JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HIGHWAY ENGINEERING STREAM

Characterization and Suitability Analysis of Recycled Waste Polymer Materials as Asphalt Mixtures in Hot Mix Asphalt.

A Thesis Submitted to Jimma University School of Graduate Studies as a Partial Fulfillment for the Requirements of Degree of Master of Science in Highway Engineering

By: - Abdissa Nagara

April, 2022

Jimma, Ethiopia

JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HIGHWAY ENGINEERING STREAM

Characterization and Suitability Analysis of Recycled Waste Polymer Materials as Asphalt Mixtures in Hot Mix Asphalt.

A Thesis Submitted to Jimma University School of Graduate Studies as a Partial Fulfillment for the Requirements of Degree of Master of Science in Highway Engineering

By: - Abdissa Nagara

Advisor: Dr.-Ing. Fekadu Fufa, (PhD)
Co-advisor: Engr. Mesfin Dinku, (MSc.)

April, 2022
Jimma, Ethiopia

Jimma University

School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Highway Engineering Stream

Characterization and Suitability Analysis of Recycled Waste Polymer Materials as Asphalt Mixtures in Hot Mix Asphalt.

By:

Abdissa Nagara

Approved by Board of Examiners:

Dr.-Ing. Alemayehu Gebissa	______________	19/04/22
External Examiner	Signature	Date
Eng. Tesha Wedajo (PhD Cand.)	______________	[illegible]/05/22
Internal Examiner	Signature	Date
Eng. Oluma Gudina	______________	26/04/2022
Chairperson	Signature	Date
Dr.-Ing. Fikadu Fufa	______________	20/04/2022
Main Advisor	Signature	Date
Eng. Mesfin Dinku	______________	20/04/2022
Co-Advisor	Signature	Date

DECLARATION

I, the undersigned, declare that the thesis entitled as: " **Characterization and Suitability Analysis of Recycled Waste Polymer Materials as Asphalt Mixture in Hot Mix Asphalt.**" is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for this thesis have to be duly acknowledged.

Candidate:	Signature	Date
Abdissa Nagara		15/11/2021

As a research advisor, we have reviewed and approved for examination, the research entitled as **"Characterization and Suitability Analysis of Recycled Waste Polymer Materials as Asphalt Mixture in Hot Mix Asphalt."** which is done by **Abdissa Nagara** under our guidance.

Dr. Fekadu Fufa		20/11/2021
Main Advisor	Signature	Date
Engr. Mesfin Dinku		20/11/2021
Co-Advisor	Signature	Date

ACKNOWLEDGEMENTS

All over, Praise and Glory be to Almighty God for giving me strength and health.

Next, I would like to express my sincere and deepest gratitude to my Advisors Dr.-Ing. Fekadu Fufa and Engr. Mesfin Dinku for all their limitless efforts in kind advice and guidance.

I would like to extend special thanks to Ethiopian Road Authority (ERA), Jimma University Institute of Technology for their kind support and sponsoring of my MSc. Study. And also I would like to thanks Ethiopian Road Authority (Jimma district), Universal Plastic Factory P.L.C (Addis Ababa), Mr. Dejene Dereje (Laboratory technician) and Engr. Oluma Gudina (Highway Engineering Chair Holder) for their kind support of material and laboratory assistance.

Last but not the least, I would like to express my sincere respect and love to my families and friends for their kind support, patience and standing with me. My warm appreciation and gratefulness also extend to all those who supported and encouraged me, but are not mentioned above by name, for their concern and kindness.

ABSTRACT

Today there is an increasing global trend to find sustainable, environmentally friendly and cost effective materials as an alternatives to the limited raw materials. Similarly the use of waste materials has been gaining popularity in the production of hot-mix asphalt (HMA). In this study, the potential possibility of recycled waste polymer materials like low density polyethylene (LDPE) as binder modifier and polyvinyl chloride pipe powder (PVC-PP) as filler in hot mix asphalt were evaluated based on the laboratory test experiments. The mixes were evaluated separately for each of the materials. Experimentally, a total of forty five Marshall Specimens were prepared with bitumen content of 4 to 6% at 0.5% increment and 5%, 5.5%, 6% of crushed stone dust as a control mix to determine optimum bitumen content and filler content. The determined optimum bitumen content was used to prepare Marshall Specimen with LDPE modifier from 0 to 10% at 2% increment and with PVC-PP filler from 0 to 100% at 25% increment. A total of thirty three (18 for LDPE and 15 for PVC-PP) specimens were prepared to evaluate the effects of the materials on Marshall Properties of hot mix asphalt, separately. Marshall Immersion test method was used to determine tensile strength ratio of modifier and filler to evaluate moisture susceptibility of the mix. All the mixes prepared with 5.43% optimum bitumen content and 5% filler content at different proportions of LDPE modifier and PVC-PP filler to meet Marshall Criteria for asphalt concrete wearing course. Maximum stability of 12.34kN was obtained at 8% of LDPE addition, while that of PVC-PP maximum stability 12.63kN was obtained at 50% replacement of PVC-PP. Marshall Immersion test resulted, tensile strength ratio of 60/70 PG binder and LDPE at its optimum content were 83.03 and 92.08 respectively, while that of crushed stone dust and partially replaced polyvinyl chloride pipe powder were 83.98 and 93.63 respectively. It was found that the addition of LDPE waste to an optimum content of 8% with the bitumen enhances Marshall Properties and 50% replacement of polyvinyl chloride pipe powder with 50% of crushed sand dust also enhances the mix's properties. It is believed that the use of recycled LDPE and PVC-PP waste in hot mix asphalt within combination of plain bitumen and crushed sand dust is very useful to cost-effectiveness and in minimizing environmental problem due to waste disposal.

***Key Words**: - Asphalt binder, filler, modifier, partial replacement and polymer modified binder.*

TABLE OF CONTENTS

LISTS OF TABLES

LIST OF FIGURES

ACRONYMS

AASHTO	American association of state highway and transportation officials
AC	Asphalt Concrete
AC-BC	Asphalt Concrete - Binder Content
ASTM	American Society for Testing and Materials
AV	Air Void
BC	Binder Content
BS	British Standard
CR	Crumb Rubber
CSD	Crushed Stone Dust
DSA	Date Seed Ash
EAPA	European Asphalt Pavement Association
ERA	Ethiopian Roads Authority
ERCC	Ethiopian Roads Construction Corporation
FC	Filler Content
GRP-WP	Glass Reinforced Pipe – Waste Powder
HDPE	High Density Polyethylene
HL	Hydrated Lime
HMA	Hot Mix Asphalt
JIT	Jimma Institute of Technology
JMF	Job Mix Formula
LDPE	Low Density Polyethylene
LLDPE	Linear Low Density Polyethylene

LS	Lime Stone
MS-2	Asphalt Institute's Manual Series – 2
NAPA	National Asphalt Pavement Association
NMAS	Nominal Maximum Aggregate Size
NP	Non Plastic
OAC	Optimum Asphalt Content
OBC	Optimum Bitumen Content
OPC	Ordinary Portland Cement
PCA	Plastic Coated Aggregate
PE	Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
PVC-PP	Polyvinyl Chloride - Pipe Powder
RHA	Rice Husk Ash
SBS	Styrene Butadiene Styrene
TFOT	Thin Film Oven & Loss on Heating Test
TSR	Tensile Strength Ratio
VFA	Voids Filled with Asphalt
VIM	Voids in Mix
VMA	Voids in Mineral Aggregate

CHAPTER ONE

INTRODUCTION

1.1 Background

In road construction, large amounts of asphalt mixtures are produced annually worldwide. Therefore, the efficient use of road construction materials such as asphalt mixtures is one of the important key materials research areas that requires in depth investigations. In utilizing waste materials for roads, both the cost-effectiveness (virgin materials replaced by waste) and environmental problems (due to waste disposal) need to be considered. Hence, these topics have attracted the research community worldwide [1].

In flexible pavement construction, large amount of asphalt concrete mixes as their binder and wearing courses are utilized. This asphalt concrete mixes mainly consists of aggregates (coarse and fine), filler and bitumen binder. The quality of pavements should be engineered to have requirements for the properly selected asphalt binder grades for the climate and traffic, aggregate characteristics including material quality and gradation, HMA volumetric requirements and HMA performance criteria [2]. Numerous research studies showed that the strength of hot mix asphalt (HMA) depends on different factors such as aggregate, filler and bitumen binder. Aggregates provide mixture stability by forming a skeleton to resist traffic load whereas asphalt provides the binding action and durability to asphalt mixes [3].

Fillers are fine particles passing the No. 200 sieve added in the asphalt mix to a maximum of 10% by mass, which affects the load-carrying capacity and stability of the mixtures [3]. Filler fills the gaps between larger aggregates in bituminous mixes, providing stability, lowering the optimal bitumen content, and increasing impermeability. It also affects the workability, moisture sensitivity, stiffness, durability, fatigue behavior, and long-term characteristics of HMAs [4]. Physical and chemical properties, shape and texture, size, and gradation all differ among fillers. As a consequence, choosing the right filler is crucial for optimal HMA efficiency [5]. In the construction of HMA, filler materials like crushed stone dust, cement, lime and hydrated limes have been using traditionally. However, due to insufficiency, economic and environmental concern regarding to production of these material, recent studies focuses on the utilization of alternative filler materials [6].

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. Polymer modified binders improved adhesion and cohesion properties, rutting resistance, thermal cracking, fatigue damage, stripping, and temperature susceptibility. These improvements have led polymer modified binders to be substituted for asphalt in many paving and maintenance applications [7].

At present, considering the risks associated with land filling of waste materials and its disposal problem, researchers have been finding ways of incorporating recycled materials into bituminous pavements construction, that have brought about action throughout the world [8]. Plastic is among the top recycled waste items used in road construction as asphalt mixtures. Plastic waste comes in many forms. Common sources of plastic waste are plastic bags, bottles, cups, packaging, and straws. Plastic is a polymer-based material which is non-biodegradable. Because of its low manufacturing cost, convenience in carrying and storage, and waterproof nature, plastic has been extensively used around the globe as a household item [9; 10]. Different types of waste polymer materials like polyethylene, polypropylene, polyvinyl chloride, styrene-butadiene block copolymer, and styrene-isoprene block copolymer have been used in asphalt mixture as additives either as filler or bitumen modifier.

Polyethylene is the type of polymer that is thermoplastic, meaning that it can be melted to a liquid and remolded as it returns to a solid state forms. It is chemically synthesized from ethylene, a compound that's usually made from petroleum or natural gas. It is used in making other plastic compounds much often than it's used in its pure form. The process of polymerization of ethylene gas result in long linear chains of hydrocarbons branching in various directions. The degree of this branching decides the type of polyethylene. Besides to the degree of branching, depending upon the density and its application there are different types of polyethylene used for a range of products from polythene bags to pipes and fixtures. These are Low Density Polyethylene (LDPE) which is used in film wraps, grocery polythene bags, and slightly right plastic bowls and bottles among others, High Density Polyethylene (HDPE) which is used in making pipes, cans, toys, tubing, fixtures, and Linear low-density polyethylene (LLDPE) which is used in producing of Gusseted bags. Using various types of polyethylene has several advantages, such as they have very high melting and freezing points [11].

Low-density polyethylene (LDPE) is a type of plastic waste that has the potential to be used as an added material in flexible pavement. The characteristics of this plastic waste which are made from petroleum have a low density of 0.941-0.959 g/cm3, and a melting point of 105–115 °C. In several study, an investigation was made about the possibility of using LDPE-type plastic waste as a bitumen modifier for asphalt concrete-binder course (AC-BC) mixtures [12]. Polyvinyl chloride (PVC), a thermoplastic material, has widely been used in construction works for being cheap, durable and easy workability. For the present study, waste PVC was collected from domestic waste, mineral water bottles, credit cards, toys, pipes and gutters, electrical fittings, furniture, folders and pens, medical disposables. It is mostly used as a filler [13].

Previous studies explored the potential use of recycled polymer materials like low density polyethylene (plastic bags) as bitumen modifier and high density polyethylene fiber-reinforced polyester pipe waste powder (GRP-WP) as a filler in asphalt mixtures [**12**,14]. Polymer materials mainly comprised of the hydrocarbon minerals. However, studies concerning the utilization of polymer waste materials like PVC pipe powder as mineral filler for asphalt concrete mixes and LDPE (shredded cups) as bitumen modifier are very limited and hence, this area is open for wide speculation.

Therefore, this study geared toward evaluating some of the Marshall Mix properties of polyvinyl chloride (PVC) pipe powder as partially replaced with crushed stone dust, and LDPE (shredded cups) as bitumen modifier in hot mix asphalt concrete. The mixes were prepared separately for each materials and evaluation also done independently for each recycled polymer materials used. The study was aimed at investigating the physical properties asphalt mixtures, blended with LDPE (low density polyethylene) as binder modifier, and PVC-PP (polyvinyl chloride pipe powder) as a mineral filler, the effect on the Marshall Mix properties and moisture sensitivity.

1.2 Statement of the Problem

The production of hot mix asphalt (HMA) mixture, consumes a substantial amounts of natural resources such as aggregates, fillers and bitumen [3]. However, the availability and adequacy of these virgin construction materials are becoming decline as rapid growth with population increase and the demand for the consumption of these materials is becoming high in road construction industry. Besides the scarcity of these materials, high production cost, shortage in supply, the need for new road pavement construction, rehabilitation and reconstruction are major problem concerns [15]. In contrast, today the availability of the waste plastics is enormous, as the plastic materials have become part and parcel of daily life. They either get mixed with Municipal Solid Waste and/or thrown over land area. If not recycled, their present disposal is either by land filling or by incineration. Both the processes have certain impact on the environment and human health [16]. Under this circumstance, an alternate use for the waste plastics is also the needed.

Nowadays in the production of HMA, there is an increasing global trend to find sustainable, environmentally friendly and cost-effective materials as an alternative to limited natural raw materials [14]. Several studies identifies the possibility use of waste polymer materials as an additives eithier as fillers or bindier modifiers in HMA not only, for sustaniability, cost-effectiveness, environmentally friendly but, also to improve the performance of bituminious pavement [17,18,19,20]. A common methodology to improve the quality of bitumen is by modifying the rheological properties of bitumen by blending with organic artificial polymers like rubber and plastics [17]. Therefore, it was mandatory to find an alternative nonconventional HMA bitumen modifier, and as well as a filler material which is locally available and ecofriendly. Hence, this study investigated the potential use of LDPE (shredded plastic cups) replacing bitumen as binder modifier and PVC pipe powder replacing crushed stone dust as a filler material in HMA. Besides this, the effect of these materials on moisture susceptibility were conducted. Comprehensive laboratory tests were conducted on the materials' ingredients of the HMA concrete and all test results met the Ethiopian Road Authority (ERA, 2013) specifications.

1.3 Significance of the Study

The justification for conducting this study provides locally available waste polymer materials (LDPE and PVC-PP) to decrease the scarcity of virgin binder and conventional filler materials with environmentally friendly and economically feasible. For this study low density polyethylene used as binder modifier and polyvinyl chloride pipe powder used as mineral fillers. Hence, the use of this alternative materials in HMA reduces production cost, time and environmental pollution, it is very important in giving attention toward the effective use of locally available materials in the construction industry. This study benefits the road construction industry, government, local community and further researchers for further investigation on recycled polymer materials such as LDPE (shredded plastic cups) and PVC pipe powder as asphalt mixtures in HMA mixtures. Furthermore, the purpose of highway authority or road sector is to provide safe, cost-effective and smooth pavements to carry the load as well. So the study has beneficial for owners, contractors, and consultant as a source of information for highway project implementation throughout the country by using the waste product of polymer materials where not only there are a shortage of asphalt binder or bitumen but also for the cost-effectiveness of the highway projects.

1.4 Research Questions

1. What are the physical properties of hot mix asphalt (HMA) mixtures, blended with waste polymer materials such LDPE (shredded plastic cups) as binder modifier and PVC pipe powder as replaced of filler mineral?
2. What are the optimum percentages or potential effects of using LDPE (plastic cups) as binder modifier and PVC-PP as a filler in asphalt mixtures on Marshall Mix properties?
3. What are the effects of LDPE modified asphalt mixtures and PVC-PP as filler in asphalt mixture on moisture susceptibility of HMA?

1.5 Objective

1.5.1 General Objective

The aim of this study is to investigate the potential use of the recycled polymer materials (LDPE as binder modifier and PVC-PP as partial replacement of mineral filler) in Hot Mix Asphalt.

1.5.2 Specific Objectives

The specific objectives of the study are:

1. To determine physical properties of hot mix asphalt (HMA) mixtures, blended with waste polymer materials such LDPE (shredded plastic cups) as binder modifier and PVC pipe powder as replaced of filler mineral.
2. To determine the optimum percentages or potential effects of using plastic cups as binder modifier and PVC-PP as a filler in asphalt mixtures on Marshall Mix properties.
3. To examine the effects of LDPE modified asphalt mixtures and PVC-PP as filler in asphalt mixture on moisture susceptibility of HMA.

1.6 Scope of the Study

The study focused on the possibility use of recycled waste polymer materials, low density polyethylene as asphalt binder and polyvinyl chloride pipe powder as mineral fillers in hot mix asphalt (HMA). The research basis on experimental investigation hence, it covers laboratory tests on the materials characterization (aggregate quality test, bitumen quality test), Marshall Mix design (gradation mix, control mix, replacement mix), tensile strength ratio (TSR) (un-conditioned and conditioned) of hot mix asphalt. The test was conducted in Jimma town and Jimma Institute of Technology (JiT).

The evaluation of the effects of using recycled polymer materials LDPE as modifier and PVC pipe powder as fillers in HMA on Marshall Mix Properties and tensile strength ratio or moisture susceptibility were also covered. The overall test results were compared to the ERA design specification and Marshall Criteria. However, the findings are limited to the effects of using recycled polymer materials like LDPE (plastic cups as modifier in bitumen) and PVC pipe powder as replacement of mineral filler on Marshall Properties of HMA mixture produced by Marshall Mix design method, and on moisture susceptibility of the mixture with material specified in this study. Hence, the results are also specific to the source, type and content of recycled polymer materials (LDPE & PVC Pipe powder) used and test procedures that have been adopted in the experimental work.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Asphalt concrete is one of the vital structures in terms of civil engineering and is used in very large-scale applications including roads and waterproofing due to its high resistance to durability, water resistance and good stability properties. Construction of AC pavement involve huge national asset to design, construct and maintain in order to provide durable and high level of services. Hence, selecting high quality paving material that can extend pavement service life is a main objective. Many experts, engineers, and researchers have been assigned to select paving materials that can reduce the magnitude and density of distress while also enhancing the overall performance of asphalt pavements in order to achieve this goal [21].

Hot mix asphalt concrete is the most popular pavement material utilized for binder and wearing course on the world. Asphalt concrete is a mixture of coarse aggregate, fine aggregate, binder, additive and filler in various relative amounts that determine the substantial characteristics of the mix. Furthermore, the proportion as well as the properties of the components (binder, aggregate and additive) into the design mix of asphalt concrete greatly depends on its performance. Thus, the binder is of relatively more important which can be normal penetration grade bitumen as well as it can be modified by adding an optimum proportion of different additives, and filler material also plays a major role in various properties of HMA, particularly those related to mixture compatibility and aggregate bitumen adhesion [22].

Recently, many studies have been attempted by adding different materials as an additive to improve the mechanical and physical properties of asphalt concrete. Polymers is one of these additives. Researchers have been found that, with the addition of some waste materials and certain polymers to asphalt binders can improve the performance of asphalt concrete [19, 23]. Another researcher has been investigated glass reinforced pipe waste polymer powder could be successfully used as a partial filler replacement with limestone filler in hot mix asphalt not only improving the properties the mix but also it was affordable and environmentally friendly alternative materials in asphalt mixtures [14].

This study was concentrated on the Marshal properties of hot mix asphalt mixtures prepared using recycled waste polymer materials [LDPE (shredded plastic cups) as a modifier and replacement rate of PVC pipe powder as fillers] on hot mix asphalt concrete. In this chapter, review of previous study conducted on the effect of polymer modified bitumen and mineral fillers on hot mix asphalt performance will be discussed.

2.2 Asphalt Concrete

Asphalt concrete commonly called hot mix asphalt (HMA) in Europe or asphalt concrete (AC) in the U.S. is a predetermined mix proportion of aggregates (coarse and fine), filler and bituminous binder [24]. Asphalt binder holds/binds the aggregate in HMA together, and without asphalt binder; HMA would simply be crushed stone or gravel. Asphalt binder is the thick, heavy residue remaining after kerosene, gasoline, diesel oil, and other fuels and lubricants are refined from crude oil. Aggregate typically makes up about 95% of an HMA mixture by weight. Because, HMA mixtures are mostly aggregate, aggregates used in HMA must be of good quality to ensure the resulting pavement will perform as expected. This mineral aggregate bounded together with bitumen, lay in layers, and compacted to form asphalt concrete pavement. When used in the construction of highway pavements, it must resist deformation from imposed traffic loads, be skid resistant even when wet and not affected easily by weathering forces. Filler fills the gaps between larger aggregates in bituminous mixes, providing stability, lowering the optimal bitumen content (OBC), and increasing impermeability [3].

2.3 Composition of Asphalt concrete

The main constituents of asphalt mixtures are aggregate (coarse and fine), filler and bitumen binder. It is crucial that the properties of the component materials of HMA meet minimum standards to ensure the material has a satisfactory performance.

2.3.1 Aggregate

Aggregates are hard inert material used in highway construction obtained from natural rock like igneous, sedimentary and metamorphic rock. Aggregates are the dominant ingredient of HMA, by making roughly 90 to 95% of the mixture by weight. Hence, aggregates are principal load supporting component of asphalt concrete pavements. Because HMA mixtures are mostly aggregate, aggregates used in HMA must be of good quality to ensure the resulting pavement will perform as expected. Aggregates are generally divided into coarse, fine, and filler fractions. Coarse aggregate are aggregates that are retained on 2.36 mm sieve and fine aggregates that are passing 2.36 mm and retain on 0.075 mm whereas fillers are fine particles with at least 75% passing sieve size 0.075 mm [3].

i. Properties of Aggregates

The physical properties of aggregates those are important to the asphalt pavement are gradation, particle shape, toughness, durability, cleanliness, absorption and adhesion. The aggregate should be angular and not excessively flaky, clean and free of clay and organic material, strong enough, resistant to abrasion and polishing, non-absorptive and good affinity with bitumen (hydrophilic aggregates may be acceptable only where protection from water can be guaranteed or a suitable adhesion agent is used).Aggregates for HMA are required to be hard, tough, strong, durable, clean and properly graded.

Table 2. 1: - Required properties for HMA aggregates (ERA, 2013)

Property	Test	Properties	
		Wearing course	Binder course
Cleanliness	Sand equivalent [1]: for < 4.75 mm fraction < 1.5 x 10E6 ESA > 1.5 x 10E6 ESA	> 35 > 40	
	Material passing 0.425 mm sieve Plasticity index [2] Linear shrinkage %	< 4 < 2	
Particle shape	Flakiness index [3]	< 35	
Strength	Aggregate crushing value (ACV) [4]	< 25	
	Aggregate impact value (AIV) [4]	< 25	

	10% FACT(dry) KN[4]	> 160	
	Los Angeles Abrasion Value(AAV) [5]	< 30	< 35
Water absorption	Water absorption [6]	< 2	
Soundness [7] (5 cycles,% loss)	Sodium sulphate Test: Coarse Fine Magnesium sulphate Test: Coarse Fine	 < 10 < 6 < 15 < 20	
Bitumen affinity	Immersion Mechanical Test: Index of retained Marshall stability Static Immersion Test [8] Retained indirect Tensile strength [9]	 > 75 > 95% coating retained > 79% (at 7% VIM)	

Notes: [1] AASHTO T176-86 [4] BS 812: Part 3 (1985) [7] AASHTO T104-99

[2] BS 1377: Part 2 (1990) [5] ASTM C131 and C535 [8] D Whiteoak (1990)

[3] BS 812: Part 105 (1990) [6] BS 812, part 2 1975 [9] AASHTO T283

ii. Aggregate gradation

The stability of asphalt mixture is affected by several features such as aggregate gradation, size, and amount of filler materials. Gradation is one of the aggregates characteristics affecting the performance of HMA. Laboratory result by Golalipour A. [25], showed that, reducing percentage air voids and VMA up to the certain amount, increases resilient modulus of the mixture and decreases deformation and non-recoverable strain. Hence, Gradation bands placed in the upper limits of asphalt mixture design gradation chart show the best performance against rutting while lower bands have the highest permanent deformation. Whereas the selected gradations are almost parallel with the job mix formula, when it gets near to upper limit curve permanent deformation is reduced and rutting resistance will be increased and when the gradation is near to the lower limit curve, the permanent deformation increases and rutting resistance will be decreased.

