix increases as the plastic content increase till it reaches the peak at the max plastic content percentage.

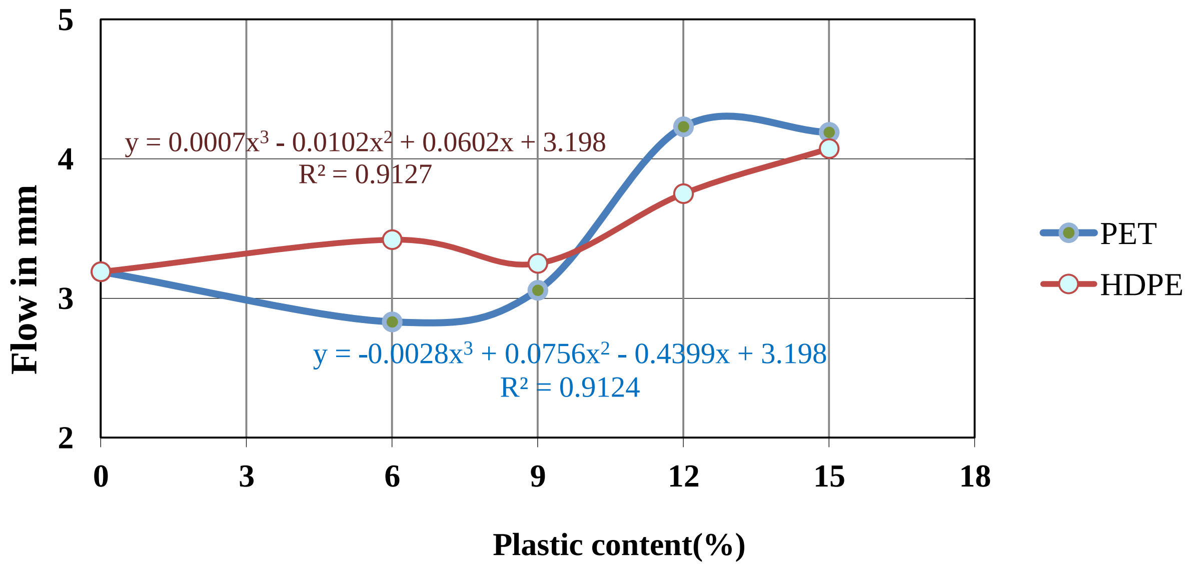

Figure 4- 9 Flow Vs Plastic Content Graph

4.4.4-Effect of Plastic on Bulk Density

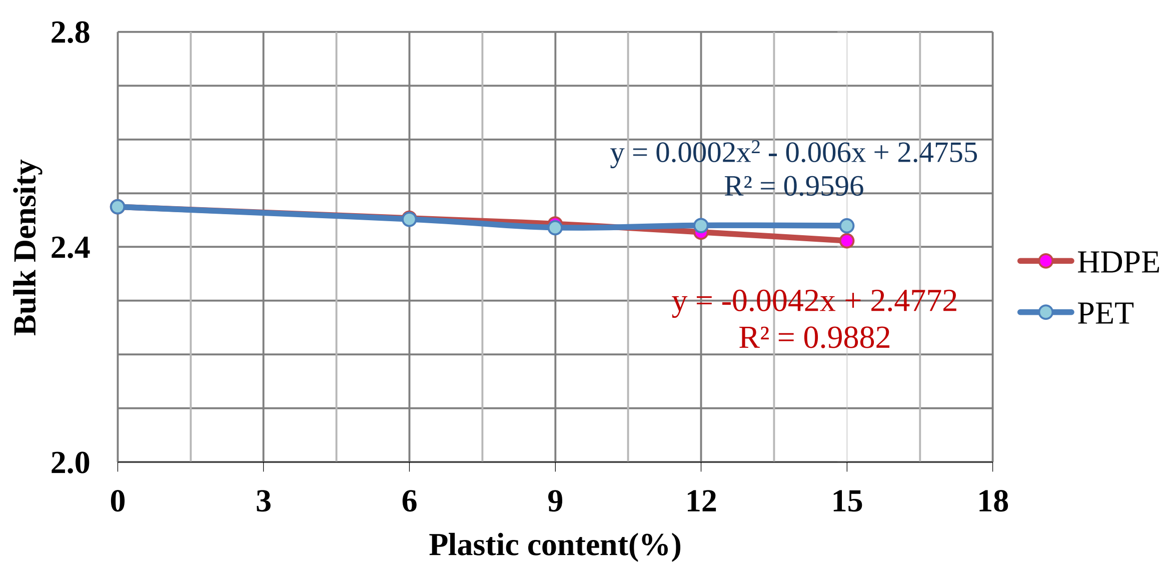

Figure 4- 10 Bulk Density VS Plastic Content Graph

4.4.5-Effect of Waste Plastic on Air Void (Va)

Total void in the mix refers that the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as percent of bulk volume of compacted paving mixture

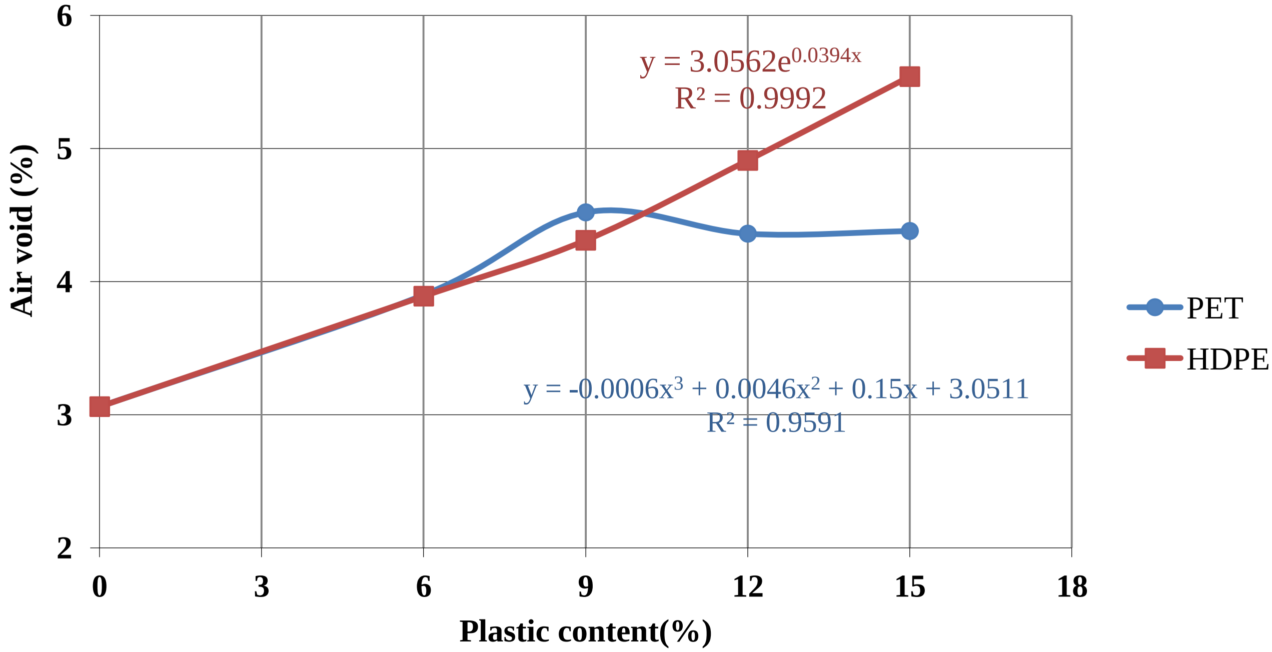

Figure 4- 11 Air Void vs Plastic Content

4.4.6-Effect of Waste Plastic on Voids in Mineral Aggregate (VMA)

The effect of different binders on voids in mineral aggregate was also evaluated and the result are shown in Figure 4-8. Minimum VMA is necessary in mixture to accommodate enough asphalt content. Voids in Mineral Aggregates (VMA) is the percentage of voids volume of the in the aggregates before adding bitumen or the sum of the percentage of voids filled with bitumen and percentage of air voids remaining in asphalt mix after compaction (Jendia,2000).