Golalipour A. and Jamshidi E**.** [25], Performed the study on the investigation of the effect of variation in gradation of aggregate on the properties of asphalt mixture. According to the researchers, five different gradations were tested to investigate the impacts of variation in gradation of aggregate on the HMA properties. The gradation was such as JMF gradation, coarse, fine, fine- coarse, and coarse-fine and their respective effects on the performance of asphalt mixture are concluded as follows: fine-coarse and coarse-fine gradation variation cause higher and lower Marshall Air void, void in mineral aggregates (VMA) respectively. In addition, the aforementioned gradation variation results lowest and highest Marshall Flow, respectively. Generally, the Marshall stability is affected by gradation variation with the fine gradation produced the highest stability, whereas the fine-coarse gradation variation resulted in the lowest stability.

Khasawneh MA. [26], evaluated the effect of nominal maximum aggregate size and aggregate gradation on the surface friction properties of HMA mixtures. Their study showed that the surface friction properties of mixtures at top surface were significantly affected by the NMAS and aggregate gradation. According to this context, by increasing the NMAS in the mix, the top surface exhibits improved micro texture and lessened micro textures for both types of aggregate gradations. On the other hand, the friction properties of the bottom surfaces were only affected by the aggregate gradation type due to the migration of fine material. Generally, According to several researcher investigation showed that aggregate gradation plays a major role in HMA performance. Hence aggregate gradation in HMA helps to determine property including stiffness, durability, stability, permeability, workability, fatigue resistance, and resistance to moisture damage. Gradation is often measured by sieve analysis, and different aggregate specification was provided in local and global pavement manual standards [25, 26].

Table 2. 2: - Particle size distributions for asphalt concrete courses (ERA, 2013)

Layer		Road base		Binder course		Wearing course					
Sieve No	Sieve size (mm)	Nominal maximum stone size (mm)									
		Percentage passing sieve size									
		37.5 mm		25 mm		19 mm		12.5 mm		9.5 mm	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2"	50	100	100	-	-	-	-	-	-	-	-
1 1/2"	37.5	90	100	100	100	-	-	-	-	-	-
1"	25	-	-	90	100	100	100	100	100	100	100
3/4"	19	56	80	-	-	90	100	100	100	100	100
1/2"	12.5	-	-	56	80	-	-	90	100	100	100
3/8"	9.5	-	-	-	-	56	80	-	-	90	100
No.4	4.75	23	53	29	59	35	65	44	74	55	85
No.8	2.36	15	41	19	45	23	49	28	58	32	67
No.16	1.18	-	-	-	-	-	-	-	-	-	-
No.30	0.6	-	-	-	-	-	-	-	-	-	-
No.50	0.3	4	16	5	17	5	19	5	21	7	23
No.100	0.15	-	-	-	--	-	-	-	-	-	-
No.200	0.075	0	6	1	7	2	8	2	10	2	10

2.3.2 Bitumen

Bitumen is a sticky and highly viscous mixture of heavy hydrocarbons that are obtained from the bottom in crude oil fractionation. They comprise aliphatic and aromatic, saturated and unsaturated compounds with almost 150 carbon atoms. Technically, it is a byproduct of the residue that is desolated after the more desired parts of the crude oil are extricated. Bitumen constitutes a mixture of a highly condensed polycyclic aromatic hydrocarbon. Bitumen generally contains about 80 wt. % carbon, 10 wt. % hydrogen, 6 wt. % sulfur, little amount of nitrogen and oxygen along with a few traces of metals [27].

Bitumen properties can be enhanced by the addition of different materials or by applying different methods. A major application of bitumen is in making roads, by adding different aggregates to bitumen. This mixture is called asphalt. However, this is a bit ambiguous because in some countries bitumen is also called asphalt [28]. The asphalt can readily be liquefied by applying heat for mixing with mineral aggregates to produce HMA. Being very sticky, it adheres to the aggregates particles and binds them to form HMA. Three methods based on penetration, viscosity or performance are used to classify asphalt cement into different grades.

Table 2. 3: - Requirements for penetration grade bitumen (ERA, 2013).

Test		Test Method (ASTM)	Penetration Grade		
			40/50	60/70	80/100
Based on original bitumen					
Penetration @ 25°C		D 5	40-50	60-70	80-100
Softening Point (°C)		D 36	49-59	46-56	42-51
Flash Point (°C),	Min	D 92	232	232	219
Solubility in trichloroethylene (%)	Min	D 2042	99	99	99
TFOT heating for 5h at 163 °C		D 1754	-	-	-
a) Loss by mass (%)	Max	-	0.5	0.5	0.8
b) Penetration (% of original)	Min	D 5	58	54	50
c) Ductility at 25 °C	Min	D 113	-	50	75

2.3.3 Filler

Filler is mineral particle finer than 75 μm in size used as one of the main constituents in asphalt mixture. Conventionally crushed stone dust, lime, hydrated lime and cement have been using as filler material in asphalt concrete mixture. Filler plays a major role in determining the properties and the behavior of the mixture especially the binding and aggregate interlocking effects. Fillers not only fill voids in the mixture, but also affect the ageing characteristics of the mix. Filler has ability to increase the resistance of particle to move within the matrix and or works as an active material when it interacts with the asphalt cement to change the properties of the mastic [5]. Mineral filler greatly influences the design, and performance of the mixture by the nature and amount, excess quantity of filler tends to increase stability, brittleness, and proclivity to cracking. Deficiency of filler tends to increase void content, lower stability, and soften the mix. The filler content is particularly important as it has a significant impact on technical properties and, hence on potential end use. The gradation, shape, and texture of the mineral filler significantly influence the performance of hot mix asphalt regarding permanent deformation, fatigue cracking, and moisture susceptibility. A better understanding of the effects of fillers on the properties of asphalt mastics and HMA mixtures, is crucial to good mix design and high performance of HMA mixtures [29].

Now a day due to environmental and economic concerns, several researchers investigated different non-conventional alternative filler material for asphalt concrete mix. Modarres A and Rahmanzadeh M. [30], investigated the application of coal waste powder as filler material in HMA, comparison to reference mix (i.e. a mix containing limestone powder) the coal west and its ash resulted in higher stability and resilient modulus. Furthermore, the combination of coal waste and limestone powders in equal proportion resulted in a desirable mix with high water resistance. Moreover, coal waste powder and especially its ash also improved the water sensitivity of mixes. Raja & Tapas, (2016) [29], investigated the effect of fly ash as alternative filler in HMA through Marshall Mix design. According to obtained Marshall Parameters, the addition of fly ash up to 4% in dense bitumen mix, by replacing conventional mineral filler like HL shows a 7.5% reduction in OBC compared to the control mix, which may provide a considerable economy of bitumen in resulting mixture. According to this context, replacement of HL by Fly Ash in HMA not only satisfies all the standard specification but also gives better strength with lesser deformation compared to that of the conventional mix. Hence, especially in the areas where fly ash generally dumped may be used as replacement of common filler to support global sustainability. Today, waste material have been increasingly utilized as alternative raw material in asphalt mixture in order to decrease construction costs, conserve natural resources and reduce environmental problems.

Tahami Seyed, et al, [6], investigated the potential usage of rice husk ash (RHA) and date seed ash (DSA), as filler material in hot mix asphalt by replacing conventional filler. They found that, asphalt mixtures with DSA and RHA fillers showed higher stability and stiffness modulus in comparison with the control mixture. Also using biomass ashes improved the thermal sensitivity of mixtures and adhesive force between asphalt and aggregates, which caused an enhancement in rutting resistance and fatigue life of HMA mixtures. Al-Hdabi [31], study on the properties of HMA with Rice Husk Ash (RHA) as filler material instead of conventional filler (OPC), showed that Marshall Stability increases by 65% more than conventional filler (OPC).

2.4 Polymer Materials

A polymer is a large molecule with high molecular weight composed of repeat units of low molecular weight known as a monomer. The polymer can be made by two processes namely Addition Polymerization and Condensation Polymerization. There are natural and synthetic polymers with different properties such as toughness, viscoelasticity, and its ability to form glassy and semi-crystalline structures [32].

2.4.1 Types of Polymer Materials

Polymer materials can be divided into two major categories based on how they join together or how their molecules are arranged which are thermosets and thermoplastics.

a) Thermoset Polymer Materials

Thermosets mostly have highly cross-linked, this enables them to have higher physical and mechanical properties, but on the other hand, they show reduced elasticity and elongation. They are a condition of plastic when it is in solid form. One major disadvantage of thermoset is that it can neither be recycled nor reshaped on heating. It retains the shape once it is cured. It degrades upon heating instead of softening for reuse. Examples of thermosets are epoxy resins, phenolic resins [33].

b) Thermoplastic Polymer Materials

The thermoplastics are the most widely used polymers as they can be reshaped and can be reused again. They remoulded at elevated temperature and they retain that shape upon cooling. In thermoplastics, the chains are concorded with the intermolecular forces, which allow the thermoplastics to be remoulded. Some examples of common thermoplastics are polyethylene, polystyrene, polyamide, polyvinyl chloride and so forth [34].

Polyethylene is one of the most widely used plastic types and is made from the polymerization of ethylene gas. They have extensive application ranging from plastic bags and bottles to certain industrial parts and components. Depending upon the application, the density of the plastic is decided. For instance, high-density plastics which are absolutely non-permeable are used in making pipes, tanks, and so on. On the other hand, low density plastic is used to make shopping bags, water bottles, and so on. These are categorized as high density, low density and linear low density polyethylene [35].

i. **High–density polyethylene (HDPE**): - This has minimal number of branches of chains resulting from polymerization. This leads to densely packed and bonded molecules making this type of polyethylene rigid, robust, and durable. This is used in making pipes, cans, toys, tubing, fixtures, and so on. So, this has more of an industrial usage.

ii. **Low-density polyethylene (LDPE):-** This is brought into being or generated from free radical polymerization which leads to long and short branching of chains. This makes this type of polyethylene highly ductile but its tensile strength and durability are low. This commonly finds applications in plastic film wraps, grocery polythene bags, and slightly right plastic bowls and bottles among others.

iii. **Linear low-density polyethylene (LLDPE): -** The polymerization of this type of polyethylene results in multiple short branches. LLDPE is strong and durable and offers puncture resistance to the product. The structurally short branches of this type polyethylene easily slide against each other, without entangling in each other, when elongated. This result in high tensile strength and durability which is more than LDPE.

Table 2. 4: - Different types of waste plastic (polymer) and its Origin**.** [35]

Polymer type	**Origin**
Low density polyethylene (LDPE)	Bags, sacks, bin lining and Squeezable detergent bottles etc.
High density polyethylene (HDPE)	Bottles of pharmaceuticals, disinfectants, milk, fruit juices, bottle caps etc.
Polypropylene (PP):	Bottle cap and closures, film wrapping for biscuits, microwave trays for ready-made Meals etc.
Polystyrene (PS)	Yoghurt pots, clear egg packs, bottle caps.
Foamed Polystyrene	food trays, egg boxes, disposable cups, protective packaging etc.
Polyvinyl Chloride (PVC)	Mineral water bottles, credit cards, toys, pipes and gutters; electrical fittings, furniture, folders and pens; medical disposables; etc.

2.4.2 Uses of Polymer Materials

Nowadays, most of recycled polymer materials such as polyethylene(PE), styrene butadiene styrene(SBS), polypropylene(PP) and polyvinyl chlorides (PVC) are used as an additives throughout the world, especially, in construction industries in different ways either as binder modification or/and mineral fillers. Polyethylene (PE) like low density polyethylene (LDPE) and high density polyethylene (HDPE) were the most widely used recycled polymer materials in several papers by many researchers as a binder modification. Imran M. Khan [36], investigated and concluded that the addition of plastic wastes, such as Low Density Polyethylene (LDPE) and High Density Polyethylene (HDPE), and Crumb Rubber (CR) to neat binder can play a significant role in improving the elastic behavior of binder in order to extend the service life of pavements in terms of reduced susceptibility to rutting and cracking. In addition, the use of these recycled wastes will play a significant role in reducing the use of non-renewable resources, in constructing sustainable pavements, and in reducing the environmental impacts of waste disposal at dumpsites.

Beycioğlu, et al., [14], studied the use of GRP pipe waste powder as a filler replacement in hot-mix asphalt and he demonstrated that GRP-WP, a sustainable material, could be successfully used as a filler replacement, not only satisfying speciation limits but also performing as well as an LS filler when it is used in its optimum content. Behl A. [18], Concluded that PVC pipe waste can be successfully used in paving applications and the addition of PVC pipe waste to the bitumen enhances both the binder's as well as the mix's properties. As a result he also stated that the binder's properties, phase angle and complex modulus values were improved after the addition of PVC pipe waste and hence this shows better resistance to the permanent deformation of the mix as compared to the mix prepared by neat VG 10 binder according to his investigation.

2.4.3 Low Density Polyethylene (LDPE) as Modifier

Different types of plastic waste have been used in asphalt as additives. Recently researchers investigated different types recycled Low Density Polyethylene (LDPE**)** materials as a binder modification in HMA mix. Waste plastics (polythene water sachets, polythene carry bags) are among the recycled thermoplastic materials used as a modifiers in asphalt mixtures. A study was carried out in Ghana to investigate the effect of low-density polyethylene (plastic water sachet) modified binder in hot mix asphalt (HMA). LDPE was mixed with the bitumen content at proportions of 0.5%–3% (by weight of optimum bitumen content). Results of the prepared sample showed that two percent (2%) polymer composition as a modifier with AC-10 bitumen can give perfect AC-20 bitumen properties that will help improve the Marshall stability, strength, design life and other desirable properties of asphalt concrete pavements with marginal saving in bitumen usage Aforla, et al., [37].

Research work in Iraqi has reported that an increased level of industrialization and fast urbanization led to an increase in solid plastic waste. Authors investigated the effect of waste plastic water bottles (PET) in asphalt mixtures. The results of the study indicated that the modified mixtures) which indicates that the values of the bulk density, stability ,stiffness and VFA increase and the values of flow, VIM, VMA decrease these results indicate that the modifier (PET) improves the properties of asphalt and asphalt mixture. These results are within specification Iraqi roads and bridges(2003), compared to the non-modified mixtures reduce Permanent Deformation and fatigue life of asphalt mixture with plastic bottles was longer in comparison with the mixture without plastic. It also contributes to recirculation of plastic wastes as well as to the protection of the environment [38].

Bitumen enhancement by various additives deals an essential answer to conquering the presence insufficiencies of bitumen accordingly, enhance the general properties and execution of bituminous blends. A standout amongst the above all utilized polymeric added substances for alteration of bitumen is LDPE and SBS. Both enhance the properties of bitumen like rutting opposition, flexible reactions, and low-temperature splitting obstruction. The SBS and LDPE acknowledged universally for a change of bitumen binder. In any case, the SBS and LDPE changed bitumen regularly indicates unstable thermos-dynamically nature when put away at high temperature which prompts prompt phase separation. Furthermore, SBS and LDPE altered bitumen tend to degrade long polymeric chain to small atoms on introduction to UV light, oxygen and heat [39, 40]. Ma Y. and Wang S. [41], also demonstrated that the expansion of SBS and LDPE makes the changed bitumen harder and more reliable than base bitumen which results in a change in the rutting obstruction of the blend. It is seen that the ductility of base bitumen diminishes with the expansion of SBS and LDPE. For the most part, SBS and LDPE plastic waste enhance the execution of bitumen when it was included in bitumen. It tends to use the enhance execution of the road asphalt which additionally decreases the rutting impact.

2.4.4 Polyvinyl Chloride (PVC) as a Mineral Filler.

Polyvinyl chloride is a thermoplastic material and has been widely used in construction works for being cheap, durable and easy workability. For the present study, waste PVC was collected from domestic waste, mineral water bottles, credit cards, toys, pipes and gutters, electrical fittings, furniture, folders and pens, medical disposables.

Today some researchers have been investigated recycled polyvinyl chloride pipe product as asphalt mixtures in hot mix asphalt. Beycioğlu, et al., [14], studied the use of GRP pipe waste powder as a filler replacement in hot-mix asphalt and he demonstrated that GRP-WP, a sustainable material, could be successfully used as a filler replacement, not only satisfying speciation limits but also performing as well as an LS filler when it is used in its optimum content. It is believed that use of GRP-WP waste in asphalt mixes would be a very useful way of recycling the huge amount of GRP pipe waste powders. Therefore, it is imperative that, like any other newly introduced material, a systematic study like this study should be carried out to find out its optimum content and identify if it produces as successful performance as its conventionally available counterpart, such as LS in this case. Considering the existence of a wide variety of industrial sectors and the potential hazards posed by the wastes, the potential use of waste in asphalt concrete or other engineering materials should continue to be explored for many years to come. Another researcher obtained the use of PVC up to 7.5% by the weight of bitumen, and it can be used for the construction of bituminous roads in warmer region from the view point of stability, stiffness and voids characteristics [13].

2.5 Hot Mix Asphalt Design Methods

Asphalt concrete mix design is to determine the combination of asphalt cement and aggregate that will give long-lasting performance to pavement structure. This mix design involves laboratory procedures to determine an appropriate blend of aggregate sources (or gradation) and selecting type and amount of asphalt cement. A properly designed asphalt mixture provides a balance of engineering properties and economics that ensures a durable pavement. The mix design is just the starting point to assure that an asphalt pavement layer will perform as required. Together with proper construction practice, mix design is an important step in achieving well-performing asphalt pavements. Correct mix design involves adhering to an established set of laboratory techniques and design criteria. The design of asphalt paving mixes, as with other engineering materials designs, is largely a matter of selecting and proportioning materials to obtain the desired properties in the finished construction product [42]. The overall objective for the design of asphalt paving mixes is gradation of aggregates and binder content that yields a mix having:

- Sufficient asphalt to ensure a durable pavement.
- Sufficient mix stability to satisfy the demands of traffic without distortion or displacement.
- Sufficient air voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading and a slight amount of thermal binder expansion without flushing, bleeding and loss of stability

- A maximum void content to limit the permeability of harmful air and moisture into the mix
- Sufficient workability to permit efficient placement of the mix without segregation and without sacrificing stability and performance and
- Aggregate texture and hardness to provide sufficient skid resistance in unfavorable weather conditions.

The final goal of mix design is to select a unique design binder content that will achieve a balance among all of the desired properties.

2.5.1 Marshall Mix Design Method

The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method [42]. In this method, the resistance to plastic deformation of a compacted cylindrical specimen of bituminous mixture is measured when the specimen is loaded diametrically at a deformation rate of 50 mm per minute. There are two major features of the Marshall method of mix design. i.e., density-voids analysis and stability-flow tests. The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60°C. The flow value is the deformation that the test specimen undergoes during loading up to the maximum load. Flow is measured in 0.25 mm units. This design procedure includes a density-voids analysis of the compacted specimens to determine the percent air voids and percent voids filled with asphalt (VFA). After these determinations, the specimens are tested at 60°C (140°F), and the Marshall Stability (maximum load observed in the test) and flow value (deformation corresponding to the maximum load) are obtained. Data resulting from these mix evaluations are plotted as a series of curves and include density versus asphalt content, percent air voids versus asphalt content, percent VFA versus asphalt content, Marshall Stability versus asphalt content, and flow value versus asphalt content.

The design asphalt content is determined as the average of the four contents selected corresponding to the peak density, 4 percent air voids, 75 percent VFA, and maximum Marshall Stability. This asphalt content is then checked to ensure that the resulting air void content and percent VFA fall within prescribed limits, that the Marshall stability exceeds a specified minimum level, and that the flow value does not exceed a prescribed maximum value [42].

According to (Asphalt institute, 2014), the binder content corresponding to 4 percent air voids is selected (on the basis of a compactive effort representative of the traffic to be applied). Compactive efforts range from 35 to 75 blows per side for traffic ranging from light to heavy. Other mix properties, including the Marshall stability, flow value, and VMA, are then checked to determine whether specified criteria have been satisfied.

Table 2. 5: - Mechanical Properties of binder and W/Course (Asphalt institute, 2014)

Total Traffic (10E6 ESA)	< 1.5		1.5 - 10		> 10	
Traffic Class	Light Traffic		Medium Traffic		Heavy Traffic	
Mixture Parameters	Min	Max	Min	Max	Min	Max
Stability (kN at 60˚C)	3.5	-	6	-	7	-
Compaction level (No of blows)	2*35		2*50		2*75	
Flow (mm)	2	4	2	4	2	4
Air void (%)	3	5	3	5	3	5
VFA (%)	70	80	65	78	65	75
VMA (%)	13	-	13	-	13	-

2.6 Moisture Susceptibility of Hot Mix Asphalt

Premature failure may result due to stripping when critical environmental conditions act together with poor and/or incompatible materials and traffic. Moisture susceptibility is a problem that typically leads to the stripping, loss in strength and durability due to the presence of water and this stripping makes an asphalt concrete mixture ravel and disintegrate. Moisture damage can occur due to three main mechanisms: loss of cohesion of the asphalt film, failure of the adhesion between the aggregate particles and the asphalt film, and degradation of aggregate particles due to freezing (Brown & Kandhal, 2001) [43].

Pavements are susceptible to low temperature cracking. Particularly in colder area the tensile strength of pavements at low temperature should be adequate enough to resist cracking. The retained stability value for asphalt mixes prepared with Rice husk ash and Slag fillers satisfy the minimum retained stability requirement of AASHTO standard specification (75%). It indicates that mixes containing Stone dust, Slag, and Rice husk ash as filler had good resistance to moisture-induced damages (Akter & Hossain), [44].

Many variables affect the amount of moisture damage which occurs in an asphalt concrete mixture. Some of these are related to the materials forming hot mix asphalt such as aggregate and asphalt binder. Others are related to mixture design and construction (air void level, film thickness, permeability and drainage), environmental factors, traffic conditions and type, and properties of the additives. The presence of moisture, combined with the repeated action of traffic, accelerates damage to the AC pavement [42]. To combat stripping, proper mix design is essential and proper field compaction with specified air void which prevent water entering into the AC layer. Many tests methods have been developed in the past to predict the moisture susceptibility of HMA mix however; no test has any wide acceptance. This is due to their low reliability and lack of satisfactory relationship between laboratory and field conditions. Selected test methods used by some agencies will be discussed briefly [28]. The first two test methods are subjective tests while the reaming are strength tests. The test methods mentioned below are not the only ones and other tests are still being used throughout the world.

i. **Boiling water test (ASTM D3625):-** Loose HMA mix is added to boiling water. ASTM specified a 10 minute boiling period. The percentage of the total visible area of the aggregate that retains its original coating after boiling is estimated as above or below 9%.