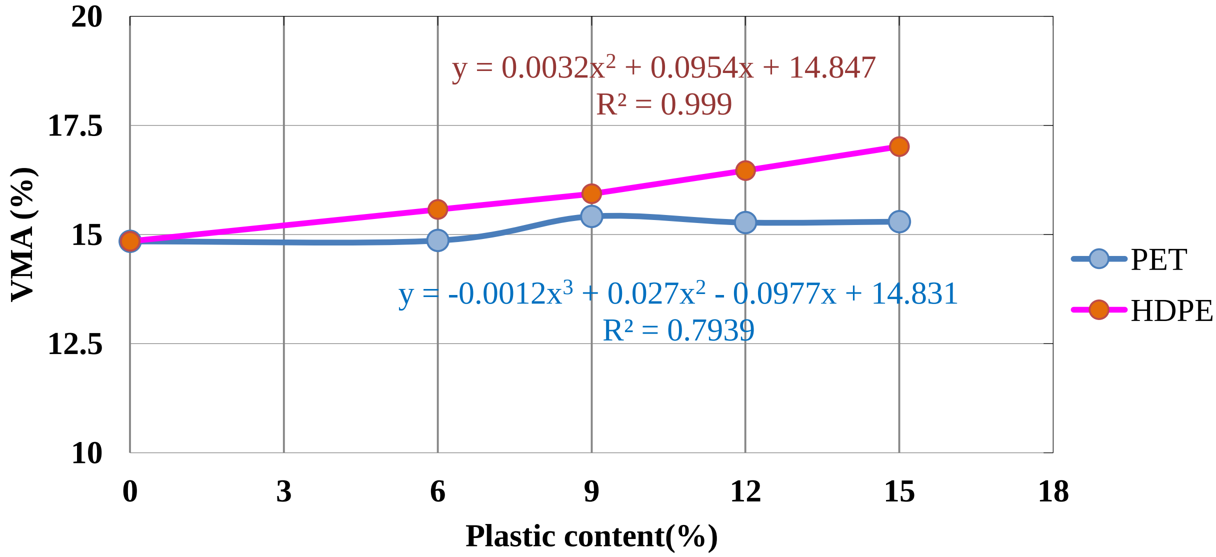

Figure 4- 12 VMA vs. Plastic content graph

4.4.7-Effect of Waste Plastic on Voids Filled with Bitumen (VFB)