Static immersion test (AASHTO T182):- HMA mix is immersed in distilled water at 25°C for 16 to 18 hours. The percentage of total visible area of the aggregate which remains coated will be estimated as above or below 95%.

ii. **Lottman test (NCHRP 246):-** This is a strength test developed by Lottman under National Cooperative Highway Research Program 246. Nine specimen 102mm in diameter and 64mm high are compacted at expected field air void content. The specimen are divided into three, three specimen per group. Group 1 is control group. Group 2 are vacuum saturated (660 mm Hg) with water for 30minutes. Groups 3 are also vacuum saturates subjected to freeze at 180°C for 15hours and thaw for 24 hours at 60°C. All nine specimen are tested for resilient modulus or indirect tensile strength.

Retained tensile strength (TSR) is the quotient of indirect tensile strength of conditioned specimen to indirect tensile strength of control specimen. A minimum TSR of 0.7 is used as a guideline.

iii. **Modified Lottman Test (AASHTO T283)**:- uses the Lottman test with some modification. The sample size is reduced to six and grouped into two containing three specimen. The specimen are compacted to 6 to 8% air void. Group 1 is a control specimen while group 2 are vacuum saturated (55 to 80% saturation) with water and then subjected to one cycle freeze and thaw. All specimen are tested for indirect tensile strength at 25°C at a loading rate of 51mm/minute. TSR is determined based on the Lottman test and a minimum value of 0.7 is usually specified.

iv. **Marshall Immersion test (ASTM D1075):-** Six Marshall specimen are prepared for this test. The specimens are grouped into two groups, each with three specimens. Group 1 is the control specimen maintained in air at 25°C while group 2 is immersed in water for 24 hrs. at 60°C or at 49°C for four days. Group 2 specimen is then transferred to 25°C water bath for 2hrs and compressive strength of both groups is determined. Index of retained strength is determined just like TSR in Lottman test. A value of at least 70% is specified as a requirement in many agencies. Super pave design guideline requires a minimum of 80% retained strength.

2.7 Summary

Generally, this chapter describes the literature review about what the researcher was focused on. The review of literature includes basic concepts of hot mix asphalt which includes aggregates, asphalt binder, basic concepts of mineral fillers, and the effect of recycled polymers as a mineral filler and binder modifiers in hot mix asphalt. Therefore by taking this issue into account, this study is required to investigate the effects of thermoplastic polymer materials (Low Density Polyethylene (LDPE) as a modifier and Polyvinyl Chloride (PVC) as mineral filler in asphalt mixtures) on Marshall Properties and Moisture susceptibility of HMA.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Sampling Area

For this study samples of recycled polymer materials (Low Density Polyethylene (LDPE) which used as binder modifier and Polyvinyl Chloride (PVC) which used as mineral filler) were collected from Universal Plastic Factory PLC, Bole Sub city, Addis Ababa, Ethiopia. Source: -Universal Plastic Factory PLC in Addis Ababa - Addis Ababa Ethiopia | Yellow Page Ethiopia. The sampling site point location map is shown in Figure 3.1

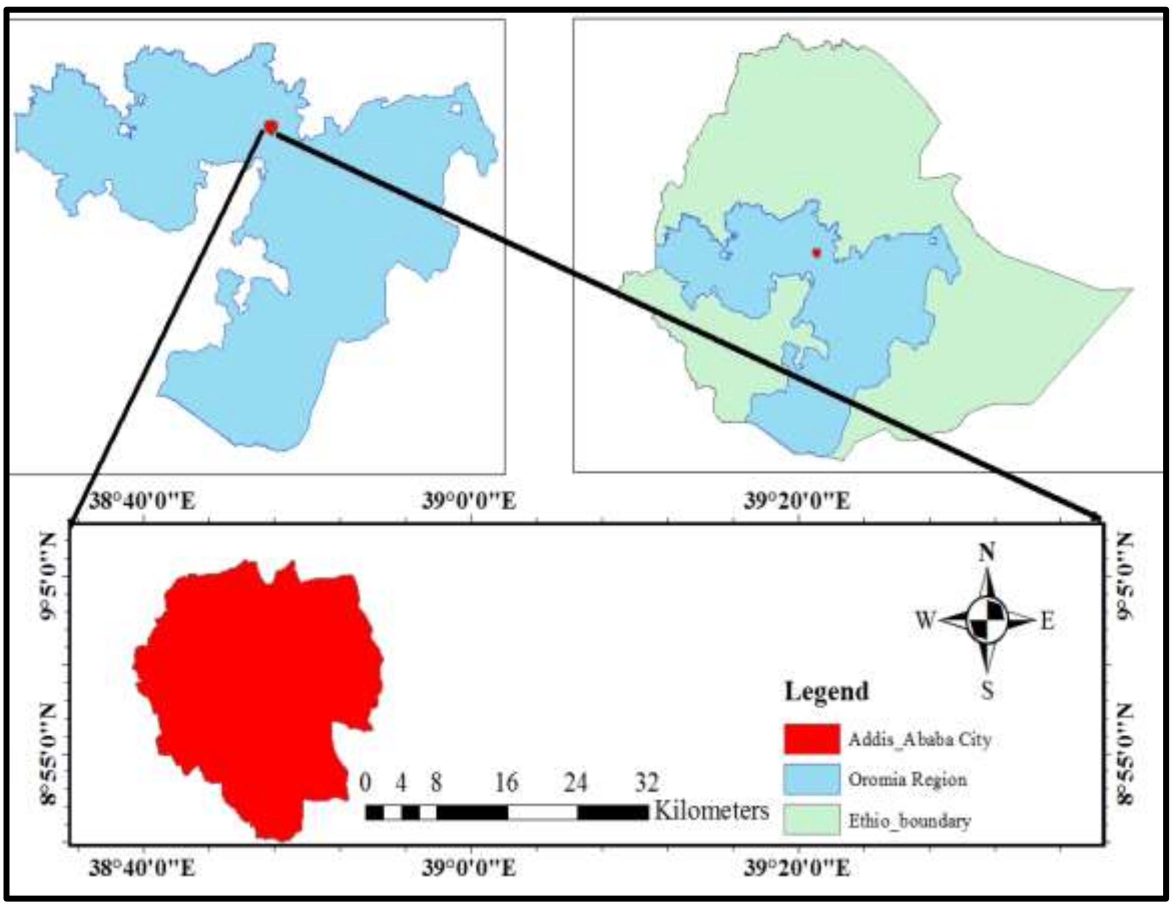


Figure 3. 1: - Location of Sampling of Recycled polymer materials.

Source for Map: - https://www.diva-gis.org/gdata.

3.2 Study Design

This study was designed to meet the objective based on experimental procedure. The experimental procedure was performed following the ERA, ASTM, AASHTO, and BS material testing standards and guidelines. The study design follows literature review, problem identification, research questions and objectives formulation, sample collection and preparation, experimental set up, data analyses and interpretation to draw conclusions based on the finding.

The experimental set up compromised the material characterization, Marshall Mix design and Moisture susceptibility test of recycled polymer materials as asphalt mixtures. The material characterization was performed for aggregates, bitumen and mineral fillers. In Marshall Mix design, aggregate gradation was performed according to ASTM D1535 and Marshall Specimens were conducted according to ASTM D1559. Three Marshall Mix specimens were prepared with bitumen content of 4 to 6% at 0.5% increments for the aggregate gradation of 5, 5.5 and 6% CSD. A total of forty five specimens were prepared to determine OBC and the corresponding volumetric properties of HMA. NAPA procedure is used to determine the OBC in the mix. Fifteen specimens were prepared with polyvinyl chloride pipe powder at percentage replacement of 0 to 100% at 25% increments. Moreover, in this study, another eighteen specimen were conducted to determine the effect of low density polyethylene at a percentage of 0 to 10% at 2% increment on the asphalt binder.

The performance of the HMA specimen against external effect of water was also analyzed with twenty four (24) specimens to evaluate for Moisture resistivity. The results were analyzed and interpreted through discussing the effect of recycled polymer materials (LDPE as modifier & PVC Pipe powder as filler) on the Marshall properties of the mix and performance of HMA. In this phase, the suitability of waste polymer materials as asphalt mixtures in HMA was evaluated for stability, flow, unit weight, Air void, void in mineral aggregate, and void filled with asphalt. Also, moisture susceptibility of hot mix asphalt was discussed. Finally, conclusions and recommendations are made based on findings. Figure 3.2 shows the overall study design flow chart for this study.

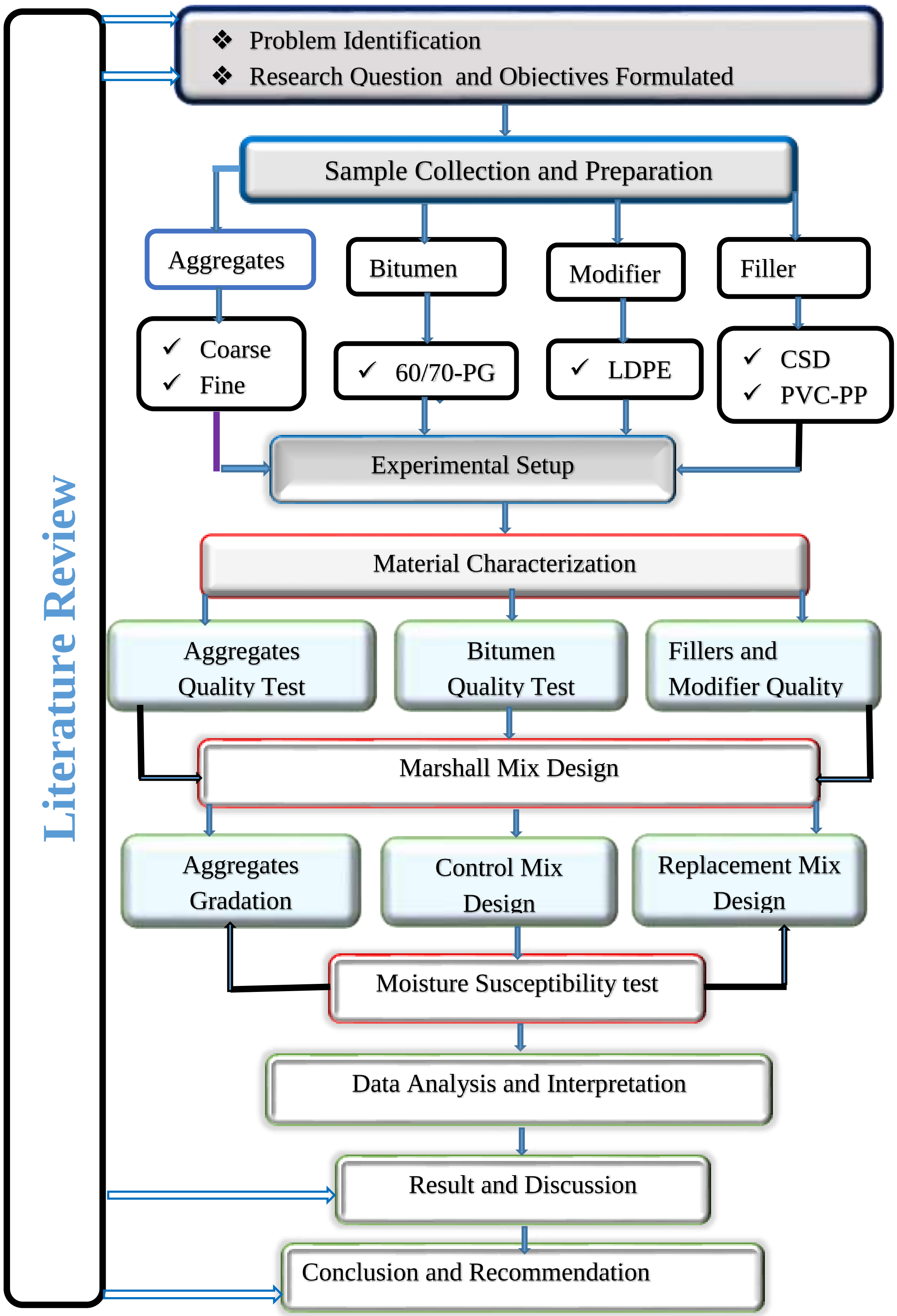


Figure 3. 2**: -** Study method flow chart

3.3 Sampling

3.3.1 Sampling Techniques

This study followed a purposive sampling, which is non-probability sampling method. Representative sample of aggregates was collected manually in accordance with AASHTO T2 methodology for sampling from stockpiles and AASHTO T40, Sampling aggregate for bituminous materials. The collected samples were prepared properly to ensure that the applicable test results accurately reflect the true characteristics of the material according to AASHTO T 248 and AASHTO T 87.

Universal plastic factory private limited company which is located in Addis Ababa, Bole sub-city collect and store waste plastic or polymer materials in his own warehouse for the purpose of recycling. The organization used a huge mechanical grinder/shredder in order to dis-integrate the plastic materials into the required size of recycling. The recycled Low density polyethylene used as binder modifier and polyvinyl chloride pipe powder used as mineral filler replacement were collected from the company for this study. Low density polyethylene (Plastic cubs) disintegrated/shredded into smaller pieces of size 2 to 3mm for use as binder modifier, and polyvinyl chloride pipe converted into smaller size or finer than 0.15mm for use as mineral filler by shredding machine.

3.3.2 Sample Size

Aggregate and other materials sampled in the field need to be reduced to appropriate sizes for testing. It is, therefore, necessary to reduce field samples while minimizing the chance of variability during handling. In some instances a few particles on a given sieve might effect a gradation significantly enough to alter an interpretation of the field sample and subsequently the entire material's compliance with specifications. The appropriate field sample reduction method is dependent chiefly on the nominal maximum size of the aggregate, the amount of free moisture in the sample, and the equipment available. For this study, the samples obtained from the field in accordance with AASHTO T2 were reduced to the test size in accordance with AASHTO T248.

3.3.3 Sample Procedure

Sieve analysis on reduced sample size were performed as per as the requirement for hot mix asphalt mixtures. Sieve analyses determine the gradation or distribution of aggregate particles within a given sample in order to determine compliance with design and production standards. Samples were dried to a constant mass in an oven maintained at 110 ± 5°C (230 ± 9°F) according to AASHTO T87 practice for dry preparation of soil samples. Finally, the samples were evaluated for physical test, mechanical analysis and moisture density.

3.3.4 Sample Preparation

In this experimental work, bitumen content was taken in percentage 4%, 4.5%, 5%, 5.5% 6% and three specimens were prepared. Filler content was taken in percentage 5%, 5.5%, 6%. For a control mix in order to obtain optimum bitumen content and filler content, a total of forty five (5*3*3 =45) were prepared. The determined optimum bitumen content 5.43% and filler content was 5%. Keeping these values constant replacement mix was conducted. The LDPE content was taken in percentage 0%, 2%, 4%, 6%, 8%, 10% and 3 specimens for each of LDPE content, a total of eighteen (6*3=18) were prepared. The PVC-PP content was taken in percentage 0%, 25%, 50%, 75%, 100% and again 3 specimens for each of PVC-PP content, a total of fifteen (5*3=15) were prepared. Generally, a total of thirty three (33) specimens were prepared for replacement mix.

3.4 Methods of Data Collection

From early development of this study topic, various data were collected and processed to achieve the objective of this study. These were conducted first by reviewing previous related literature and different international & local standard specification, secondly by laboratory tests regarding the preparation of HMA. Specifically, both primary and secondary data were used in this study.

3.4.1 Primary Source of Data

These sources of data were obtained through laboratory tests on aggregates, filler and bitumen and Marshall Property's results.

3.4.2 Secondary Source of Data

The secondary data were collected from previous studies, scientific researches, national and international pavement design manuals & standards.

3.5 Study Variables

3.5.1 Dependent Variable

The dependent variable are the increment or decrement in the volumetric parameters of hot mix asphalt (HMA) mixtures such as practical bulk specific gravity, stability, flow, voids in total mix, voids filled with asphalt content, and voids in mineral aggregate.

3.5.2 Independent Variables

The independent variables are additive rate or the amount of low density polyethylene added to the bitumen as a binder, the amount of polyvinyl chloride pipe powder added to the mix as a filler, material properties, temperature, bitumen content and number of blows.

3.6 Materials

Hot mix asphalt mixture is a combination of different size of aggregates with mineral filler, uniformly mixed and coated with bitumen. This mixture require selection, characterization and proportioning of ingredients to provide the required quality and properties of the mix. The overall mix design procedure starts with the selection and evaluation of aggregates and bitumen binder. The aggregates, CSD filler and bitumen used in this study were collected from ERA, Own force road maintenance, Deneba site located at 80 km from Jimma town.

3.6.1 Aggregates

Aggregates used for HMA are generally required to be hard, tough, strong, durable, clean, rough and hydrophobic surface (ERA, 2013). The physical properties of aggregates used for HMA is determined by evaluating size and gradation, cleanliness, hardness, durability, surface texture, particle shape and water absorption. Various quality tests were conducted on the physical properties of aggregates to ensure its suitability in HMA. Sieve analysis, Specific gravity, water absorption, Los Angles abrasion, Flakiness index, Aggregate crushing value, Aggregate impact Value were the tests performed for aggregates following their respective test methods.

3.6.2 Bitumen

Performance characterization of asphalt specifically depends on its physical properties. Typically, the physical properties of the asphalt binder are a direct outcome of its chemical properties. In this study, 60/70 penetration grade bitumen was used as it is a common type of bitumen which is mostly used in tropical areas. The physical characteristics of the bitumen were determined conformed to AASHTO and ASTM standards and compared with ERA standard specification. The properties of bitumen such as penetration, ductility, softening point, specific gravity and flashpoint were performed and evaluated as per ASTM standards experimentally.

3.6.3 Low Density Polyethylene (LDPE)

Low density polymer used for this experiment was a waste recycled plastic household goods that collected from Universal Plastic Factory PLC, Bole Sub city, Addis Ababa, Ethiopia. Universal plastic factory private limited company which is located in Addis Ababa, Bole sub-city is collect and store waste plastic or polymer materials in his own warehouse for the purpose of recycling. The organization used a huge mechanical grinder/shredder in order to dis-integrate the plastic materials into the required size of recycling. Low density polyethylene (Plastic cubs) disintegrated/shredded into smaller pieces of size 2 to 3mm for use as binder modifier.

3.6.4 Fillers

Fillers consist of finely divided mineral matter such as crushed rock dust, hydrated lime or cement. Filler has an important effect on the voids content and the stiffness of the bitumen fines matrix. The filler materials used in the study were crushed stone dust (as a control) and Polyvinyl Chloride pipe powder (as a replacement). The physical properties of crushed stone dust were conducted according to AASHTO T84-95.

a. Crushed sand stone (CSD)

For this study, filler minerals used as controller in conventional mix were fines from sand and stone dust finer than 0.075 mm. A considerable amount of stone dust is produced during crushing and some stone dust remains in crushed stone. These are mixed with fine sand for proper utilization of stone dust.

b. Polyvinyl Chloride (PVC)

For this study, the grinded recycled PVC pipe powder was obtained from the local recycler company which is called Universal Plastic Factory PLC located in Gerji, Bole Sub city, Addis Ababa, Ethiopia. Universal Plastic Factory PLC is a huge recycler in Addis Ababa, Ethiopia and uses a mechanical grinder in order to disintegrate the waste polymer materials for reuse. PVC pipe was converted into a smaller size (smaller than 0.15 mm) by this mechanical grinder. In order to use PVC-PP as filler, PVC-PP was first sieved through a 0.075mm sieve and the powder passing through the sieve was used as filler in asphalt mix.

3.7 Experimental Setup

This study was performed based on laboratory tests to evaluate the suitability of recycled waste polymer materials (Low Density Polyethylene and PVC Pipe Powder) in HMA. In this study Marshall Mix design and Moisture susceptibility tests were performed. The physical characterization of aggregates, bitumen and fillers were evaluated experimentally. To evaluate these material properties different quality control tests were performed and compared with ERA, AASHTO, ASTM, and BS standards. The experimental procedures, considerable data concerning the Marshall parameters of HMA were obtained from the test results. These data were recorded on the standard formats of laboratory reports and used as input for the analysis of the study results and findings of the research.

3.7.1 Marshall Mix Design

The overall procedure for mixture design always begins with acceptance tests performed on aggregates and bitumen binder considered for the design. HMA is a homogenous substance formed when aggregate and bitumen are combined with new physical properties but not similar to the physical properties of its components. It is the procedure of determining what aggregate to utilize, what bitumen to use, and what the best blend of these both ingredients should be. After determining the quality and quantity of all mixture constituents, the asphalt mix design proceeds. Generally, HMA mix design has included some laboratory tests that use various critical procedures to provide characterizations of each trial HMA blend.

In this step, several trial blends of aggregates gradation were prepared According to ASTM D1535 specification to obtain the design aggregate gradation. Afterward, the several specimens of HMA mixture were prepared at bitumen content of 4 to 6% by 0.5% increments for aggregate gradation of 5, 5.5 and 6% filler content. For each binder content amount and filler content, three samples were prepared, making a total of 45 samples (3*5*3). Hence, a total of forty five Marshall Specimens were prepared to obtain OBC. These Marshall specimens were subjected to Marshall Stability and flow test as per AASHTO T 1559 or ASTM D 6927 standards. Marshall Stability parameters such as stability, flow, air void, void filled with asphalt, and void in mineral aggregates were determined and evaluated following ERA (2013) standards. The OBC and optimum filler content were determined based on the maximum stability of the mixtures.

For all the mixes, keeping OBC and design gradation constant, crushed stone dust was replaced by Polyvinyl Chloride pipe powder as a replacement from 0 to 100% at 25% increments. A total of 15 specimens were prepared for replacement to obtain the acceptable percentage of PVC Pipe Powder. On other hand, in the same manner, keeping OBC and design gradation constant, the weight of the pure liquid bitumen was measured into a steel cylinder and heated till it fully liquefied and was in a state to dissolve the low density polyethylene. The bitumen was heated to a temperature of 140°C to 170°C. The shredded low density polyethylene materials were separately heated in a blast furnace to liquefy before it was weighed and blended into measured bitumen and after continuous stirring by steel spoon, it was thoroughly mixed with hot bitumen. The polyethylene was weighed with respect to 0%, 2%, 4%, 6%, 8% and 10% weight of the optimum bitumen content. A total of 18 specimen were prepared to obtain acceptable polymer modified bitumen. HMA design requires aggregate gradation, preparing Marshall Specimen and determination of optimum bitumen content.

a. Aggregate gradation

Aggregate gradation is the distribution of particle sizes expressed as a percent of the total weight. This can be determined by sieve analysis, through series of sieves stacked with progressively smaller openings from top to bottom, and weighing the material retained on each sieve. Gradation of aggregate is expressed as total percent passing sieve sizes and represented by a gradation curve for which the ordinate is the total percent by weight passing a given size on an arithmetic scale, while the abscissa is the particle size plotted to a logarithmic scale. In this study sieve opening; 25, 19, 12.5, 9.5, 4.75, 2.36, 1.18, 0.6, 0.3, 0.15, and 0.075 mm standard sieve were used. The coarse aggregate, fine aggregate, and the filler material were proportioned so as to fulfill the requirements of the relevant standards. The required quantity of the mix is taken so as to produce compacted bituminous mix specimens of thickness 63.5 mm approximately 1200 gm. of aggregates and filler are required to produce the desired thickness. In the designing of aggregate blending, any number of the trial could be attempted. However, three trials is the standard number of blends. For this study, aggregates were sieved and three trial blends were prepared in the laboratory according to ASTM D3515 specifications.

b. Marshall Specimens preparation (Control mix)

Marshall Specimens for HMA were prepared for the desired aggregate gradation and binder content in bulk to provide a sample for Marshall Parameter determination procedure in accordance of ASTM D1559. The coarse aggregate, fine aggregate, and the filler material were proportioned so as to fulfill the requirements of the relevant standards. The required quantity of the mix is taken so as to produce compacted bituminous mix specimens of thickness 63.5mm approximately 1200gm of aggregates and filler. The aggregates were heated to a temperature of approximately 160°C to 170°C, the compaction mold assembly and rammer are cleaned and kept pre-heated. The bitumen was heated to a temperature of 140°C to 170°C. Marshall Specimens were prepared at bitumen content of 4 to 6% at 0.5% increments for aggregate gradation of 5, 5.5 and 6% filler content. The mix were placed in a mold and compacted with a compaction effort of 75 blows on each side.

Finally, the specimens were permitted to cool overnight and removed from the mold with the help of extrusion jack and the compacted specimens were subjected to determination of bulk density and Marshall Stability and flow tests. The Marshall stability and flow data collected were graphically plotted to determine the OBC. This OBC was used for the replacement mix following the Marshall Specimen preparation above. The Marshall properties of the asphalt mix such as stability, flow, air voids in the total mix, density, void in mineral aggregates and voids filled with bitumen were determined. Finally, the results were analyzed and compared with standard specifications of bituminous wearing course as per (Asphalt institute, 2014).

c. Optimum bitumen content determination

The main intention of the Marshall Mix design is to determine the OBC that satisfy the required values of design parameters. In this study the NAPA procedure was used to determine the optimum bitumen content. NAPA suggests the optimum asphalt content is simply the asphalt content that produce exactly 4% air voids. Finally, the Marshall parameters were determined based on optimum bitumen content and compared with the specification for acceptability as indicated in Table 4.5.

3.7.2 Marshall Mix Design for Recycled Polymer Materials

The design gradation and OBC determined in Marshall Mix design were used for the examination of Marshall Properties and moisture susceptibility of recycled polymer materials (low density polyethylene and polyvinyl chloride pipe powder) in hot mix asphalt.

a. Marshall Mix Design for Low Density Polyethylene

In this study, HMA mixes were prepared (as per the Marshall mix design procedure refer to ASTM designation D 1559-62T) by adding bitumen to the mix (as per the Job Mix) by weight of optimum bitumen content and the LDPE were added in different percentages to the mix by weight of bitumen. Keeping OBC and design gradation constant, the weight of the pure liquid bitumen was measured into a steel cylinder and heated till it fully liquefied and was in a state to dissolve the low density polyethylene. The bitumen was heated to a temperature of 140°C to 170°C. In the same manner, the shredded low density polyethylene materials were separately heated in a blast furnace to liquefy before it was weighed and blended into measured bitumen and after continuous stirring by steel spoon, it was thoroughly mixed with hot bitumen. The polyethylene was weighed with respect to 0%, 2%, 4%, 6%, 8% and 10% weight of the optimum bitumen content. A total of 18 specimen were prepared to obtain acceptable polymer modified bitumen. Marshall Stability tests were conducted on polymer modified bituminous mixes.

b. Marshall Mix Design for Polyvinyl Chloride Pipe Powder

The crushed stone dust was replaced with polyvinyl chloride (PVC) Pipe Powder from 0 to 100% at increments of 25%. The Marshall Mix specimens were prepared, compacted, and tested according to ASTM D 1559. Marshall Mix specimens were produced for each filler proportion, and the average values of bulk specific gravity, Marshall Stability, flow, air void, and void in mineral aggregate, void filled with asphalt were determined.

3.7.3 Volumetric Parameters of HMA Mixtures

HMA mixture design determines the volume of bitumen and aggregate necessary to a mixture with the desired properties. Since weight, measurements are typically much easier; weights are taken and then converted to volume by using specific gravities. The volumetric properties of a compacted paving mixture provide some indication of the mixture’s probable pavement service performance. The properties that are to be considered include: theoretical maximum specific gravity (Gmm), bulk specific gravity (Gmb), air voids (VIM), volume of bitumen, voids in mineral aggregate (VMA), voids filled with asphalt (VFA) and effective asphalt content (Pbe). The performance of the hot mix asphalt could be determined from the computation of the volumetric properties of the compacted mixture.

Bulk specific gravity of compacted specimen (Gmb): is the ratio of mass of compacted specimen in air to volume of permeable material (including both permeable and impermeable voids). The bulk specific gravity is determined for the compacted specimens after extruded from the mold taking the weight in air, in water and in saturated surface dry. This value is used to determine the mass per unit volume of the compacted mixture. The bulk specific gravity of the compacted specimen increases with increasing asphalt content up to certain point, after which it decreases. In this study, the bulk specific gravity of compacted mixtures was determined by using saturated surface dry specimen as per AASHTO T 166 or ASTM D 2726. The standard bulk specific gravity of compacted specimen is expressed in Eq. (1).

$$Gmb = \frac{Wd}{wssd - Ww} \quad \text{.......} \quad (1)$$

Where; Gmb =bulk specific gravity of compacted asphalt mixture, Wd = weight of sample in air, Wssd = weight of saturated surface dry of sample, Ww = weight of sample in water.

Theoretical Maximum specific gravity of loose specimen (G_{mm}): is the ratio of the weight in air of a unit volume of loose asphalt mixture at a stated temperature to the weight of an equal volume of gas-free distilled water at a stated temperature. The theoretical maximum specific gravity (G_{mm}) at various asphalt binder content was used to determine the air void percentage in the mix. The theoretical maximum specific gravity of loose mix is defined as in Eq. (2).

$$Gmm = \frac{A}{(A+B)-C} \quad (2)$$

Where; A = weight of loose asphalt sample (g), B = weight of pycnometer filled with water (g) C = weight of pycnometer filled with water and lose asphalt sample (g).

Voids in the Mineral Aggregates (VMA): is the total volume of inter-granular void space between the mineral aggregate particles of a compacted mixture expressed as a percentage of the total mix volume. It represents the volume of air void and volume of effective asphalt binder (non-absorbed by aggregates).VMA significantly affects the performance of mixture. Hence, too small VMA leads the durability problem whereas too large VMA shows stability problem and un-economical to produce. The VMA has two components: the volume of the voids filled with asphalt and the volume of voids remaining after compaction. The VMA generally decreases to a minimum value then increase with increasing asphalt contents. Specifically, a minimum value of VMA is described in different standard specifications, whereas a maximum VMA may or may not be specified. VMA is expressed mathematically as in Eq. (3).

$$VMA = 100 - \left(\frac{Gmb}{Gsb}\right) * Ps \quad (3)$$

Where; VMA = void in the mineral aggregates (%), Gmb = bulk specific gravity of compacted mixture (g/cm^3), Gsb = bulk specific gravity of total aggregate and Ps = aggregate content, the percentage by mass of the total mixture.

Air voids (VIM): is the total volume of the small pockets of air between the coated aggregate particles in the compacted asphalt mixture. The amount of air voids in a mixture is particularly vital and closely related to stability and durability. The percent of air voids decreases with increasing bitumen contents. It is given mathematically by, Eq. (4).

$$VIM = \left(\frac{Gmm-Gmb}{Gmm}\right) * 100 \quad (4)$$

Where; VIM= percentage of Air Void in the compacted mixture, Gmm= maximum specific gravity of the loose mixture, Gmb = bulk specific gravity of the compacted mixture (g/cm^3)

Voids Filled with Asphalt (VFA): is the portion of the voids in the mineral aggregate that contain asphalt binder. VFA is the percentage of inter-granular void pocket between the aggregate particles filled with asphalt binder and can expressed as the ratio of the difference of VMA and VIM to VMA. The VFA value increases with increasing bitumen contents. Mathematically it is computed as in Eq. (5).

$$VFA = \left(\frac{VMA - VIM}{VMA}\right) * 100 \quad \ldots \quad (5)$$

Where; VFA = percentage of void filled with asphalt binder, VMA = percentage of void in mineral aggregate, VIM= percentage of air voids in the compacted mixture

Volume of absorbed Bitumen (Pba): is the volume of bitumen expressed by percentage in the mixture that has been absorbed by the pore space of the aggregate. It is expressed as in Eq. (6).

$$Pba = Gb * \left(\frac{Gse - Gsb}{Gse * Gsb}\right) * 100 \quad \ldots \quad (6)$$

Where; Pba = percentage of absorbed asphalt binder, Gb = specific gravity of asphalt binder, Gse = effective specific gravity of total aggregate, Gsb = bulk specific gravity of total aggregate

Effective Asphalt Content (Pbe): is the total asphalt content of the HMA less the portion of asphalt binder that is lost by absorption into the aggregate. The effective asphalt content is the measure of the asphalt film around the aggregate. The asphalt film thickness around the aggregate particle can be correlated to the durability, fatigue and moisture damage. The effective asphalt content is calculated as in Eq. (7).

$$Pbe = Pb - \frac{Pba}{100} * Ps \quad \ldots \quad (7)$$

Where; Pbe = effective asphalt content, percent by total weight of the mix, Pb = asphalt content, percent by total weight of mix, Ps = aggregate content, percent by total weight of mixture, Pba = absorbed asphalt, percent by weight of aggregate.

3.8 Moisture Susceptibility

Marshall Immersion test (ASTM D1075) was used for this study to evaluate HMA against moisture susceptibility. The laboratory test was conducted on both low density polyethylene (LDPE) which was used as binder modifier in asphalt mixtures and polyvinyl chloride (PVC) pipe powder that was used as filler replacement with crushed sand dust. The tensile strength of water conditioned as well as an unconditioned specimen for each materials mix was determined. A value of at least 70% is specified as a requirement in many agencies. Then the tensile strength ratios were calculated using the following equation:

$$\text{TSR} = \frac{St\ (cond)}{St\ (un\text{-}cond)} * 100 \qquad (8)$$

Where; TSR= Tensile Strength Ratio (%), St (cond.) = Average tensile strength of conditioned Sample (kpa), St (un-cond.) = Average tensile strength of unconditioned sample (kpa). The materials at optimum asphalt content is subjected to moisture sensitivity test.

3.8.1 Low Density Polyethylene (LDPE) Moisture Susceptibility Test

A total of 12 Marshall Specimens were prepared at optimum asphalt binder content for aggregate gradation with a binder material and low density polyethylene (LDPE). The specimen is grouped into two groups, each with three specimens. The first group, control group were kept at a temperature of 25°C for a period of 2 hours without soaking. The second group, conditioned samples were immersed in a water bath at 60°C, for a period of 24 hours. The samples were then removed from the water bath and kept in a water bath maintained at a temperature of 25°C for a period of 2 hours. These specimens are then attached between two load stripes and are loaded radially at a speed of 50mm/min and the load at failure is recorded at each case. Then the tensile strength of water conditioned as well as an unconditioned specimen for each mix was determined.

3.8.2 Polyvinyl Chloride (PVC) Pipe Powder Moisture Susceptibility Test

In the same manner that of LDPE procedure, a total of 12 Marshall Specimens were prepared at optimum asphalt binder content for aggregate gradation with crushed stone dust (CSD) and polyvinyl chloride pipe powder (PVC-PP). The specimen is grouped in to two groups, each with three specimens. The first group, control group were kept at a temperature of 25°C for a period of 2 hours without soaking. The second group conditioned samples were immersed in a water bath at 60°C, for a period of 24 hours. The samples were then removed from the water bath and kept in a water bath maintained at a temperature of 25°C for a period of 2 hours. These specimens are then attached between two load stripes and are loaded radially at a speed of 50mm/min and the load at failure is recorded at each case. Then the tensile strength of water conditioned as well as an unconditioned specimen for each mix was determined.

3.9 Data Quality Management

The quality of data is assured through the replication of measurements and standard specifications. To check the accuracy and validity of data instrument calibration and verification was carried out. Laboratory test data recording formats were prepared in order to avoid error of data. Finally, duplicate and triplicate measurements of parameters were conducted and mean ± standard deviation values are reported or presented in a figure.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Materials Properties

4.1.1 Aggregates physical properties

The physical properties of the aggregates are shown in Table 4.1. The water absorption, flakiness index, aggregate crushing value, Loss Angeles Abrasion test and aggregate impact value are 1.191, 23, 14.86, 11.58 and 6.31%, respectively. The water absorption of the aggregates is less than 2% indicated that the aggregate has low water absorption with durable and economic mix. Similarly, the aggregate crushing value is less than 25% which shows that the aggregate had resistance to crushing under a gradually applied compressive load. Also, the aggregate impact value indicates the aggregate is strong. The Los Angeles Abrasion loss values indicated that an aggregate is tough and resistant to abrasion. Therefore, the aggregate used for this study is applicable for HMA wearing course.

Table 4. 1**: -** Aggregate Physical Properties

Properties	Test Method	Test Result/Values			ERA(2013) Specifications
		9.5 to 25 (mm)	2.36 to 9.5 (mm)	0 to 2.36 (mm)	
Gsb	AASHTO T85 - 91	2.604	2.611	2.636	-
Gss		2.635	2.648	2.678	-
Gsa		2.688	2.714	2.753	-
WA, (%)	BS 812, Part 2	1.191	1.443	1.610	< 2
FI, (%)	BS 812, Part 105	23	-	-	< 35
ACV, (%)	BS 812, Part 110	14.86	-	-	< 25
LAA, (%)	AASHTO T96	11.58	-	-	< 35
AIV, (%)	BS 812, Part 112	6.31	-	-	< 25

Where; Gsb = Bulk dry specific gravity, Gss = Bulk Saturated Surface dry specific gravity, Gsa = apparent specific gravity, WA = Water Absorption, FI = Flakiness Index, ACV = Aggregate Crushing Value, LAA = Loss Angeles Abrasion, AIV = Aggregate Impact Value

4.2.2 Bitumen

The results of penetration, ductility, softening point, specific gravity and flash point are 65.90 mm, 109 cm, 48.41 ˚C, 1.02, and 320 ˚C respectively as shown in Table 4.2. Based on the standard specification, the bitumen used for this study is applicable for asphalt concrete mix design.

Table 4. 2**: -** Bitumen Quality Test Results

Test	Test method	Value	ERA (2013)
Penetration @ 25˚C (0.1 mm)	AASHTO T 49	65.90	60 – 70
Ductility @ 25˚C (cm)	AASHTO T 51	109	Min 50
Softening point (˚C)	AASHTO T 53	48.41	46 – 56
Specific gravity @ 25˚C	ASTM D 70	1.02	1.01 - 1.06
Flash point (˚C)	ASTM D 92	320	Min 232

4.1.3 Low Density Polyethylene (LDPE)

The physical properties of polyethylene material used in this study listed in Table 4.3. The melting temperature, boiling point, a glass transition temperature, density, molecular weight of repeat unit and specific gravity are indicated in below as sourced from the recycler of the material Universal Plastic Factory plc located in Bole Sub city, Addis Ababa, Ethiopia.

Table 4. 3**: -** The Physical Properties of LDPE

Properties	**Value**
Melting Temperature, °C	<115
Boiling Point, °C	> 360
Glass Transition Temperature, °C	80
Density @ 25°C	0.95gm/cm³
Molecular Weight of repeat unit	199.2gm/mol.
Specific Gravity	1.40gm/cm³

Source: - Universal Plastic Factory PLC in Bole Sub city- Addis Ababa, Ethiopia

4.1.4 Mineral Fillers

The filler materials used in this study were crushed stone dust as control and polyvinyl chloride (PVC) pipe powder as an ingredient. The results of gradation, and apparent specific gravity of crushed stone dust and polyvinyl chloride (PVC) pipe powder are summarized in Table 4.4.

Table 4. 4: - Physical Properties of Mineral Fillers

Sieve size	Passing (%)		Specification	
	CSD	PVC-PP	ASTM D242	ERA (2013)
No 30 (600 µm)	100	100	100	-
No 50 (300 µm)	100	96	95 – 100	-
No 200 (75 µm)	100	83.3	70 – 100	-
PI	NP	NP	-	< 4
Gsa	2.678	2.472	-	-

4.2 Marshall Mix Properties

4.2.1 Aggregate Gradation

Figure 4.1 shows percentage passing at each corresponding sieve size for three different aggregate gradations with 5%, 5.5%, and 6% filler contents for bituminous paving wearing course. The combined aggregate of the three gradations on the basis of three different percentages of fillers is applicable for HMA wearing course.

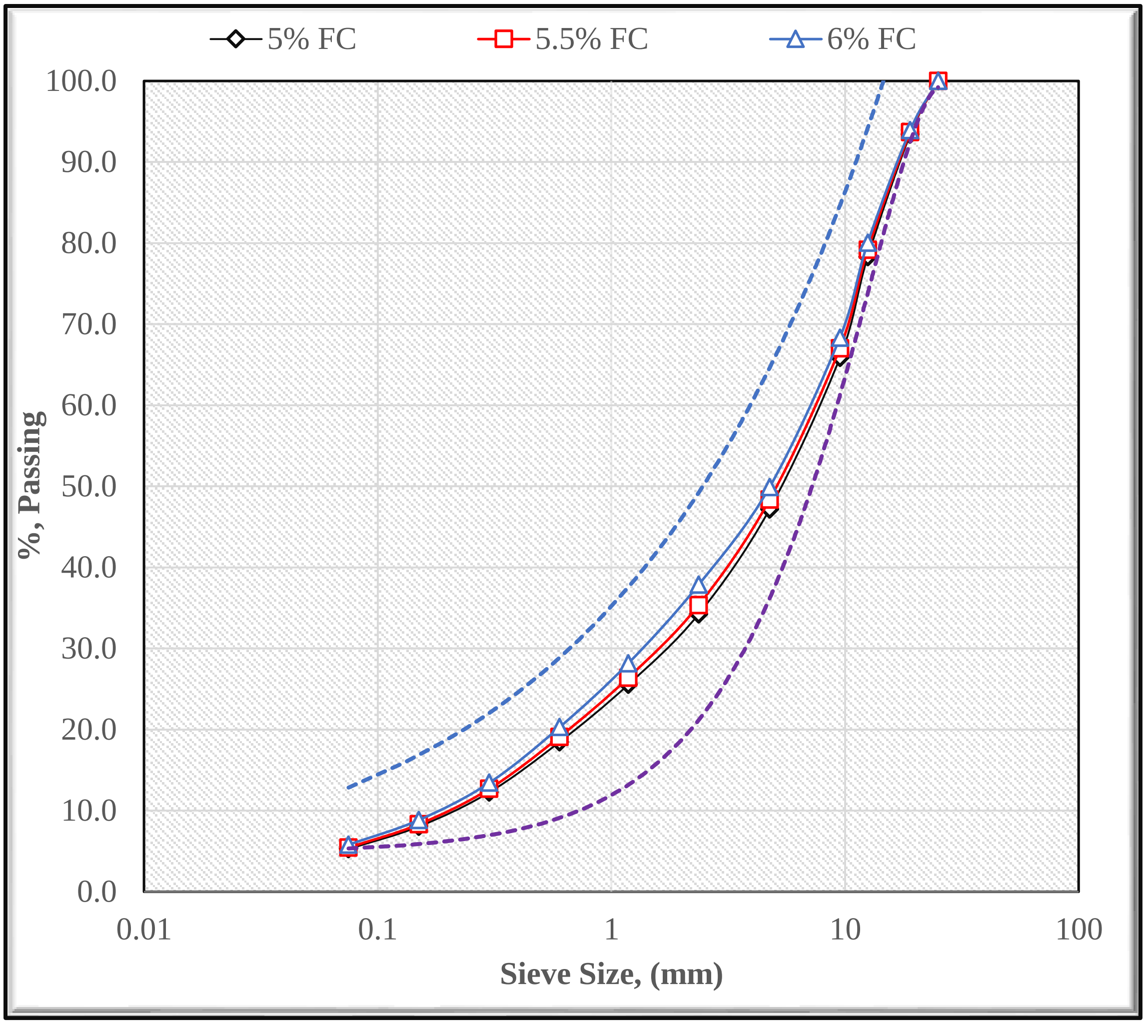


Figure 4. 1: - Aggregate gradation curve

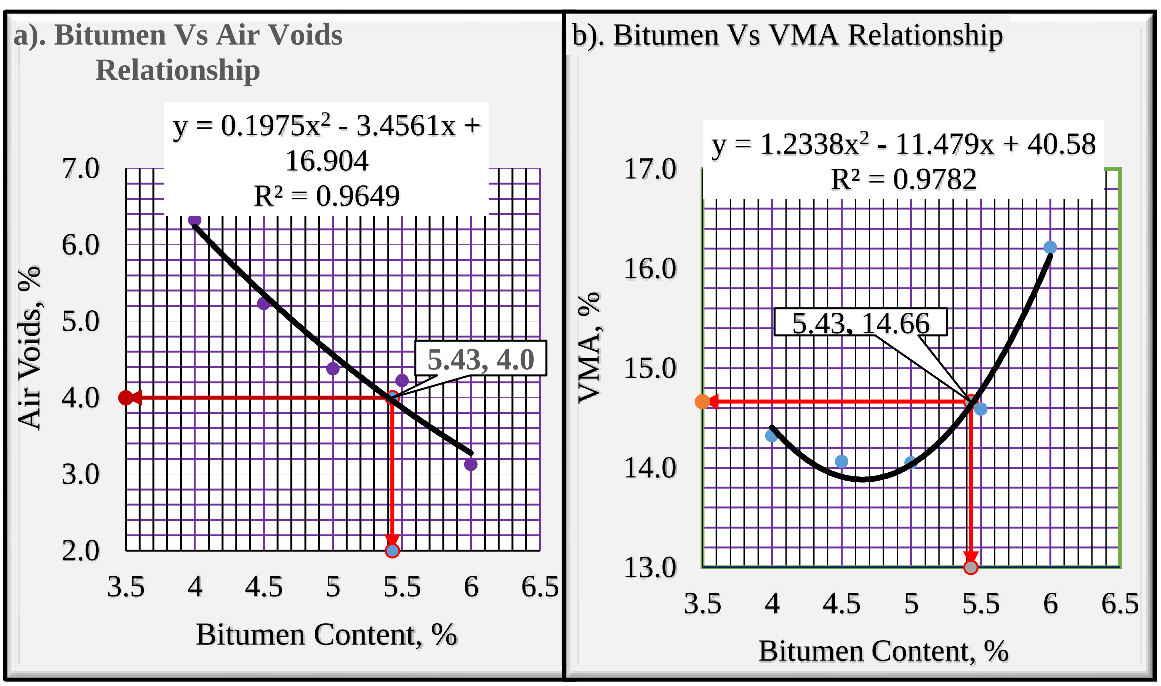
4.2.2 Marshall Mix Properties of Control Mix

The variation of Marshall Mix properties at bitumen contents 4 to 6% at 0.5% increments for mixes containing different proportion of filler 5, 5.5 and 6% are given as Figure 4.2 to 4.4 consequently.

a. Marshall Mix properties of 5% CSD

The air void in the mix decreased as bitumen content increases as shown on Figure 4.2a. The air void curve showed the usual concave up wards. This indicate that as bitumen content increases hot bitumen lubricates the aggregates allowing closer together in which air void decreases hence density increases. Figure 4.2b presents the graph for bitumen content versus void in mineral aggregates which is flattened U-shape. With the increase in bitumen content, the mix became workable and compacted easily, which increases density. However, as the bitumen content increases more than bitumen content at maximum density the thicker films around the individual aggregates were formed there by resulting low density and high VIM.

The graph of bitumen content versus void filled with asphalt is as presented on Figure 4.2c. The graph showed the usual convex upward, as bitumen content increased void filled with asphalt also increased. This indicated that the void in the mineral aggregates were filled with bitumen while the air void in the mix decreases. Figure 4.2d indicated the bulk specific gravity slightly increased to 2.343 g/cm^3 with increase bitumen content, after which it decreases. The stability increased with increase bitumen up to a maximum of 12.8KN after which the stability decreased as presented on Figure 4.2e. This indicated as bitumen content increases hot bitumen lubricates the aggregates allowing closer together in which the density increases. The flow value increased with the increase of bitumen content as shown on Figure 4.2f. The curve showed the usual concave down wards which indicates as the bitumen content increases the mix became plastic and loss stability.