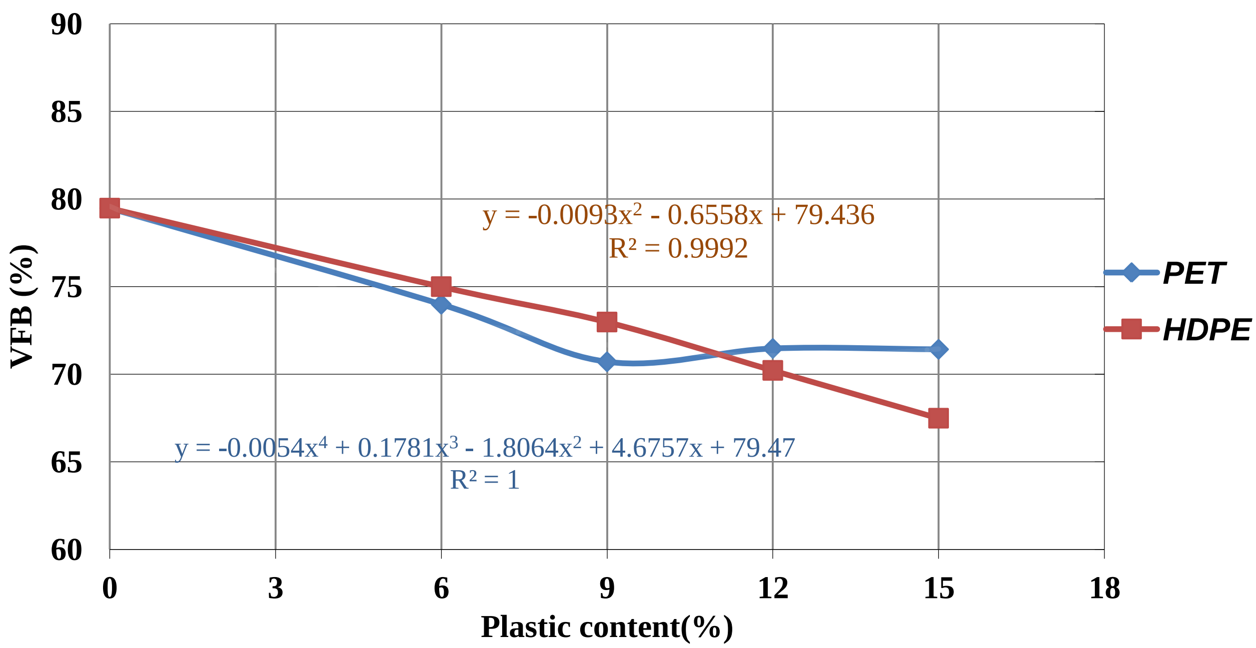

Figure 4- 13 VFB vs. Plastic content

Table 4 - 9 Mechanical Property of Modified Asphalt mix

S.N	Plastic (%)		Stability(Kg)	Flow(mm)	ρA(g/cm^3)	Va(%)	Vb (%)	VMA(%)	VFB(%)
1		0	909	3.19	2.47	3.06	11.77	14.84	79.47
2	HDPE	6	1017	3.42	2.45	3.98	11.67	15.57	74.99
3		9	1069	3.25	2.44	4.31	11.62	15.93	72.97
4		12	1166	3.75	2.43	4.91	11.55	16.46	70.21
5		15	1115	4.07	2.41	5.54	11.47	17.01	67.48
6	PET	6	1181	2.83	2.45	3.90	10.96	14.86	73.98
7		9	1216	3.06	2.44	4.52	10.89	15.41	70.70
8		12	1197	4.23	2.44	4.36	10.91	15.27	71.46
9		15	1179	4.19	2.44	4.38	10.91	15.29	71.41

4.5-Optimum Waste Plastic Content

The optimum modifier content is selected as the specimen satisfies the following characteristic:

Table 4 10 Major characteristics of Plastic Modified Bitumen

	Conventional Bitumen	*Plastic Type*	
		HDPE Modified	*PET Modified*
Maximum Marshall Stability	909	1166 (at 12%)	1216 (at 9%)
Maximum Bulk Density	*247*	*2.45(at 6%)*	*2.45(at 6%)*
Median of allowed percentages of air voids (Va = 3-5%)	*306*	*3.98 (6%)*	*3.90 (6%)*
Optimum Modified bitumen content		*=(12+6+6)/3 = 8%*	*=(9+6+6)/3 = 7%*

$$\text{Optimum Modified bitumen content \%} = \frac{(\%\text{Mb})_{\text{Stability}} + (\%\text{Mb})_{\text{bulk density}} + (\%\text{Mb})_{\text{Va}}}{3}$$

$(\% \, m_b)_{Stability}$ = Plastic Bitumen content at the highest stability

$(\% \, m_b)_{bulk\ density}$ = Plastic Bitumen content at the highest value of bulk density

$(\% \, m_b)_{Va}$ = Plastic Bitumen content at the median of allowed percentages of air voids (Va = 3-5%)

To have a uniform practice on the determination of optimum binder content, it is necessary to determine the optimum asphalt content to beat a balance between density, stability and % air void, percent air voids of 4.0 is considered optimum.(Roberts et al., 1996)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The use of such innovative technology is not only strengthened the road construction but also it will help to improve the environment and also creating a job opportunity. It is hoped that in near future we will have strong, durable and eco-friendly roads which will relieve the earth from plastic waste. The physical properties such as penetration decreased with the increase of plastic waste percentage, this means that the addition of plastic waste makes the modified bitumen harder and more consistent. This is good in one sense since it might improve the rutting resistance of the mix. But the softening point increase with the addition of plastic additive to bitumen. This increment will alleviate the bleeding problem that characterized high tropical climate.