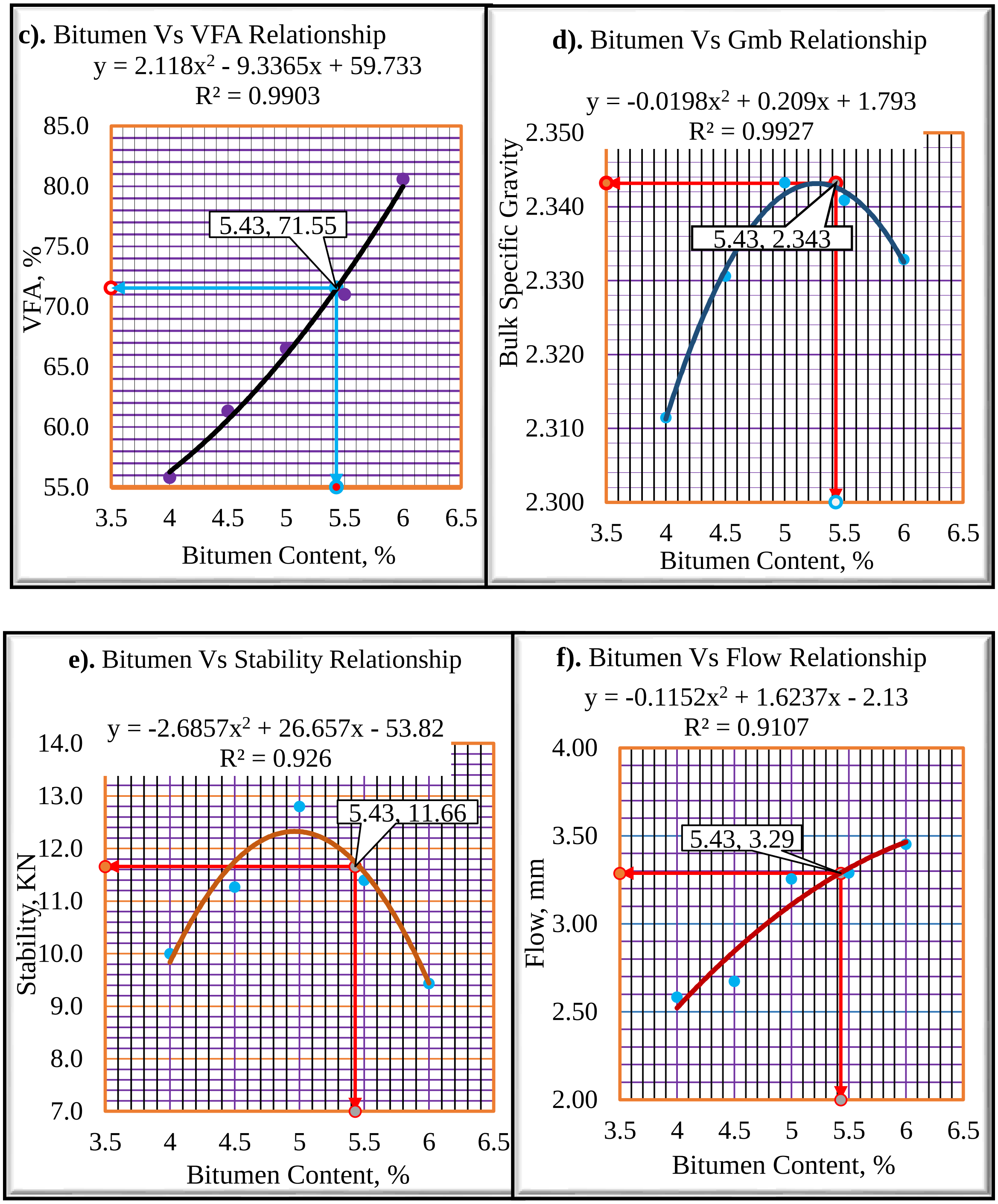
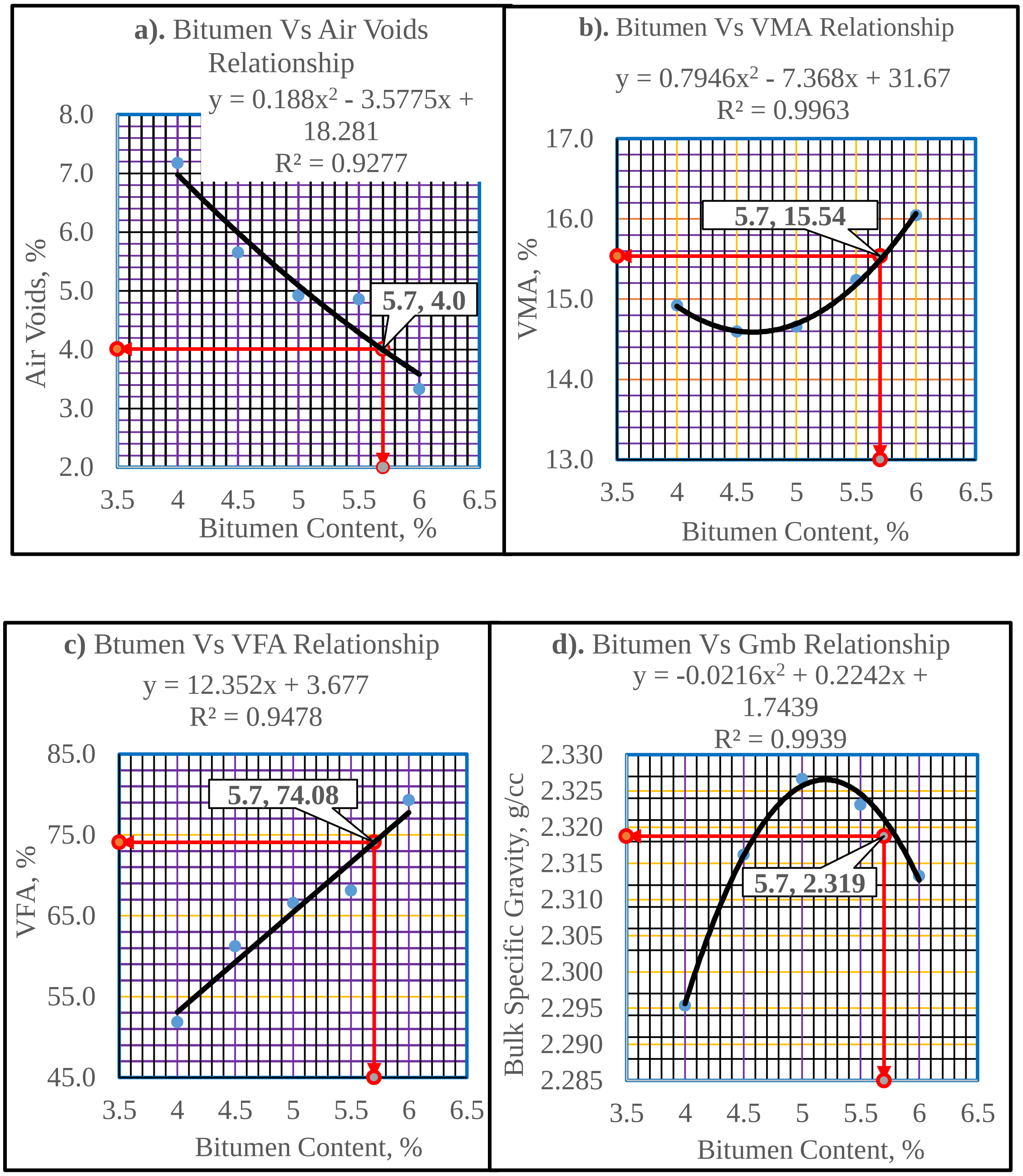


Figure 4. 2: - Marshall Mix property of 5% CSD

b. Marshall Properties of 5.5% CSD

The graph of bitumen content versus air void indicated that the void in mix decreased as bitumen content increases as shown on Figure 4.3a. The air void curve showed the usual concave up wards. This indicates that as bitumen content increases hot bitumen lubricates the aggregates allowing closer together in which air void decreases hence the density increases. The graph of bitumen content versus void in mineral aggregates is as shown on Figure 4.3b. The graph showed flattened U-shape, decreased void in mineral aggregates to a minimum value of 14.6% then increased with increase bitumen content. With the increase in bitumen content, the mix became workable and compacted easily, which increases density. However, as the bitumen content increases more than bitumen content at maximum density the thicker films around the individual aggregates were formed there by resulting low density and high VIM. Therefore, up to lower VIM value, the bulk density of the mix increase to maximum value of 2.328 g/cm^3. Figure 4.3c presents the graph of bitumen content versus Void filled with asphalt. The graph showed the usual convex upward which indicates the void in the mineral aggregates were filled with bitumen while the air void in the mix decreases.

Figure 4.3d shows the graph of bitumen content versus bulk specific gravity. The graph showed that bulk specific gravity slightly increased to 2.328 g/cm^3 with increase bitumen content, after which it decreases. The stability increased to a maximum value of 11.9 KN with increase of bitumen after which the stability decrease as shown on Figure 4.3e. This indicated as bitumen content increases the density increases because hot bitumen lubricates the aggregates allowing closer together. The graph of bitumen content versus flow shown on Figure 4.3f indicated the flow value increased with increase of bitumen content. The concave down-ward curve of bitumen content versus flow indicated as the bitumen content increases the mix became plastic and loss stability.


a). Bitumen Vs Air Voids Relationship
y = 0.188x² - 3.5775x + 18.281
R² = 0.9277
Air Voids, %
5.7, 4.0
Bitumen Content, %
b). Bitumen Vs VMA Relationship
y = 0.7946x² - 7.368x + 31.67
R² = 0.9963
VMA, %
5.7, 15.54
Bitumen Content, %
c) Btumen Vs VFA Relationship
y = 12.352x + 3.677
R² = 0.9478
VFA, %
5.7, 74.08
Bitumen Content, %
d). Bitumen Vs Gmb Relationship
y = -0.0216x² + 0.2242x + 1.7439
R² = 0.9939
Bulk Specific Gravity, g/cc
5.7, 2.319
Bitumen Content, %

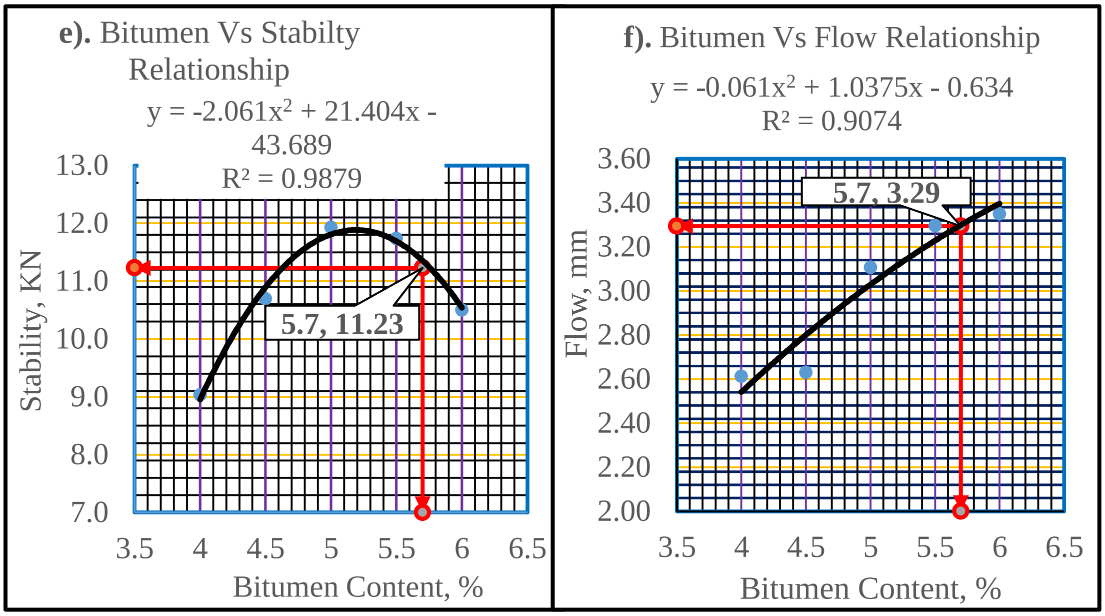
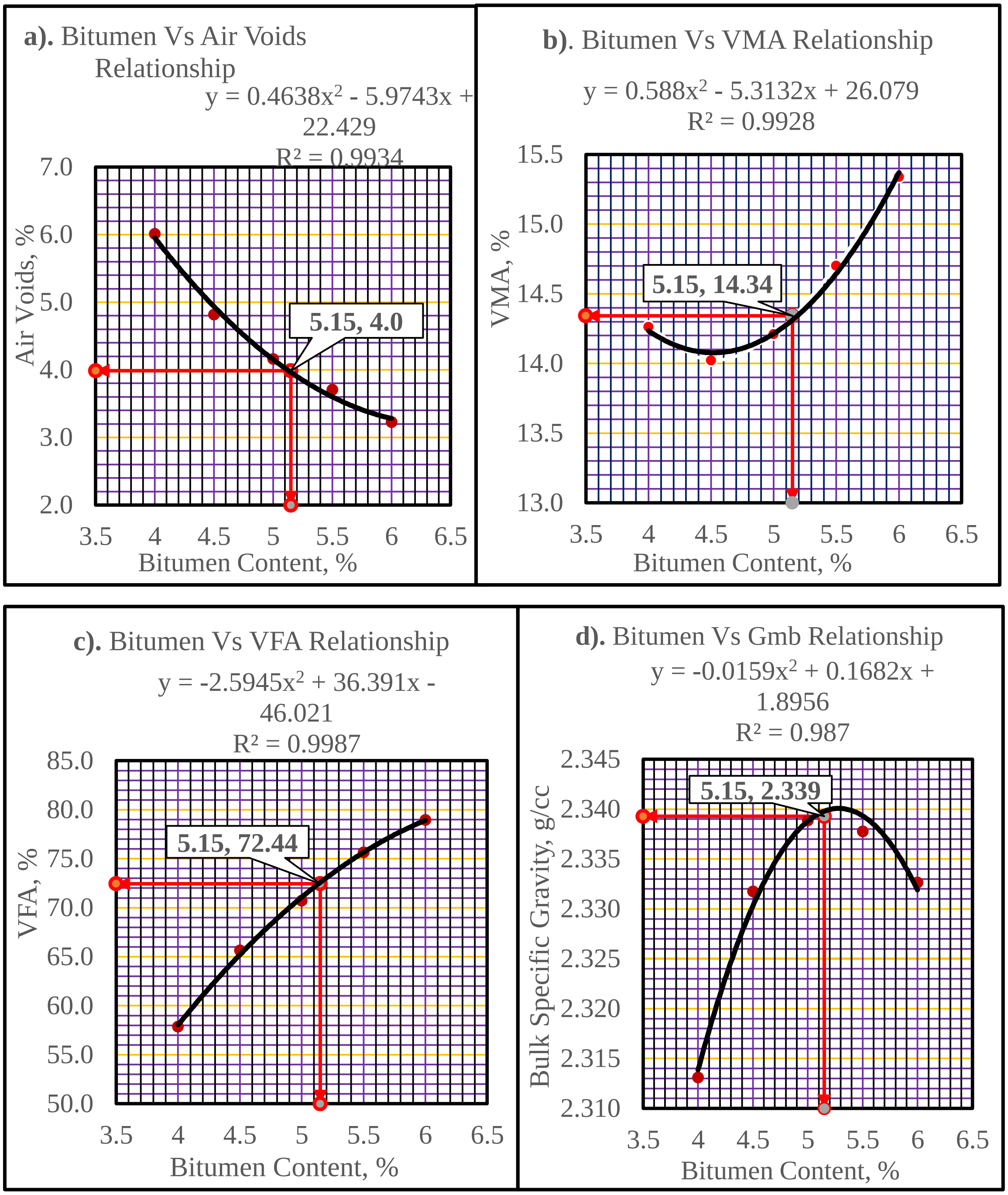


Figure 4. 3: - Marshall Mix property of 5.5% CSD

c. Marshall Properties of 6% CSD

The graph of bitumen content versus air void shown on Figure 4.4a indicated the void in mix decreased as bitumen content increased. The relationship showed the usual concave up wards curve which indicate that as bitumen content increases density increases while air void decreases. Figure 4.4b shows the graph for bitumen content versus void in mineral aggregates which is flattened U-shape. The curve showed a minimum value of 14.0% then increases with increasing bitumen content. With the increase in asphalt, the mix actually became more workable and compacts more easily, meaning more weight can be compressed into the unit volume.

Therefore, the bulk density of the mix increases to 2.344g/cm^3 while VMA decreases to a minimum value of 14.0%. The void filled with asphalt increased as the bitumen content increases as presented on Figure 4.4c. The graph showed the usual convex upward which indicates the void in the mineral aggregates were filled with bitumen while the air void in the mix decreases. The result of bulk specific gravity shown on Figure 4.4d slightly increased to 2.344 g/cm^3 with increasing bitumen content, after which it decreases. The graph of bitumen content versus stability presented on Figure 4.4e indicated that Marshall Stability increased with increase bitumen content to a maximum value of 11.5 KN after which the stability decreases. This indicate that as bitumen content increases hot bitumen lubricates the aggregates allowing closer together which increasing the density. Figure 4.4f shows the graph of bitumen content versus flow. The flow increased with the increase of bitumen content. The concave up wards curve of bitumen content versus flow indicated as the bitumen content increases the mix became plastic and loss stability.



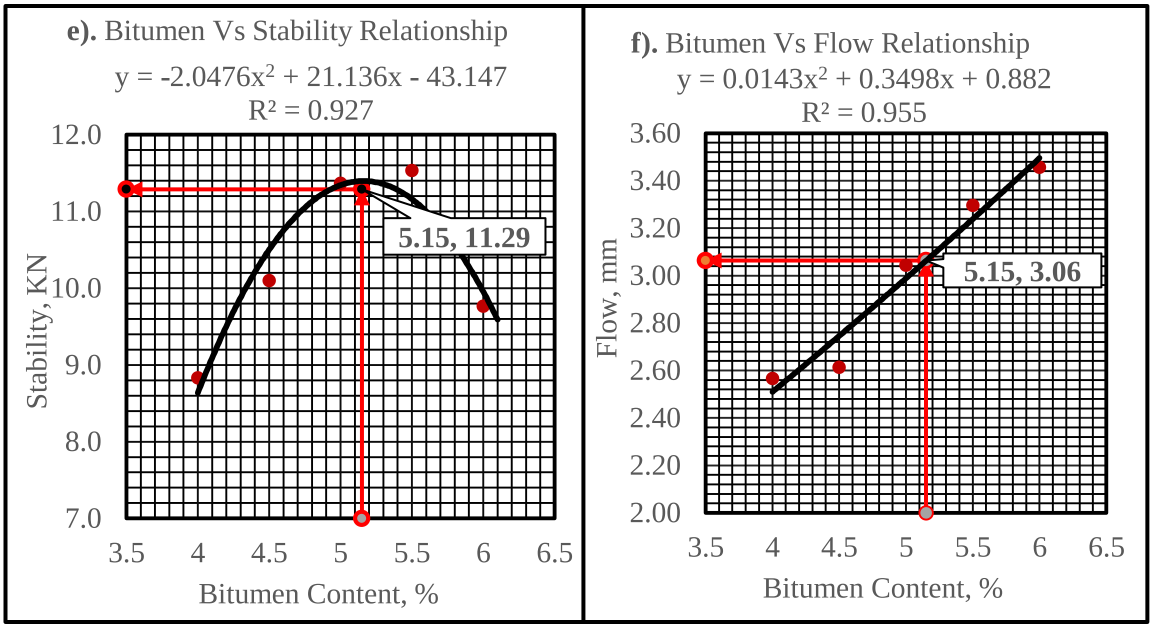


Figure 4. 4: - Marshall Mix property of 6% CSD

d. Optimum bitumen content

The Marshall Parameters relationships, bitumen content along x-axis and Marshall Parameters along y-axis for different gradation are shown on Figure 4.2 to 4.4. The graph plot indicated the OBC for different gradation according to NAPA procedure. Accordingly, Marshall Stability, flow, VMA, VFA, and VIM with corresponding OBC for each gradations were indicated. As Figure 4.2 shows, the OBC for aggregate gradation with 5% filler content at 4% medium Air voids is 5.43% and the corresponding bulk specific gravity (Gmb), Voids in mineral aggregate (VMA), Voids filled with asphalt (VFA), Stability and flow value were (2.343 g/cm^3, 14.66%, 71.55%, 11.66 kN, 3.29 mm) respectively. All the results obtained shows Marshall Parameters satisfies the specification requirements.

Figure 4.3 shows, the OBC of aggregate gradation with 5.5% filler content at 4% Air voids is 5.7% and the corresponding bulk specific gravity (Gmb), Voids in mineral aggregate (VMA), Voids filled with asphalt (VFA), Stability and flow value are (2.319 g/cm^3, 15.54%, 74.08%, 11.23 kN, 3.29 mm) respectively. The result shows all the Marshall parameters satisfies specification requirements. Figure 4.4 shows, the OBC of aggregate gradation with 6% filler content at 4% Air voids is 5.15% and the corresponding bulk specific gravity (Gmb), Voids in mineral aggregate (VMA), Voids filled with asphalt

(VFA), Stability and flow value are (2.341 g/cm^3, 14.28%, 72.81%, 11.29 kN, 3.06 mm) respectively. The result shows all the Marshall parameter satisfies the specification requirements. Summary of this section is as shown on Table 4.5.

Table 4. 5: - Summary of Marshall Mix properties at OBC

Marshall property	Marshall Mix Result			ERA (2002) Specification		Asphalt Institute (1996)		Remark
	5% FC	5.5% FC	6% FC	Lower	Upper	Lower	Upper	
BC (%)	5.43	5.7	5.15	4	10	4	10	Ok
Air Void (%)	4.0	4.0	4.0	3	5	3	5	Ok
Gmb (gm/cm^3)	2.343	2.319	2.341	-	-	-	-	Ok
VMA (%)	14.66	15.54	14.28	13	-	13	-	Ok
VFA (%)	71.55	74.08	72.81	65	75	65	75	Ok
Stability (kN)	11.66	11.23	11.29	7	-	8.006	-	Ok
Flow (mm)	3.29	3.29	3.06	2	4	2	3.5	Ok

e. Design bitumen content

Marshall Mix properties of three different gradations at their respective OBC are shown in Table 4.5. Accordingly, stability of three gradation with 5, 5.5 and 6% filler content was obtained 11.66, 11.23, and 11.29 KN respectively. From this result, the maximum Marshall stability of 11.66 KN was found from gradation mixtures with 5% filler content. The Marshall Flow values of 3.29, 3.29, and 3.06 mm corresponding to their OBC were obtained for gradation with 5, 5.5 and 6% filler content respectively. The bulk density of all mixtures produced from gradation with different filler content of 5, 5.5, and 6% was 2.343, 2.319, and 2.341 g/cm^3 respectively. The results shows HMA mixture with 5% filler content was relatively provided highest values of bulk density. Thus the mixture with 5% optimum filler content was selected as design gradation. The percentage of VMA corresponding to OBC was 14.66, 15.54, and 14.28% for the mixture gradation with 5, 5.5, and 6% filler content respectively. The percentage of void filled with asphalt (VFA), which controls the quantity of bitumen-filled micro voids at OBC for gradation with 5, 5.5 and 6% filler content were obtained 71.55, 74.08, and 72.81 % respectively.