The experimental work while comparing the performance of conventional asphalt mixtures and plastic modified asphalt mixtures, plastic modified bitumen has increased softening point. This phenomenon indicates that the resistance of the binder to the effect of heat is increased and it will reduce its tendency to soften in hot weather. Thus, with the addition of plastic the modified binder will be less susceptible to temperature changes.

The effect of waste plastic on strength and stability indicates that the values of the stability and the values of flow, VFB, VMA decrease these results indicate that the modifier HDPE & PET improves the properties of asphalt and asphalt mixture.

The optimum modifier content was found to be 8% of waste plastic (HDPE) and 7% of waste plastic (PET). The Marshall stability of the mix with addition of 12% HDPE plastics and 9% PET plastic modified bitumen is higher (22.1% HDPE and 25.25% PET) than the mix without plastics in one of the case study.

From an environmental and economic standpoint, the use of waste plastic, as a bitumen modifying agent may contribute to solving a waste disposal problem and to improving the quality of road pavements.

In general, this investigation not only utilizes beneficially, the waste non-degradable plastics but also provides us an improved pavement with better strength and longer life period and also create a source of job opportunity

5.2-RECOMMENDATIONS

- This technology is not well understood and used in our country, therefore Government agencies like ERA and ERCC should come up with at least one comprehensive project of processing waste plastics and constructing roads using the waste plastic modified bituminous mix.
- the researcher believes that further studies is recommended to evaluate the effect of aging on PET and HDPE-modified asphalt binders, the effect of PET & HDPE on the fatigue behaviour of the asphalt binder, and Dynamic Shear Rheometer (DSR) to study the low , medium and high temperature cracking stiffness.
- It is recommended to conduct similar studies on the wearing course layer of asphalt pavement and recommended for incorporating other waste plastic materials in asphalt mix such as plastics formed from Polypropylene (PP) and Polystyrene (PS) which widely used in construction.

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Appendix A

Physical Properties of Aggregates and Modified Bitumen

Laboratory Results of Physical Properties of Aggregates Quality Test

Properties Tested	Test Result	Specification
Specific gravity		
Coarse aggregate	2.71	2.5-3.0
Fine aggregate	2.83	2.5-3.0
Water Absorption Test	1.41%	Max 2%
Impact Value Test	17%	Max 24%
Los Angeles abrasion value Test	18.38%	Max 30%
Flakiness index	25%	Max 45%

Laboratory Results Summary of Physical Properties of Modified Bitumen

% of waste plastic	Penetration (in mm)		Ductility (in cm)		Softening Point(^{o}C)		Loss on Heat (%)	
	PET	HDPE	PET	HDPE	PET	HDPE	PET	HDPE
0	95.7	95.7	115.3	115.3	48.8	48.8	0.030	0.030
6	68.0	65.0	102.0	104.5	55.7	54.5	0.025	0.028
9	63.5	59.0	94.5	98.0	64.5	61.5	0.020	0.023
12	58.7	51.0	87.0	91.0	71.0	69.2	0.013	0.019
15	43.1	39.5	76.8	82.7	78.2	76.5	0.008	0.010

Appendix B

Marshal Test Result

Used Equations to calculate the mechanical properties of asphalt mix

Bulk specific gravity (Gm) =A/(B−C)

Where Gm = bulk specific gravity of compacted specimen

A = mass of the dry specimen in air,

B = mass of the saturated surface-dry specimen in air, and

C = mass of the specimen in water

Air void content, Va = 1−(Gmb/Gmm)

Where Va = Air void content, volume %

Gm =Bulk specific gravity of compacted mixture

Gt =Theoretical maximum specific gravity of loose mixture

Voids in the mineral aggregate, VMA= Va-Vbe

Where VMA =Voids in the mineral aggregate, % by total mixture volume

Va = Air void content, % by total mixture volume

Vbe = Effective binder content, % by total mixture volume

Marshal Tests Results

Conventional Mix Waste Plastic = 0% Bitumen = 5.1 % (By total weight)

Description	Asphalt Binding course
Location	AAiT Highway Lab
Date tested	29/04/2017
Tested by	Andinet Bekele

Source	TCDE
Grade	85/100
No of Blow	2*75

S/N	Wt in Air	Wt in Water	SSD	Volume	Density (Gm)	Theoretical Specific Gravity (Gt)	Vb (%)	Vv (%)	VMA (%)	VFB (%)	Stabilit y	Flow Value
1	1213	726.5	1218	487	2.49	2.55	11.85	2.40	14.26	83.1 6	8.00	2.71
2	1260	751.5	1261	509	2.48	2.55	11.78	3.00	14.78	79.6 9	9.35	3.50
3	1229	729	1230	500	2.46	2.55	11.69	3.78	15.47	75.5 5	9.91	3.35
Ave rg	1234	735.6	1236	498	2.47	2.55	11.77	3.06	14.84	79.4 7	9.09	3.19

Vb: Percent bitumen volume.

VFB: Voids filled with bitumen

Vv: Air voids contents in total mix.

VMA: Voids in mineral Aggregates

Bitumen Mix with HDPE Waste Plastic 6%-15%

Description	Asphalt Binding course
Location	ERCC Highway Lab
Date tested	23/05/2017
Tested by	Andinet Bekele

Source	TCDE
Grade	85/100
No of Blow	2*75

S/N	Plastic content	Wt in Air	Wt in Water	SSD	Volume	Density (Gm)	Vb	Vv	VMA	VFB	Stability	Flow Value
1	6%	1232	729	1236	503	2.45	11.66%	4.01%	15.67%	74%	10.07	4.10
2		1234	731	1238	503	2.45	11.68%	3.85%	15.53%	75%	10.33	2.94
3		1243	737	1237.5	506	2.46	11.68%	3.82%	15.50%	75%	10.11	3.22
4	9%	1244	732	1233.2	512	2.43	11.56%	4.83%	16.39%	71%	11.01	2.31
5		1239	733	1235.5	505.6	2.45	11.66%	4.02%	15.67%	74%	11.12	3.90
6		1232.2	729	1233.5	503.2	2.45	11.65%	4.09%	15.74%	74%	9.95	3.54
7	12%	1252	734	1260.5	518	2.42	11.50%	5.33%	16.83%	68%	12.54	3.45
8		1245	731	1236.5	513.5	2.42	11.53%	5.07%	16.60%	69%	11.95	3.60
9		1245	735	1239.0	509.5	2.44	11.62%	4.33%	15.95%	73%	10.49	4.20
10	15%	1249	728	1251	521	2.40	11.40%	6.10%	17.51%	65%	11.25	4.12
11		1243	729	1254	514	2.42	11.50%	5.28%	16.78%	69%	11.31	3.90
12		1246	731	1248.0	515	2.42	11.51%	5.24%	16.75%	69%	10.90	4.20

Bitumen Mix with PET Waste Plastic 6%-15%

Description	Asphalt Binding course
Location	ERCC Highway Lab
Date tested	24/05/2017
Tested by	Andinet Bekele

Source	TCDE
Grade	85/100
No of Blow	2*75

S/N	Plastic content	Wt in Air	Wt in Water	SSD	Volume	Density (Gm)	Vb	Vv	VMA	VFB	Stability	Flow Value
1	6	1253	744	1254.3	509	2.46	11.0%	3.5%	14.52%	76%	11.56	2.8
2		1242	729	1242	513	2.42	10.8%	5.1%	15.93%	68%	12.2	2.83
3		1246	742	1249.3	504	2.47	11.1%	3.1%	14.15%	78%	11.68	2.86
4	9	1256.2	739	1257.7	517.2	2.429	10.9%	4.8%	15.66%	69%	11.97	3.06
5		1258.9	743	1261.6	515.9	2.44	10.9%	4.3%	15.26%	71%	12.72	3.1
6		1256	741	1258.2	515	2.44	10.9%	4.4%	15.31%	71%	11.78	3.01
7	12	1247	735	1249	512	2.44	10.9%	4.5%	15.42%	71%	12.10	4.21
8		1256	742	1258	513.9	2.44	10.9%	4.2%	15.14%	72%	11.99	4.25
9		1252	739	1253.4	513	2.44	10.9%	4.3%	15.25%	72%	11.82	4.23
10	15	1250	738	1255	512	2.44	10.9%	4.3%	15.22%	72%	11.56	4.27
11		1248	734	1257	514	2.43	10.9%	4.8%	15.69%	69%	11.89	4.17
12		1254	742	1258	512	2.45	11.0%	4.0%	14.95%	73%	11.92	4.13