Generally, depending on stability, density, and medium air voids, gradation with 5% CSD filler demonstrated greater stability and density than all other mixtures at medium air voids. Thus, for this study, mixture with gradation of 5% optimum filler content was considered as design aggregate gradation with 5.43% OBC. The optimum bitumen content (OBC) was obtained as 5.43% at maximum stability, maximum bulk density and medium air void for 5% mineral filler content as a designation for all replacement mixtures throughout study.

4.3 Marshall Mix Properties of Polymer Modified Bitumen (PMB)

The selected OBC of 5.43% and design gradation with 5% optimum filler content, OBC was substituted with LDPE at replacement rate of 2% increment from 0 to 10%. The Marshall parameters like bulk density, VIM, VMA, VFA, stability and flow for different proportion of low density polyethylene replacement were determined.

Generally, the effects of low density polyethylene on the Marshall properties of HMA are discussed in this sub-sections.

4.3.1 Effect of LDPE on Bulk Density of HMA Mixes

The bulk specific gravity of different percentage replacement of low density polyethylene at OBC were given in Figure 4.5 below. Bulk density is the actual density of the compacted mix. It is evident from Fig. 4.5 that the bulk density of the mix was also increasing with increase in the recycled waste polymer content from 0 to 10% at 2% increment. The most significant percentage of recycled waste polymer is observed as 8% at which the density is maximum (2.308g/cm^3) after which it tend to decrease as additive content increase. This result indicate that the low density polyethylene can be suitable in road construction to the percentage of eight at which it achieves the maximum density. Compared to the plain bitumen, it was about 2.3% more than the density of the mix in the control. This result agrees with other researcher investigations [33, 45, 46].

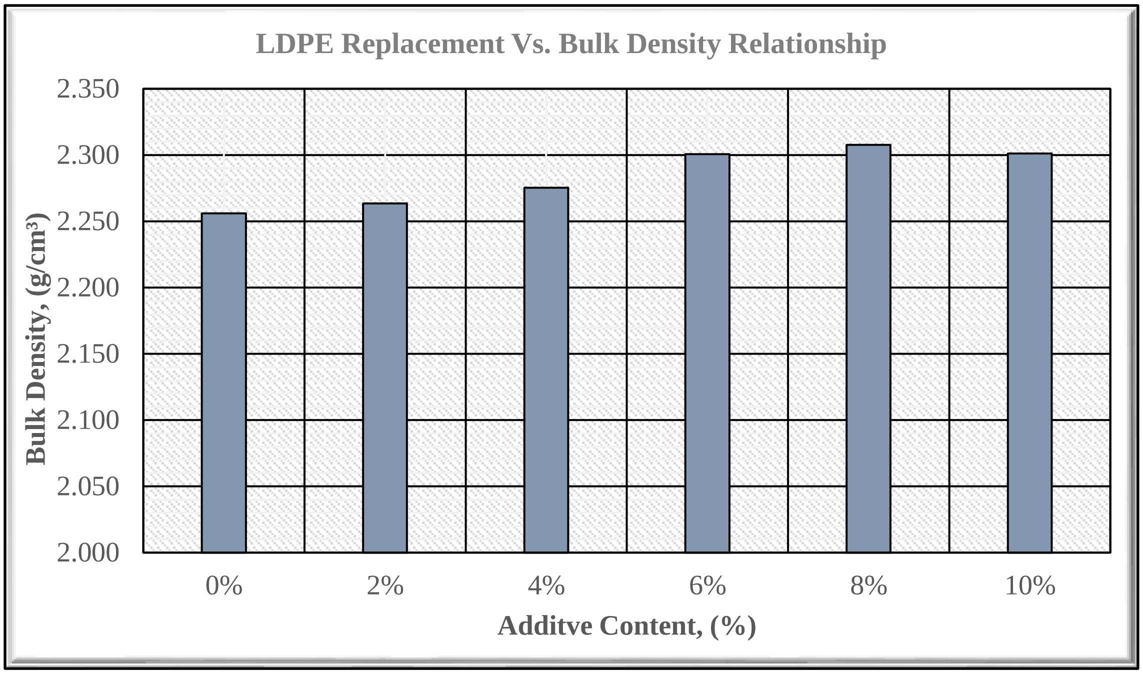


Figure 4. 5: - Effects of LDPE on Gmb at different percentage replacement of LDPE

4.3.2 Effect of LDPE on Percentages Air Voids of HMA Mixes

The void in mix slightly decreased from 4.97 to 4.56% as percentage of replacement increases as shown on Figure 4.6. Decrease in air void increases the density. All the values of the air voids are lies in between the limits of laboratory air void requirements of ERA (2013), 3 to 5% as shown on Figure 4.6 below. Marshall Properties of asphalt mixtures are related to each other. Density is inversely related to air voids in this case indicating that as air void decreased density increases. However, as indicated on Figure 4.5 above, the maximum density (2.308 g/cm^3) is obtained at 8% of LDPE at which air void is 4.67% after which it tends to decrease to 2.301g/cm^3 at 10% at which air void is 4.56%. These values determines the suitability of LDPE is limited to the use in road construction fulfilling the Marshall criteria to the percentage of eight. When air void contents are too low or high, the asphalt binder content may be affected in similar manner, resulting in a mixture prone to a road damage. Hence, the effect of air void can be adjusted by field compaction. The decrement in the voids in total mix values show that the stability of the mixes were improving on addition of plastic waste [47].

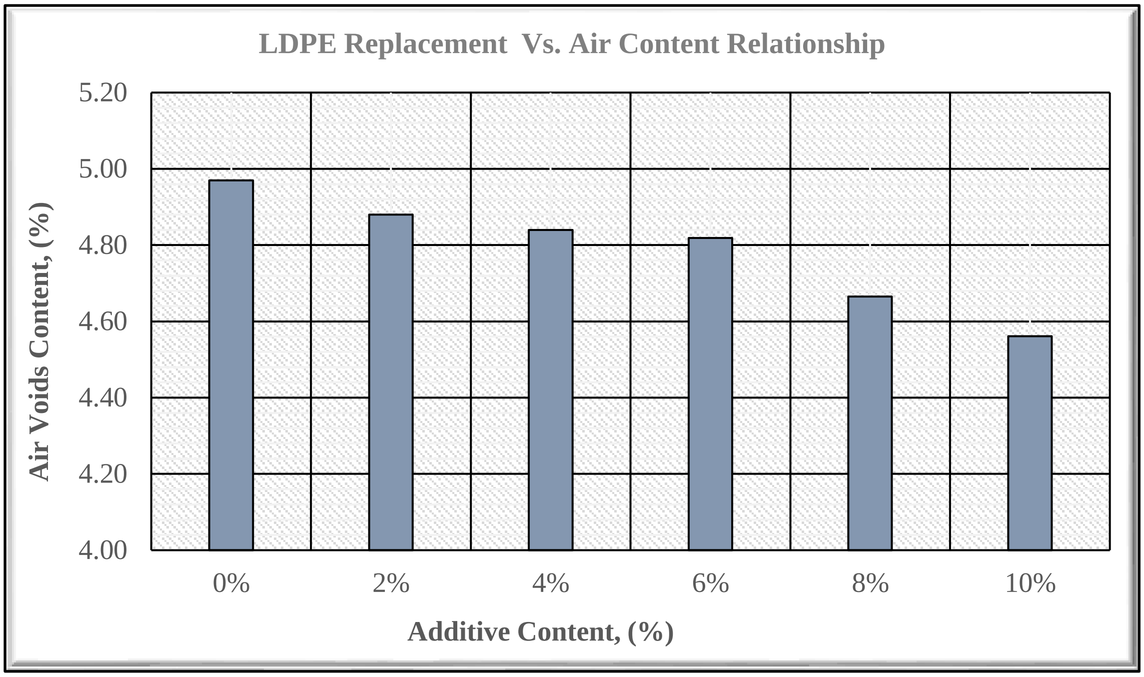


Figure 4. 6: - Effects of LDPE on Air void at different proportion

4.3.3 Effects of LDPE on Void in Mineral Aggregate of HMA Mixes

VMA is the volume of inter-granular void space between the aggregate particles of a compacted paving mixture. The value of VMA decreased from 17.63 to 15.65% as the low density polyethylene replacement content increases as shown in Figure 4.7. This is due to the fact that LDPE is coating the aggregate and increasing the density. This makes air void decrease which decreases the VMA. The increase in density but decrease in air voids and VMA indicates that the high level of porosity in the aggregates also are decreased due to LDPE coating and which can in turn increases rut resistance. Too small VMA value less than the specification limit suffer durability problem and too large VMA results stability problem and un-economical mix. However, in all cases for all proportion VMA value satisfied the standard requirement of ERA and asphalt institute which is greater than 13%. The result agrees with other previous studies [48, 49].

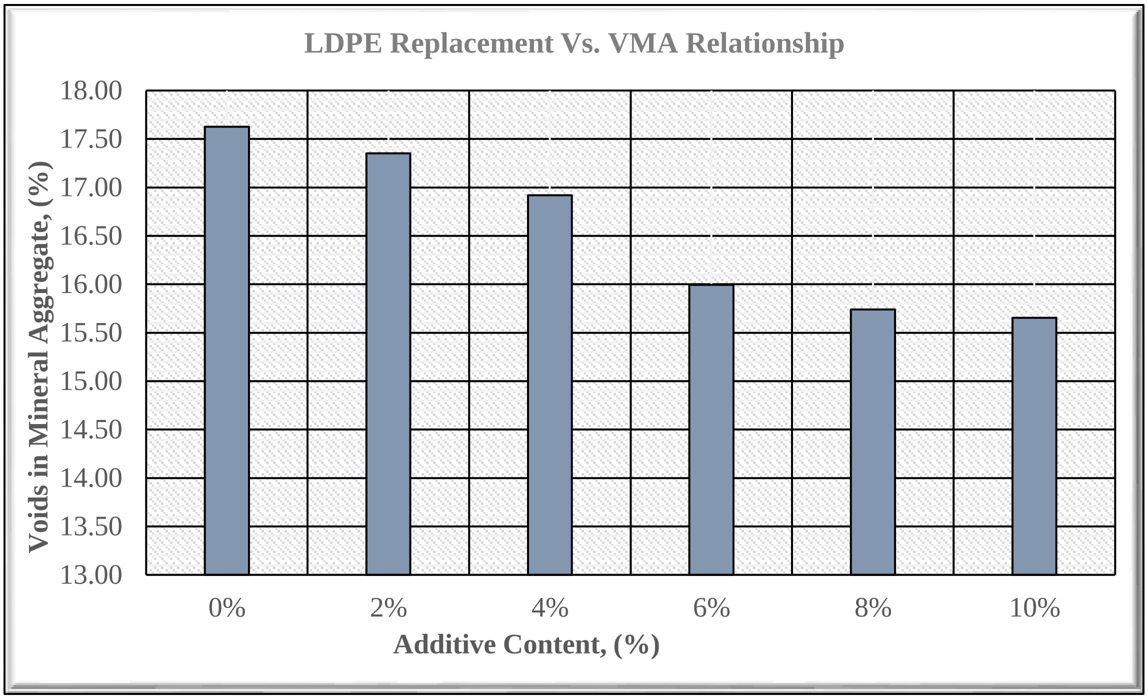


Figure 4. 7: - Effect of LDPE on Void in mineral aggregate at different proportion

4.3.4 Effect of LDPE on Void Filled with Asphalt of HMA Mixes

Volumetric properties of asphalt mixtures are related to each other. VFA is inversely related to VIM and VMA: as VIM and VMA decrease, the VFA increases. This is why, as LDPE content increases, VIM and VMA results decrease but VFA results increases as shown in Figure 4.8. This indicates the increase in density, decreases VIM and VMA, leading to the increasing of VFA. Fig. 4.8 indicates that, the value of VFA slightly increases as the waste LDPE plastic content increases. All values conforms Marshall Criteria, (65% to 75%) of ERA, 2013 national standard specification and Asphalt institute. The Marshall Criteria is important for the durability of mixes, hence the lower VFA value than the limit indicates, there will be less asphalt film around the aggregate particles. This indicates the percentage of available space between the aggregate particles (the VMA) is occupied by or filled with the addition of waste LDPE plastic content rather than by air voids.

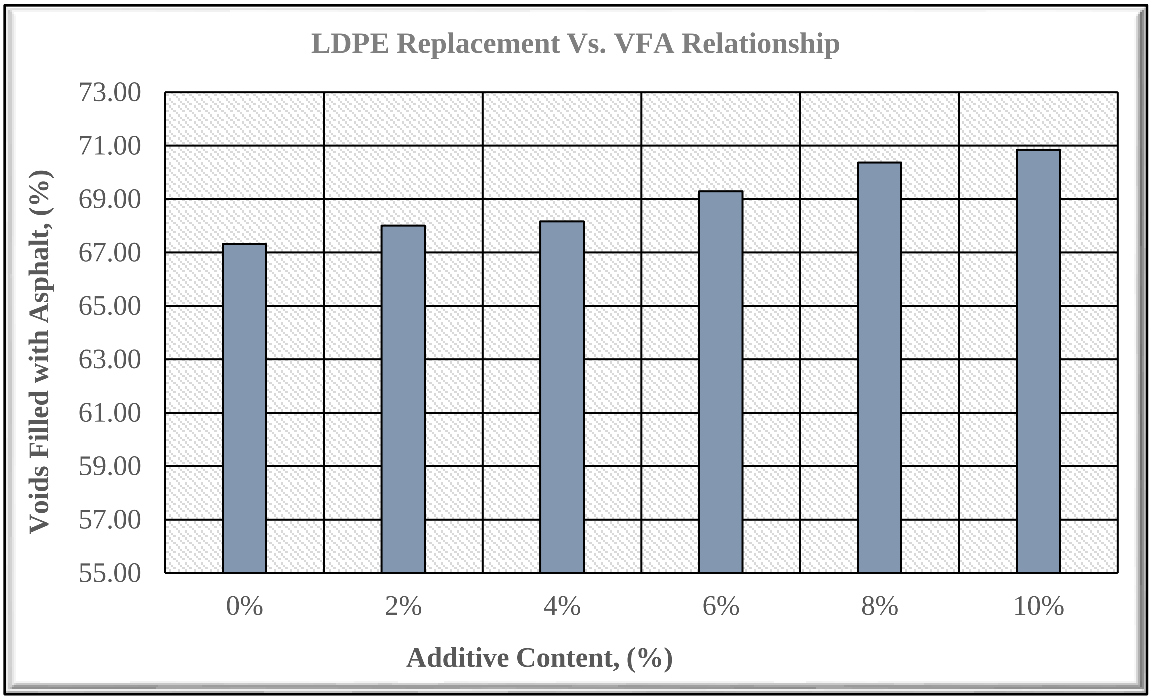


Figure 4. 8: - Effect of LDPE on Void filled with asphalt at different proportion

4.3.5 Effect of LDPE on Marshall Stability of HMA Mixes

Marshall Stability with different percentage of low density polyethylene at OBC is shown in Figure 4.9. Stability is the maximum vertical load required to produce failure of the specimen when load is applied. It has been observed from Fig.4.9 that the stability value of mixes modified with polymer waste material have been increased significantly up to the tune of 8% waste at which it is maximum 12.34KN and after which it tends to decrease as compared to mix prepared with plain bitumen. This shows the enhancement in strength of the mix due to addition of recycled polymer waste which signifies that the inclusion of low density polyethylene waste increases the density of the mix. Hence, the highest maximum stability value was obtained for the samples with 8% LDPE. This indicates that, the mixture polymer modified bitumen with 8% replacement of low density polyethylene material has high resistance to traffic loading. Previous studies confirmed that increasing LDPE contents in HMA increases the stability of the mix up to certain LDPE amount and then it starts to declines as a plastic content increases [35, 39].

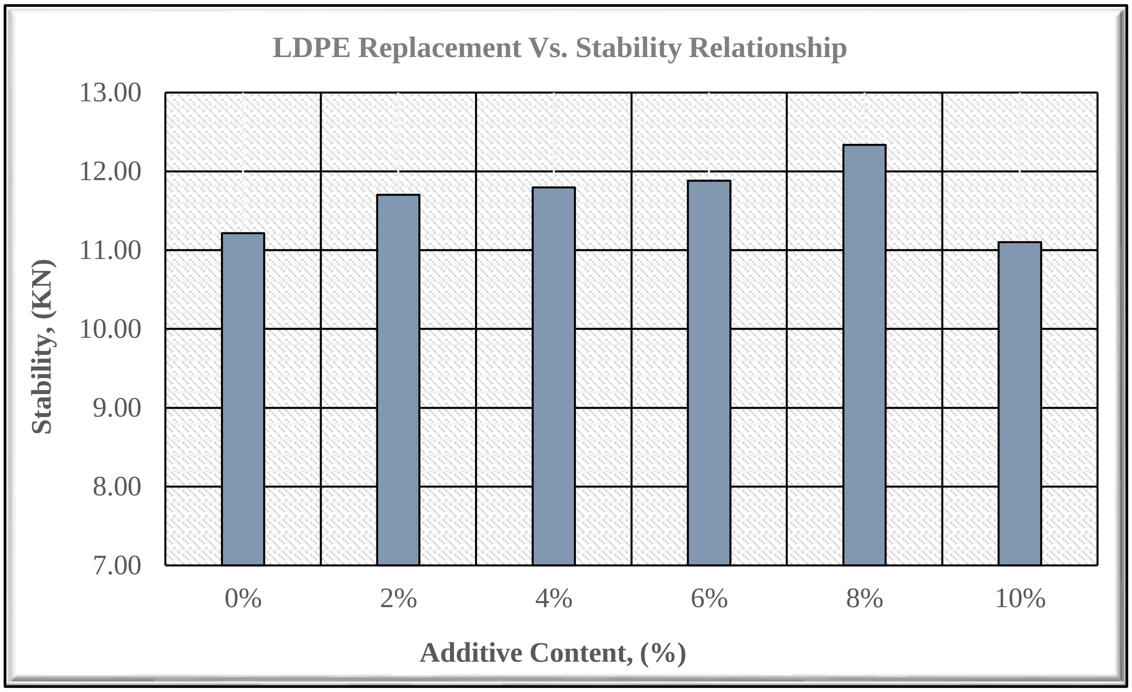


Figure 4. 9: - Effect of LDPE on Marshall Stability at different proportion

4.3.6 Effect of LDPE on Flow Value of HMA Mixes

The flow value is a measure evaluating the behavior of asphalt mixes subjected to traffic loadings and representing the plasticity and elasticity properties of the mixes. Furthermore, the flow value, the vertical deformation value at the maximum load, is a parameter related to the internal friction and cohesion of the compacted asphalt mixes, where it is inversely proportional to the internal friction value [14]. As can be seen in Figure 4.10, flow value of waste LDPE modified asphalt mix decreases at higher waste LDPE plastic content. The values of flow decrease from 3.13mm to 2.90mm at 0% and 10% waste LDPE plastic content respectively. This indicates that waste LDPE modified bitumen makes the resulted asphalt mix stiffer and rigid. As a result, it reduces the flow of HMA. The decrease in flow value of the Marshall Mix as the waste LDPE content increase was also, shows that the increase in resistance to rutting. Higher flow value shows higher flexibility while lower flow value shows higher rigidity. All the flow values were within the acceptable range of ERA, 2013, 2 to 4% and asphalt institute, 2 to 3.5% specification requirement. Also the resulted values indicated that the mix had capable to resist vertical deformation corresponding to maximum load. Similar studies assures that, increasing the percentages of LDPE result in decrease the flow values of HMA [45, 48].

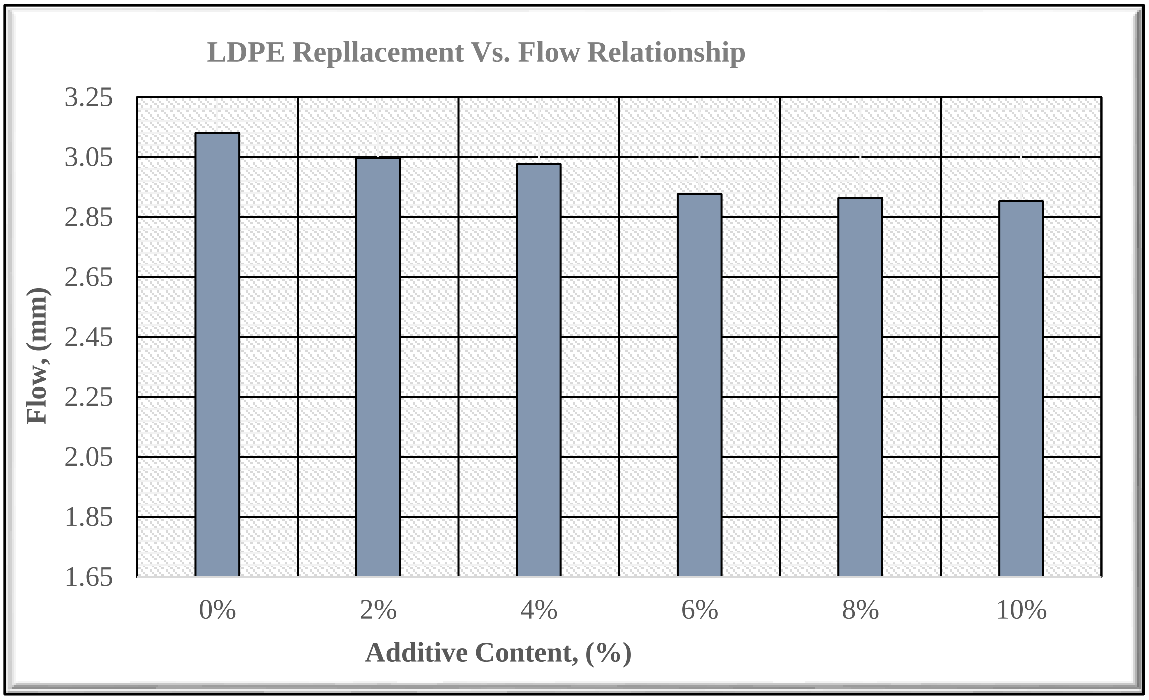


Figure 4. 10: - Effect of LDPE on Marshall Flow at different proportion

4.3.7 Optimum Percentage of Polymer Modified Bitumen (PMB)

In order to find the optimum binder content that produces an HMA mixture with the best Marshall Properties, a combination of mechanisms and control are suggested. All the Marshall Properties satisfied the specification requirement of asphalt concrete wearing course. However, the maximum stability value was obtained from the mixture corresponding to 8% of LDPE relative to other proportions. Also corresponding to this proportion, air void, and bulk density values were 4.67% and 2.308gm/cm^3, respectively, which are satisfactory. As Table 4.6 shows the Marshall properties of polymer modified bitumen at a maximum stability 12.34KN and density 2.308g/cc with 8% of modifier content as satisfies the national (ERA, 2002) and international (Asphalt institute, 1996) specification requirement. Therefore, low density polyethylene used in this study can be used as an alternative nonconventional binder at a percentage of eight (8%) of conventional bitumen.

Table 4. 6: - Marshall Properties of Polymer Modified Bitumen at 8% of LDPE

Marshall property	Test Result	ERA(2002) Specification		Asphalt Institute (1996) specification		Remarks
		Lower	Upper	Lower	Upper	
OBC (%)	5.43	4	10	4	10	Ok
Gmb (gm/cm3)	2.308	-	-	-	-	Ok
VIM (%)	4.67	3	5	3	5	Ok
VMA (%)	15.74	13	-	13	-	Ok
VFA (%)	70.37	65	75	65	75	Ok
Stability (kN)	12.34	7	-	8.006	-	Ok
Flow (mm)	2.91	2	4	2	3.5	Ok

4.4 Marshall Mix Properties of PVC-Pipe Powder as Mineral Filler

An experimental test matrix consisting of 15 samples with determined of optimum binder content 5.43% and a 5% filler content with five different amounts of PVC-PP content (0%, 25%, 50%, 75% and 100% filler replacement) was prepared to determine which sample would produce the highest Marshall stability and flow values as well as satisfying the national (ERA, 2002) and international (Asphalt institute, 1996) specification limits.

Generally, the effects of polyvinyl chloride pipe powder as a mineral filler on the Marshall properties of HMA are discussed in this sub-sections.

4.4.1 Effects of PVC-PP filler on Bulk Density of HMA Mixes

Bulk specific gravity of different percentage replacement of PVC-pipe powder at OBC resulted slightly decreased with increase percentage replacement from 0 to 100% at 25% increment as shown in figure 4.11. The reason is the specific gravity of crushed stone dust is greater than specific gravity of PVC-Pipe Powder which is 2.678 and 2.472 respectively. However density can be achieved by increased field compaction, by increased bitumen content, and other method that reduces air voids. Because as the air void in the mix decreases the density increases. Most of the researchers agree on the decrement in bulk density is due to the bulk density of waste materials blended with conventional materials [6, 14, 48].

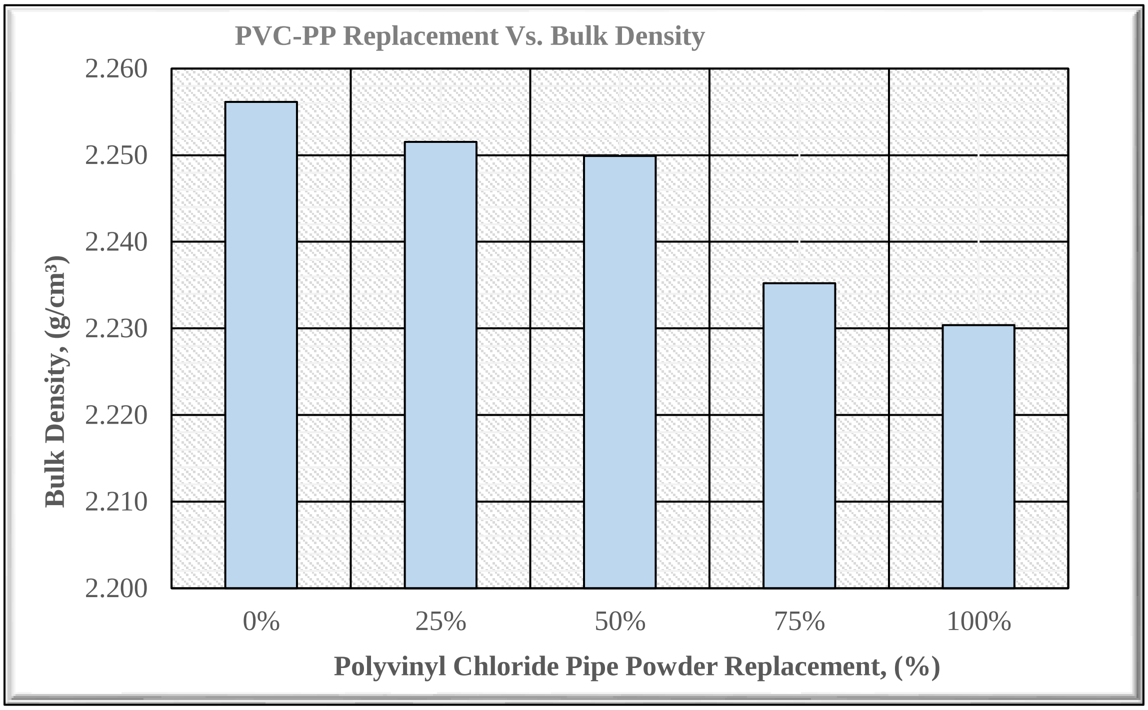


Figure 4. 11: - Effects of polyvinyl chloride pipe powder on bulk density

4.4.2 Effects of PVC-PP Filler on Air Content of HMA Mixes

The void in total mix increased from 4.83 to 5.26% as percentage replacement increases as shown on Figure 4.12. However, samples with the air voids results within the national (ERA, 2002) 3 to 5% and international (Asphalt institute, 1996) 3 to 5% limits of the specification were 4.83%, 4.97%, and 4.98%, which are at 0%, 25%, and 50% of additive content respectively. Furthermore, no samples with 75% of PVC-PP and 25%CSD, and 100% PVC-PP and no CSD filler content amounts were found to meet the air voids specification requirements. Hence, this results indicate that Polyvinyl chloride pipe powder can be suitable in road construction as a mineral filler to maximum percentage of fifty (50%) which is a partial replacement. There was a general trend among the samples with PVC-PP that as PVC-PP content increases, VMA and VIM results increase but VFA results decrease. Higher VIM results with increasing PVC-PP content might be due to the lower level of absorption in between ingredients, lower porosity in PVC-PP compared to CSD and resistance to compaction. In order to solve this issue, excessive level of number of compaction, and an optimum asphalt binder content could be determined for each filler content to avoid excessive VIM [14].

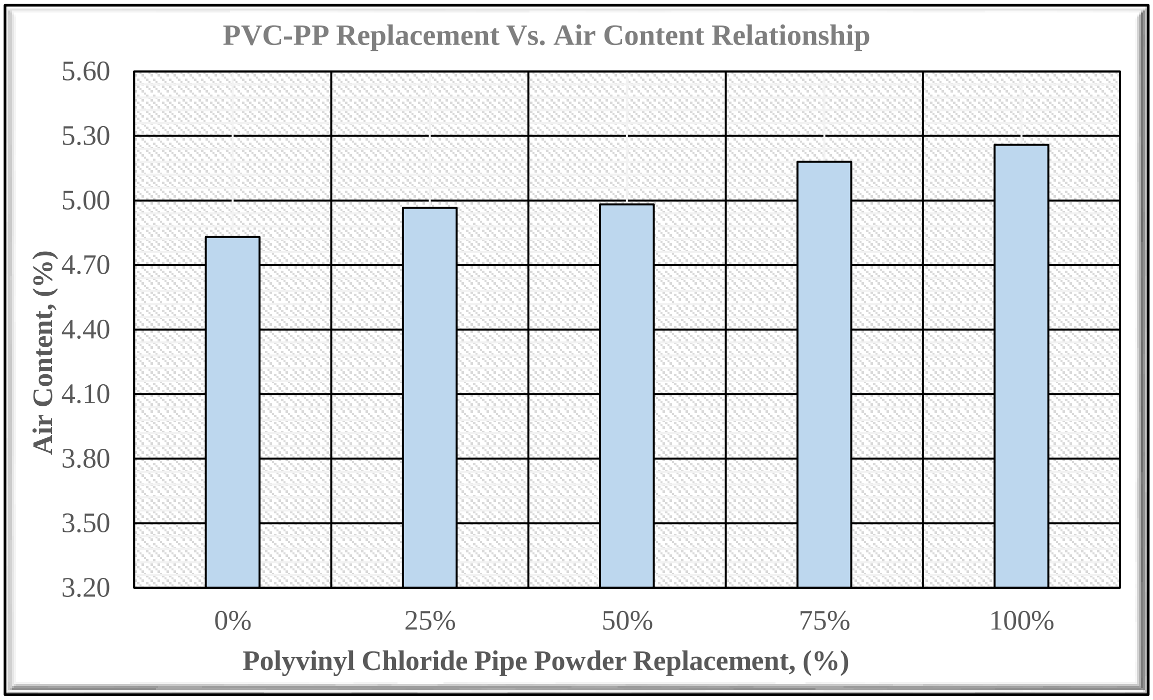


Figure 4. 12: - Effects of polyvinyl chloride pipe powder on Air Voids

4.4.3 Effects of PVC-PP Filler on Voids in Mineral Aggregate of HMA Mixes

As can be seen in Figure 4.13, VMA results were found to increase as polyvinyl chloride pipe powder content increased from 17.6% to 18.6%. Compared to the control samples, VMA results of the samples with 100% PVC-PP and no CSD filler content increased by 5.68% for the binder content amounts of 5.43%.The increasing value for VMA indicates that the absorbance of bitumen could be increased, due to a high level of porosity in the surface of the aggregates and mineral fillers particle. Also, increasing VMA can also decrease rut resistance. However, for all proportion VMA value satisfied the standard requirement of ERA and asphalt institute which is greater than 13%. Beycioğlu, et al., sates that the volumetric properties of hot mix asphalt mixtures are related to each other. VFA is inversely related to VIM and VMA: as VIM and VMA increase, the VFA decreases. This is why, as PVC-PP content increases, VIM and VMA results increase but VFA results decrease [14].

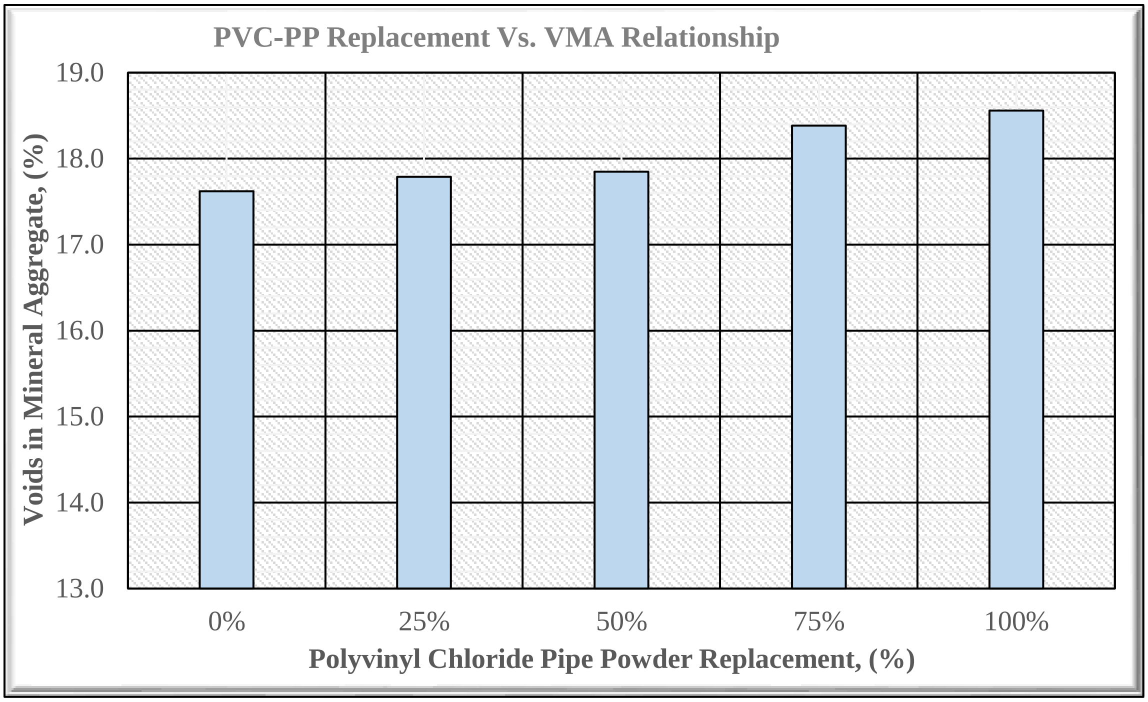


Figure 4. 13: - Effects of polyvinyl chloride pipe powder on VMA

4.4.4 Effects of PVC-PP Filler on Voids Filled with Asphalt of HMA Mixes

Effect of polyvinyl chloride pipe powder on the voids filled with asphalt is indicated on Figure 4.14. The graph shows void filled with asphalt decreased with increasing percentage replacement of additive content replacement. This indicates the decrease in density, increases VIM and VMA leading to the decreasing of VFA. The Marshall Criteria is important for the durability of mixes hence the lower VFA value than the limit indicates, there will be less asphalt film around the aggregate particles. Lower asphalt films are more subjected to moisture and weather effects where they can be detached from the aggregate particles and subsequently lower performance. On the other hand, if the limit is exceeded, more voids are filled with asphalt than required for durability. However, for all the mix at different proportions of polyvinyl chloride pipe powder (PVC-PP), the VFA value ranges from 72.6 to 71.7% which conforms to the Marshall Criteria, 65 to 75%. Decrease in VFA can be explained as a result of the CSD mineral filler added to the mix is being substituted by waste PVC-PP which are comparable with studies reported previously [48].

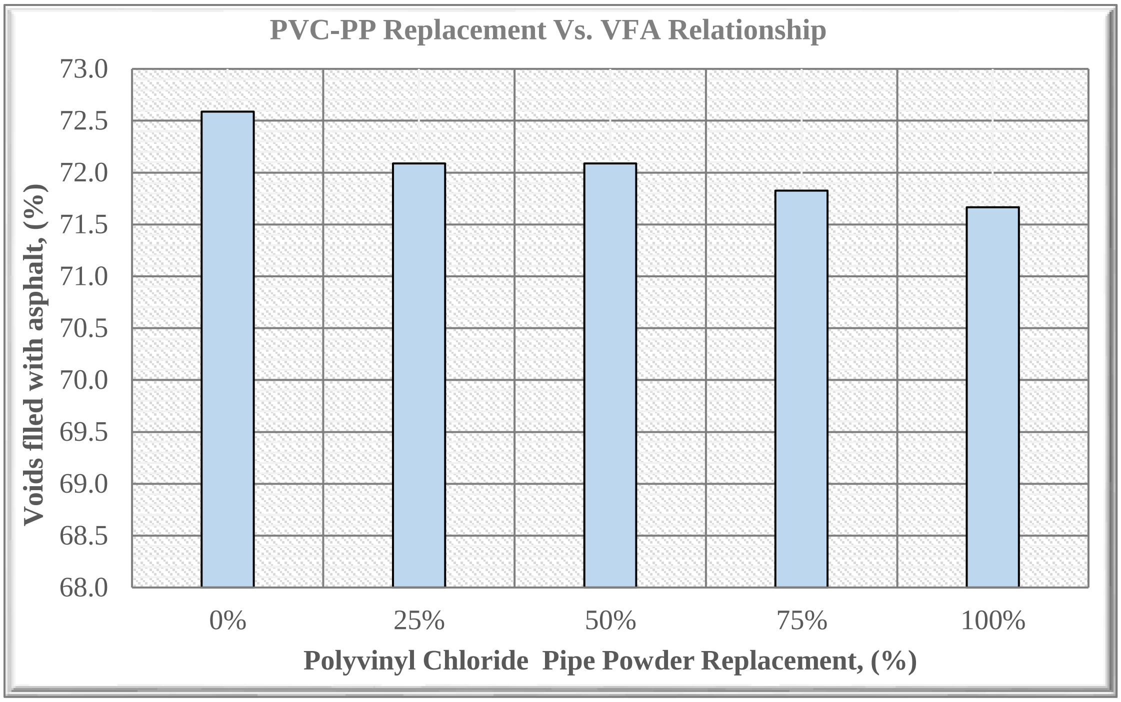


Figure 4. 14: - Effects of polyvinyl chloride pipe powder on VFA

4.4.5 Effects of PVC-PP Filler on Marshall Stability of HMA Mixes

Marshall Stability with different percentage of polyvinyl chloride pipe powder at OBC is shown in Figure 4.15. As can be seen in Fig. 4.15, the highest maximum stability value was obtained for the samples with 50% polyvinyl chloride pipe powder (PVC-PP) and 50% crushed sand stone (CSD) filler content. Maximum stability results tend to increase as PVC-PP content increases until a PVC-PP content of 50% is reached, and then it starts to decrease. Moreover, the highest maximum stability value of 12.63KN was observed at 50% PVC-PP and 50% CSD filler content, whereas the lowest maximum stability value of 9.87KN was observed for 100% PVC-PP and no CSD filler content with the sample 5.43% binder content. Compared to the control samples, all samples except for the samples with 100% PVC-PP and no CSD filler content produced higher maximum stability values. The highest maximum stability value of 12.63KN indicates that, the mixture with (50%) which can be taken as partial replacement of polyvinyl chloride pipe powder has high resistance to traffic loading. The results agree with other previous studies [14].

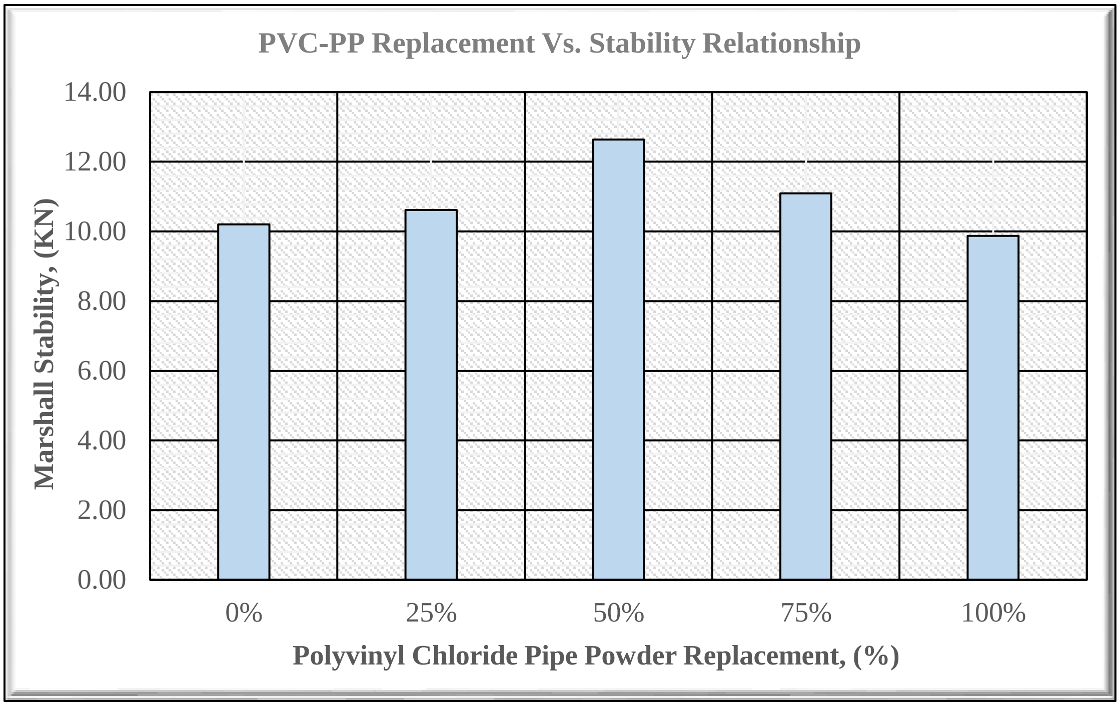


Figure 4. 15: - Effects of polyvinyl chloride pipe powder on stability

4.4.6 Effects of PVC-PP Filler on Flow Value of HMA Mixes

In terms of flow results, the maximum allowable flow values in the specifications control the plasticity and maximum allowable binder content, while the lowest flow values control the brittleness and strength of the mixes [14, 44]. Therefore, it is required that the flow results of the asphalt mixtures must be between the lower and upper specification limits. Figure 4.16 shows the mean flow value results for the samples tested. The results indicated that all the flow value were within the acceptable range of ERA, 2 to 4% and asphalt institute, 2 to 3.5% specification requirement. Compared to the plain bitumen, the mean flow values of the sample tested decreased from 3.14 to 3.11 reaching at 50% PVC-PP and 50% CSD filler content after which it tends to increase to 3.15 at 75% PVC-PP and 25%CSD filler content and 3.16 at 100% PVC-PP and no CSD filler content. The decrease in flow value shows that the mix become more stable even at 60°C temperature. Hence, the flow value of 3.11 at 50% PVC-PP and 50% CSD filler content shows the mix is more stable compared to the conventional mix. It also indicates that polyvinyl chloride pipe powder used in this study, is suitable in road construction as a mineral filler to optimum percentage of fifty (50%) which is a partial replacement.

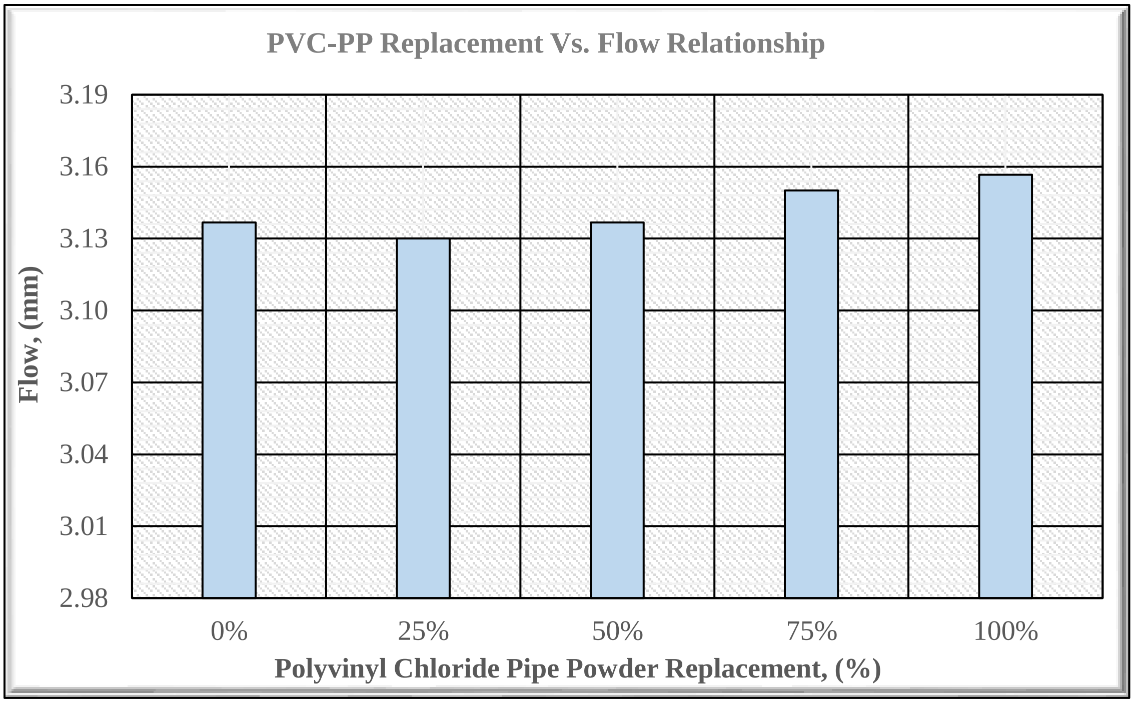


Figure 4. 16: - Effects of polyvinyl chloride pipe powder on flow

3.4.7 Optimum Percentage of Polyvinyl Chloride Pipe Powder as Mineral Filler

In order to find the optimum filler content that produces an HMA mixture with the best Marshall properties, a combination of mechanisms and control are suggested. All the Marshall properties satisfied the specification requirement of asphalt concrete wearing course. However, the maximum stability value was obtained from the mixture corresponding to 50% PVC-PP and 50% CSD filler content relative to other proportions. Also corresponding to this proportion, air void, and bulk density values were 4.98% and 2.250 gm/cm3, respectively, which are satisfactory. As Table 4.7 shows the Marshall properties with partial replacement of polyvinyl chloride pipe powder satisfied the national (ERA, 2002) and international (Asphalt institute, 1996) specification requirement. The optimum filler content is selected as the content satisfies the maximum stability, the closet to the maximum percentage of Air Voids content of 5% which are 12.63 KN, 4.98% at 50% PVC-PP and 50% CSD filler content respectively. Therefore, PVC-PP can be used as an alternative non-conventional filler at partial replacement of conventional filler.