Marshal Tests Results

(on obtained Optimum Plastic Modifier Content)

Description	Asphalt Binding course
Location	ERCC Highway Lab
Date tested	30/05/2017
Tested by	Andinet Bekele

Source	TCDE
Grade	85/100
No of Blow	2*75

HDPE (8%)

S/N	Wt in Air	Wt in Water	SSD	Volume	Density (Gm)	Theoretical Specific Gravity (Gt)	Vb (%)	Vv (%)	VMA (%)	VFB (%)	Stability	Flow Value
1	1249	748	1251	501	2.44	2.55	11.15%	2.28%	13.43%	83.02%	11.12	4.01
2	1243	738	1254	505	2.46	2.56	11.01%	3.52%	14.53%	75.77%	11.39	4.19
3	1246	729	1256	517	2.41	2.54	10.78%	5.53%	16.31%	66.08%	11.81	4.35
Averg	1246	738.3	1253.7	507.7	2.44	2.55	10.98%	3.78%	14.75%	74.96%	11.44	4.18

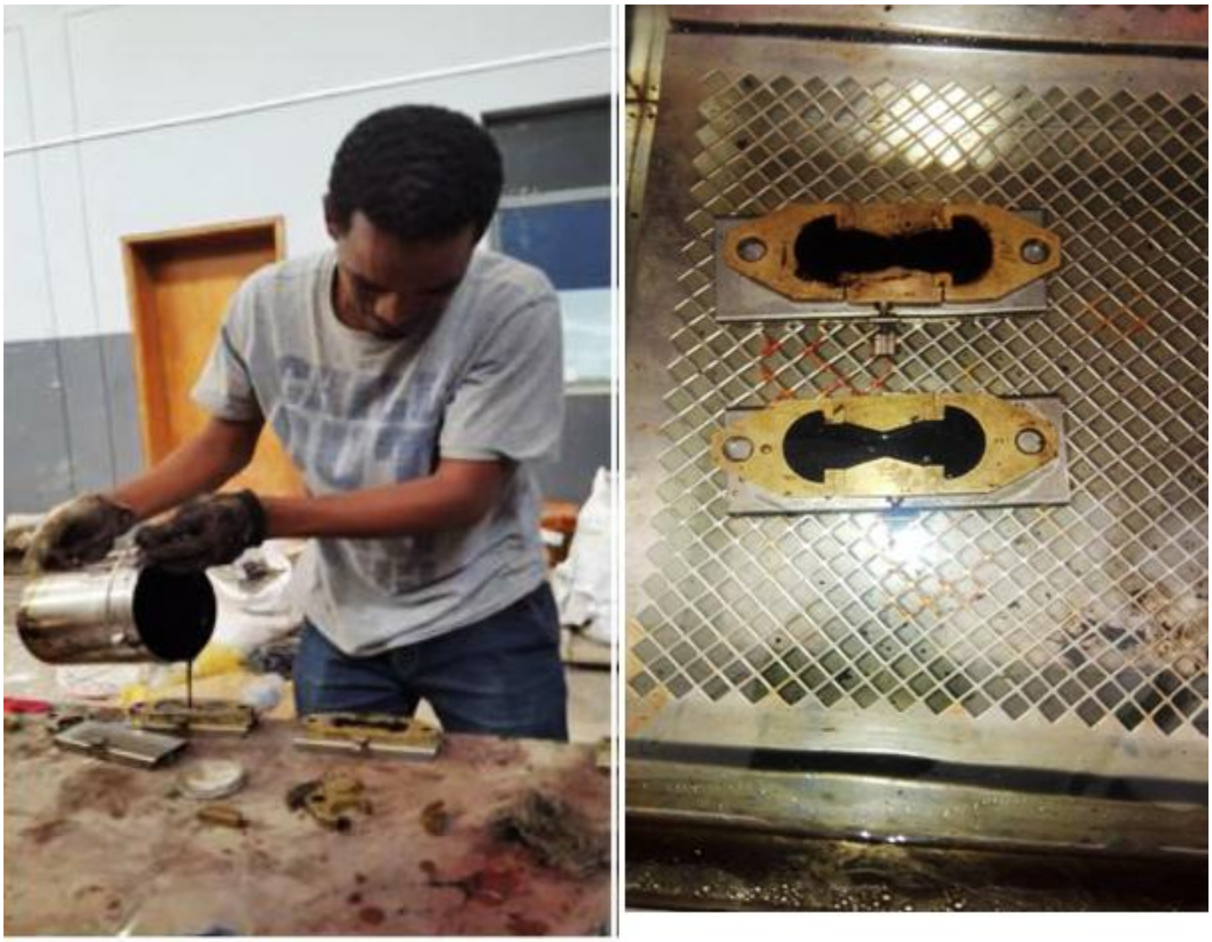
PET(7%)

S/N	Wt in Air	Wt in Water	SSD	Volume	Density (Gm)	Theoretical Specific Gravity (Gt)	Vb (%)	Vv (%)	VMA (%)	VFB (%)	Stability	Flow Value
1	1247	742	1251	505	2.47	2.56	11.04%	3.21%	14.25%	77.48%	11.91	4.12
2	1251.9	743	1254	508.9	2.46	2.55	11.00%	3.57%	14.57%	75.48%	11.83	4.21
3	1252	731	1256	521	2.40	2.55	10.75%	5.81%	16.55%	64.93%	11.62	4.16
Averg	1250.3	738.7	1254	511.6333	2.44	2.55	10.93%	4.20%	15.13%	72.63%	11.79	4.16

Appendix C

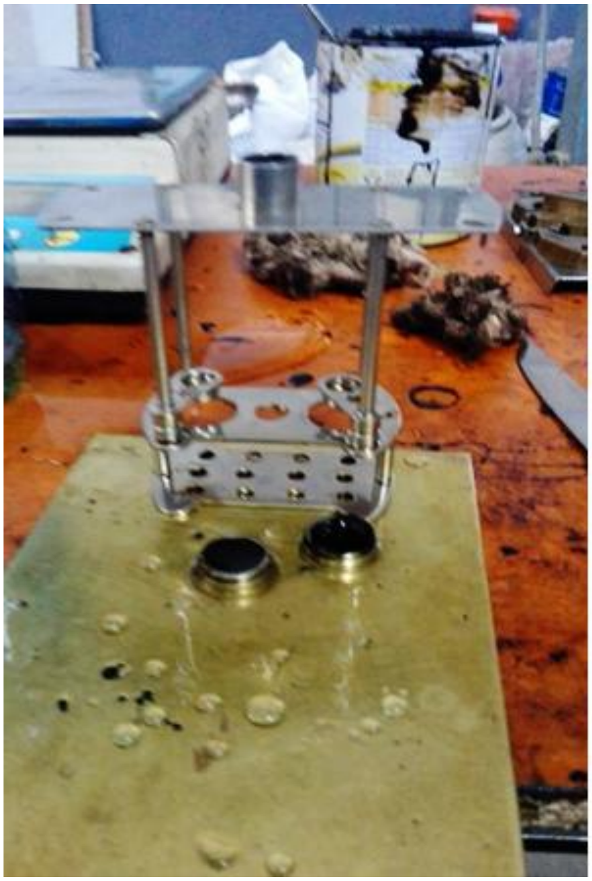
Photos

Sample Preparation



Ductility Sample Preparation (21/04/2017)

Softening Point Preparation (25/04/2017)



Softening Point Test (25/04/2017)

Marshal Test Activities

Aggregate Sample Preparation

(15/05/2017)

Blending Asphalt Mix (18/05/2017)

Compacting the mix by the Marshall Hammer (18/05/2017)

Marshal Samples weighting in air (19/05/2017)

Marshal Samples weighting in water (19/05/2017)