Table 4. 7: - Marshall Properties at 50% (Partial replacement) of PVC-PP

Marshall property	Test Result	ERA(2002) Specification		Asphalt Institute (1996) specification		Remarks
		Lower	Upper	Lower	Upper	
OBC (%)	5.43	4	10	4	10	Ok
Gmb (gm/cm3)	2.250	-	-	-	-	Ok
VIM (%)	4.98	3	5	3	5	Ok
VMA (%)	17.8	13	-	13	-	Ok
VFA (%)	72.1	65	75	65	75	Ok
Stability (kN)	12.63	7	-	8.006	-	Ok
Flow (mm)	3.14	2	4	2	3.5	Ok

4.5 Moisture Susceptibility of HMA

A total experimental test matrix consisting of 24 samples which are 12 samples for 60/70-PG and 8% optimum content of low density polyethylene, and 12 samples were for crushed sand dust and partial replacement of Polyvinyl chloride pipe powder at a determined optimum binder content 5.43% and a 5% filler content. Then the tensile strength of water conditioned as well as an unconditioned specimen for each mix was determined. A value of at least 70% is specified as a requirement in many agencies.

Generally, the tensile strength ratio of LDPE as binder modifier and PVC-PP as a mineral filler on the Marshall properties of HMA are discussed in this sub-sections.

4.4.1 The Tensile Strength Ratio of Polymer Modified Bitumen (PMB)

Table 4.8 presents the test results of the tensile strength ratio for mixes prepared with 5.43% OBC of 60/70 penetration grade and 8% optimum content obtained replacement of low density polyethylene. From the Marshall Immersion test result, the tensile strength ratio values were obtained as a ratio of conditioned to unconditioned tensile strength. As Marshall Immersion test result indicated, asphalt mixes with low density polyethylene and plain bitumen gives tensile strength ratio of 92.08% and 83.03% respectively. The test result shows mixes prepared with low density polyethylene provide higher tensile strength ratio relative to conventional mix. Thus, mixes prepared with low density polyethylene provide better resistance to moisture induced damage.

Table 4. 8: - Tensile Strength Ratio Test Result of LDPE

Sample Type	Binder Type	Specim. Height (mm)	Weight of specimen (gm)			Gmb (g/cm³)	Max. Load (kN)	TSR, (%)
			in air	in water	SSD			
Control	60/70 - PG	65.37	1197.32	669.08	1207.20	2.224	12.08	83.03
Conditioned		66.27	1192.17	667.45	1194.83	2.261	10.03	
Control	LDPE	64.00	1190.40	676.20	1191.04	2.312	14.52	92.08
Conditioned		64.00	1195.30	676.30	1196.80	2.296	13.37	

4.4.2 The Tensile Strength Ratio of PVC Pipe Powder as Mineral Filler

Table 4.9 presents the test results of the tensile strength ratio for mixes prepared with crushed rock and partial replacement of polyvinyl chloride pipe powder at 5.43% OBC and 5% filler content. From the marshal immersion test result, the tensile strength ratio values were obtained as a ratio of conditioned to unconditioned tensile strength. As Marshall Immersion test result indicated, asphalt mixes with polyvinyl chloride pipe powder and crushed stone dust gives tensile strength ratio of 93.63% and 83.98% respectively. The test result shows mixes prepared with polyvinyl chloride pipe powder provide higher tensile strength ratio relative to conventional crushed rock. Thus, mixes prepared with polyvinyl chloride pipe powder provide better resistance to moisture induced damage.

Table 4. 9: - Tensile Strength Ratio Test Result of Polyvinyl Chloride Pipe Powder

Sample Type	Binder Type	Specim. Height (mm)	Weight of specimen (gm)			Gmb (g/cm³)	Max. Load (kN)	TSR, (%)
			in air	in water	SSD			
Control	CSD	64.53	1197.35	669.08	1200.87	2.252	12.54	83.98
Conditioned		64.94	1190.17	667.45	1192.17	2.268	10.53	
Control	PVC-PP	64.33	1193.33	665.20	1194.90	2.253	13.45	93.63
Conditioned		65.00	1190.30	655.50	1192.00	2.219	12.59	

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The investigation aimed to evaluate the potential use the waste polymer materials that are low density polyethylene (LDPE) as a binder modifier and polyvinyl chloride pipe powder (PVC-PP) as mineral filler for a mass scale usage. An endeavor was made to measure the stabilization of the bitumen with LDPE waste and crushed sand dust with PVC-PP waste in the shredded frame by performing characterization like density, voids in total mix, and voids in mineral aggregate, voids filled with asphalt, stability and flow tests. The present stabilization process is exceptionally powerful in controlling environmental pollution, because the waste materials were totally reused with no antagonistic effect on nature [14]. This investigation likewise empowers the mass scale usage of LDPE and PVC-PP.

The addition of LDPE increases bulk density from 2.256 to 2.308 g/cc and reduces the air voids from 4.97 to 4.56% which prevents the moisture absorption and oxidation of bitumen by entrapped air. This has resulted in enhancement of Marshall Stability value. However, the maximum stability value of 12.34 KN was obtained at 8% replacement of low density polyethylene in the mix. This shows the enhancement in strength of the mix due to addition of recycled polymer waste was signifies that the inclusion of polymer waste increases the density and as well as reduces the air content of the mix. Compared to the plain bitumen the flow value of 2.91% was obtained at 8% of LDPE indicating that the value is not too much or less but, near to the mean values of lower limit 2% and upper limit 4% of national (ERA, 2013) standard specification which is satisfactory. Hence, too small or too large of flow value may be resulting in stability problem and un-economical mix, the closet to mean flow value was more preferable in this study.

The laboratory test result of VMA and VFA at maximum stability (12.34 KN) and 8% optimum modifier content were 15.74% and 70.37% respectively which are satisfactory to the national (ERA, 2013) standard specification. The mix with 8% of optimum modifier content resulted higher moisture resistance (92.08%) compared to the mix produced with 60/70 binder (83.03%) at optimum bitumen content (5.43%).

Furthermore, the potential use of PVC-PP as a mineral filler was evaluated. To investigate the potential use of PVC-PP as a filler, at first, optimum binder content which is 5.43% and optimum filler content 5% was obtained at maximum stability, maximum density, and closet median value of specification limits for air voids. Then, an experimental test matrix consisting of 15 samples at optimum binder content of 5.43% and a 5% filler content with five different percentages of PVC-PP content (0%, 25%, 50%, 75% and 100% replacement by weight of the filler), was prepared in order to determine which sample would produce the highest Marshall stability while satisfying specification limits for flow and volumetric results. Considering the all test results for bulk density, air content, maximum stability, flow, VMA and VFA it was observed that all samples produced the results both satisfying the specification requirements and providing an optimum mix design. However, maximum stability of (12.63 KN) was obtained at 50% of Polyvinyl chloride pipe powder content and 50% crushed sand dust filler contents which indicates that polyvinyl chloride pipe powder can be used as a mineral filler in highway construction as partial replacement with crushed sand dust.

The mix with partial replacement polyvinyl chloride pipe powder resulted higher moisture resistance (93.63%) compared to the mix produced with crushed stone dust (83.98%) at optimum bitumen content.

Generally, based upon the laboratory test results the following conclusion can be drawn:

- LDPE and PVC pipe waste powder can be successfully used in paving applications.
- The addition of LDPE waste to an optimum content of 8% with the bitumen enhances both the binder's as well as the mix's properties. Partial replacement(50%) of polyvinyl chloride pipe powder with crushed sand dust also enhances the mix's properties.
- Improved volumetric property values were achieved after addition of waste LDPE and PVC-PP to the binder and mineral filler respectively.
- Both polymer materials (LDPE and PVC-PP) show better moisture resistance to the permanent deformation of the mix as compared to the mix prepared by neat 60/70 binder and CSD filler respectively.

5.2 Recommendation

In Ethiopia, construction of asphalt pavement is still in infant stage and needs much more effort to make construction materials. The awareness about the different alternative locally available, economically feasible as well as environmentally friendly modifiers and fillers material for HMA materials and their advantages is negligible. Therefore, based on the findings of this study, the following recommendations are forwarded:

- Recycled polymer materials like low density polyethylene (LDPE) can be used as binder modifier with 60/70 binder to 8% optimum of modifier content, and polyvinyl chloride pipe powder (PVC-PP) can be used as a filler material as a partial replacement in hot mix asphalt in combination with crushed stone dust at 5.43% OBC and 5% filler content in national road sectors with its standards.
- Both polymer materials LDPE and PVC-PP investigated in this study can be used as 60/70 binder and crushed stone replacement respectively. Therefore, concerned government and private companies like contractors and consultants should have to made awareness about.
- Finally the researcher recommends the Ethiopian Road Authority and other road sectors to apply the potential use of this recycled waste polymer materials on asphalt concrete pavements to their potential use.

The following further investigations are required:

- Evaluation of the suitability of polymer waste materials like LDPE and PVC-PP in hot mix asphalt at different bitumen content and grade.
- Rutting effect investigation of recycled waste polymer materials that are used in this study on HMA mixture.
- The economic analysis on the use of low density polyethylene as binder modifier and polyvinyl chloride pipe powder as a filler as alternative material.
- Evaluation of HMA mixture with different super-pave gradation using low density polyethylene as binder modifier and polyvinyl chloride pipe powder as a filler.

REFERENCES

[1]. **Naskar M, Chaki TK, Reddy KS.** *Effect of waste plastic as modifier on thermal stability and degradation kinetics of bitumen/waste plastics blend. Thermochimica Acta.* 2010. pp. 128-134. Vols. 509(1-2).

[2]. **Asphalt institute.** *Asphalt Mix Design Methods MANUAL SERIES NO. 02 (MS-2).* 7th edition ed. 2014.

[3]. **ERA.** *Ethiopia Roads Authority Pavement Design Manual Volume 1.* 2013.

[4]. **Yan KZ, Xu HB, Zhang HL.** *Effect of mineral filler on properties of warm asphalt mastic containing Sasobit. Construction and Building Materials.* 2013. pp. 622–6227. Vol. 48.

[5]. **Muniandy R, Aburkaba E, Mahdi L.,.** *Effect of Mineral Filler Type and Particle Size on Asphalt-Filler Mastic and stone Mastic Asphalt Laboratory measured properties. Australian Journal of Basic and Applied Sciences.* 2013. p. 475. Vol. 7(1).

[6]. **Tahami SA, Arabani M, Mirhosseini AF.** *Usage of two biomass ashes as filler in hot mix asphalt. Construction and Building Materials.* 2018. pp. 547-56. Vol. 170.

[7]. **Kwame, B.A.A.W.D. and Baako, A.S.Y.** *Assessment of Suitability of Plastic Waste in Bituminous Pavement Construction. Assessment.* 2015. Vol. 7(11).

[8]. **Al-Hadidy AI, Yi-qiu T.** *Effect of polyethylene on life of flexible pavements. Construction and Building Materials.* 2009. pp. 1456–1464. Vol. 23(3).

[9]. **Salehi S, Arashpour M, Kodikara J, Guppy R.** *Sustainable pavement construction: A systematic literature review of environmental and economic analysis of recycled materials. Journal of Cleaner Production.* . 2021.

[10]. **Heydari S, Hajimohammadi A, Javadi NH, Khalili N.** *The use of plastic waste in asphalt: A critical review on asphalt mix design and Marshall properties. Construction and Building Materials.* 2021.

[11]. **T, Rogers.** *Everything you need to know about polyethylene (PE). Dostopno na: https://www. creativemechanisms. com/blog/polyethylene-pe-for-prototypes-3dprinting-and-cnc, ogled.* 2018. Vol. 8(8).

[12]. **Gawande A, Zamre GS, Renge VC, Bharsakale GR, Tayde S.** *A review utilization of waste plastic in asphalting of roads.* 2012. pp. 147–57. Vol. 2(2).

[13]. **Rahman, Md. Nobinur.** *Performance Evaluation of Waste Polyethylene and PVC on Hot Asphalt Mixtures.* 2013.

[14]. **Beycioğlu A, Kaya O, Yıldırım ZB, Bağrıaçık B, Dobiszewska M, Morova N, Çetin S.** *Use of GRP Pipe Waste Powder as a Filler Replacement in Hot-Mix Asphalt. Materials.* 2020. p. 4630. Vol. 13(20).

[15]. **Han C, Johnson AM.** *Waste products in highway construction. Minnesota Department of Transportation.* 1993.

[16]. **Thompson RC, Moore CJ, Vom Saal FS, Swan SH.** *Plastics, the environment and human health: current consensus and future trends. Philosophical transactions of the royal society B: biological sciences.* 2009. pp. 2153-66. Vol. 364(1526).

[17]. **Prasad DS, Raju GP, Kumar MA.** *Utilization of industrial waste in flexible pavement construction.* 2009. pp. 207-11. Vol. 13(2).

[18]. **Behl A, Jain PK, Sharma G.** *Study on waste polyvinyl chloride modified bitumen for paving applications. InARRB Conference, 25th.* 2012.

[19]. **Jew, P, and Woodhams, RT.** *"Polyethylene modified bitumens for paving applications", Proceedings of the Association of Asphalt Paving Technologies* . 1982. pp. 55-82. Vol. 541.

[20]. **Khan IM, Kabir S, Alhussain MA, Almansoor FF.** *Asphalt design using recycled plastic and crumb-rubber waste for sustainable pavement construction. Procedia Engineering.* 2016. pp. 1557-64. Vol. 145.

[21]. **Muniandy, R., E.Aburkaba & Taha, R.,.** *Effect of mineral filler type and particle size on the engineering properties of stone mastic asphalt pavements.TJER,.* 2013. pp. 13–32.

[22]. **Stroup-Gardiner M, Epps J.** *Laboratory test for assessing moisture damage of asphalt concrete mixture. T.R.R.,.* 2009. pp. 15–23. Vol. 1353.

[23]. **Little, DN.** *Enhancement of Asphalt Concrete Mixtures to Meet Structural Requirements through the Addition of Recycled Polyethylene Use of Waste Materials in Hot-Mix Asphalt, ASTM.* 1993.

[24]. **Association, National Asphalt Pavement.** *HMA pavement mix type selection guide. Information Series.* 2001. Vol. 128.

[25]. **Golalipour A, Jamshidi E, Niazi Y, Afsharikia Z, Khadem M.** *Effect of Aggregate Gradation on Rutting of Asphalt Pavements. Social and Behavioral Sciences.* 2012. pp. 440 – 449. Vol. 53.

[26]. **Khasawneh MA, Alsheyab MA.** *Effect of nominal maximum aggregate size and aggregate gradation on the surface frictional properties of hot mix asphalt mixtures. Construction and Building Materials.* 2020. p. 118355. Vol. 244.

[27]. **Niloofar Z, Kalantar MR, Karim AM.** *A review of using waste and virgin polymer in the pavement. Constr. Build. Mater.* 2015. pp. 315-9. Vol. 84.

[28]. **Yadav, A. and Chandrakar, R.,.** *"Construction of plastic roads: An effective way to utilize wastes", International Research Journal of Engineering and Technology.* 2017. pp. 650-652. Vol. 4 (11).

[29]. **Aburkaba E, Muniandy R.** *An Overview of the Use of Mineral Fillers in Asphalt Pavements. Austr. Journal of Basic and Applied Sciences.* 2016. pp. 279-292. Vol. 10(9).

[30]. **Modarres A, Rahmanzadeh M.** *Application of coal waste powder as filler in hot mix asphalt. Construction and Building Materials.* 2014. pp. 476-83. Vol. 66.

[31]. **Al-Hdabi, A.,.** *Laboratory investigation on the properties of asphalt concrete mixture with Rice Husk Ash as filler. Constr. and Build.Materials.* 2016. pp. 544-551. Vols. 126,.

[32]. **Zhu, J., Birgisson, B. and Kringos, N.,.** *"Polyme modification of bitumen: Advances and challenges",European Polymer Journal.* 2014. pp. 18-38 . Vol. 54.

[33]. **Abdullah ME, Ahmad NA, Jaya RP, Hassan NA, Yaacob H, Hainin MR.** *Effects of waste plastic on the physical and rheological properties of bitumen. InIOP Conference Series: Materials Science and Engineering.* 2017. p. 012016. Vol. 204(1).

[34]. **Sienkiewicz, M., Borzędowska-Labuda, K., Wojtkiewicz, A. and Janik, H.,.** *"Development of methods improving the storage stability of bitumen modified with ground tire rubber: A review", Fuel Processing Technology.* 2017. pp. 272-279. Vol. 159.

[35]. **Rajmane PB, Gupta AK, Desai DB.** *Effective utilization of waste plastic in construction of flexible pavement for improving their performance. OSR Journal of Mechanical and Civil Engineering.* 2009. pp. 27-30. Vol. 2(17).

[36]. **Imran M. Khan, Shahid Kabir, Majed A. Alhussain, Feras F. Almansoor.** *Asphalt Design using Recycled Plastic and Crumb-rubber Waste for Sustainable Pavement Construction.* 2016.

[37]. **Aforla, Bright.** *Assessment of Suitability of Plastic Waste in Bituminous Pavement Construction.* 2015.

[38]. **Awaeed KM, Fahad BM, Rasool DA.** *Utilization of waste plastic water bottle as a modifier for asphalt mixture properties. J. Eng. Dev.* 2015. pp. 89-108. Vol. 20(2).

[39]. **Padhan, R.K. and Gupta, A.A.,.** *"Preparation and evaluation of waste PET derived polyurethane polymer modified bitumen through in situ polymerization reaction", Construction and Building Materials.* 2018. pp. 337-345. Vol. 158.

[40]. **Karahrodi, M.H., Jazani, O.M., Paran, S.M.R., Formela, K. and Saeb, M.R.** *"Modification of thermal and rheological characteristics of bitumen by waste PET/GTR blends", Construction and Building PET/GTR blends", Construction and Building.* 2017. pp. 157-166. Vol. 134.

[41]. **Ma Y, Wang S, Zhou H, Hu W, Polaczyk P, Huang B.** *Potential Alternative to Styrene–Butadiene–Styrene for Asphalt Modification Using Recycled Rubber–Plastic Blends.Journal of Materials in Civil Engineering.* 2021. Vol. 33(12).

[42]. **Ahmad J, Abdul Rahman MY, Hainin MR, Hossain M.** *Comparative evaluation of hot-mix asphalt design methods. International Journal of Pavement Engineering.* 2012. pp. 89-97. Vol. 13(2).

[43]. **Brown ER, Kandhal PS, Zhang J.** *Performance testing for hot mix asphalt. NCAT Report 01-05. National Center for Asphalt Technology.* 2001.

[44]. **Akter R, Hossain MK.** *Open Access Influence of Rice Husk Ash and Slag as Fillers in Asphalt Concrete Mixes.* 2018. pp. 303–311. Vol. 6(1).

[45]. **Moghaddam TB, Karim MR, Soltani M.** *Utilization of waste plastic bottles in asphalt mixture. Journal of Engineering Science and Technology.* 2013. pp. 264-71. Vol. 8(3).

[46]. **AM, Othman.** *Effect of low-density polyethylene on fracture toughness of asphalt concrete mixtures. Journal of Materials in Civil Engineering.* 2010. pp. 1019-24. Vol. 22(10).

[47]. **Ahmad, Malik Shoeb.** *Low Density Polyethylene Modified Dense Graded Bituminous Macadam.* 2014. Vol. 16(8).

[48]. **Genet MB, Sendekie ZB, Jembere AL.** *Investigation and optimization of waste LDPE plastic as a modifier of asphalt mix for highway asphalt: Case of Ethiopian roads. Case Studies in Chemical and Environmental Engineering.* 2021.

[49]. **Ullah S, Raheel M, Khan R, Khan MT.** *Characterization of physical & mechanical properties of asphalt concrete containing low-& high-density polyethylene waste as aggregates. Construction and Building Materials.* 2021.

[50]. **Muniandy, R. & Aburkaba, E.** *The effect of type and particle size of industrial wastes filler on Indirect Tensile Stiffness and Fatigue performance of Stone Mastic Asphalt Mixtures. Australian Journal of Basic and Applied Sciences.* 2011. pp. 297–308. Vol. 5(11).

APPENDICES

Appendix A: Aggregate Test Results

Table A1: Particle size distribution for coarse aggregate (9.5-25 mm)

Test method: Sieve analysis (AASHTO T 27)

Material Type: Crushed Stone Coarse Aggregate (9.5-25mm)											
Dry Sample Weight, (gm)				5000		5040					
Washed Dry Sample Weight, (gm)				4989.2		5028.5					
Sieve size, mm	Weight Ret. (g)	% Ret.	Cumm. Ret. (%)	Weight of passing (g)	% Passing	Weight Ret. (g)	% Ret.	Cumm. Ret. (%)	Weight of passing (g)	% Passing	Average cumm. Pass (%)
25	0.0	0.0	0.0	5000.0	100.0	0.0	0.0	0.0	5040.0	100.0	100.0
19	1115.8	22.3	22.3	3884.2	77.7	1089.3	21.6	21.6	3950.7	78.4	78.0
12.5	2490.5	49.8	72.1	1393.7	27.9	2561.8	50.8	72.4	1388.9	27.6	27.7
9.5	1203.4	24.1	96.2	190.3	3.8	1200.1	23.8	96.3	188.8	3.7	3.8
4.75	131.6	2.6	98.8	58.7	1.2	133.2	2.6	98.9	55.6	1.1	1.1
2.36	27.3	0.5	99.4	31.4	0.6	23.7	0.5	99.4	31.9	0.6	0.6
1.18	12.1	0.2	99.6	19.3	0.4	11.6	0.2	99.6	20.3	0.4	0.4
0.6	6.3	0.1	99.7	13.0	0.3	7.7	0.2	99.8	12.6	0.2	0.3
0.3	2.2	0.0	99.8	10.8	0.2	2.9	0.1	99.8	9.7	0.2	0.2
0.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.075	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W.loose	10.8					9.7					
Total	4989.2					5030.3					

Table A2: Particle size distribution for intermediate aggregate (2.36-9.5 mm)

Material Type: Crushed stone intermidiate aggregate, (2.36 - 9.5mm)											
Dry Sample Weight, (gm)				4800		4700					
Washed Dry Sample Weight, (gm)				4774.2		4676.7					
Sieve size,mm	Weight Ret. (g)	% Ret.	Cumm. Ret. (%)	Weight of passing (g)	% Passing	Weight Ret. (g)	% Ret.	Cumm. Ret. %	Weight of passing (g)	% Passing	Average cumm. Pass %
25	0.0	0.0	0.0	4800.0	100.0	0.0	0.0	0.0	4700.0	100.0	100.0
19	0.0	0.0	0.0	4800.0	100.0	0.0	0.0	0.0	4700.0	100.0	100.0
12.5	0.0	0.0	0.0	4800.0	100.0	0.0	0.0	0.0	4700.0	100.0	100.0
9.5	698.7	14.6	14.6	4101.3	85.4	690.9	14.7	14.7	4009.1	85.3	85.4
4.75	2337.1	48.7	63.2	1764.2	36.8	2291.8	48.8	63.5	1717.3	36.5	36.6
2.36	1442.0	30.0	93.3	322.2	6.7	1400.6	29.8	93.3	316.7	6.7	6.7
1.18	130.5	2.7	96.0	191.7	4.0	132.6	2.8	96.1	184.1	3.9	4.0
0.6	122.8	2.6	98.6	68.9	1.4	117.5	2.5	98.6	66.6	1.4	1.4
0.3	32.9	0.7	99.3	36.0	0.8	33.9	0.7	99.3	32.7	0.7	0.7
0.15	10.2	0.2	99.5	25.8	0.5	9.4	0.2	99.3	23.3	0.5	0.5
0.075	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W. Loose	25.8					23.3					
Total	4800.0					4700.0					

Table A3: Particle size distribution for fine aggregate (0-2.36 mm)

Material Type: Crushed stone fine aggregate, (0 - 2.36mm)											
Dry Sample Weight, (gm)				3800		4000					
Washed Dry Sample Weight, (gm)				3317.2		3531.3					
Sieve size,mm	Weight Ret. (g)	% Ret.	Cumm. Ret. (%)	Weight of passing (g)	% Passing	Weight Ret. (g)	% Ret.	Cumm. Ret. (%)	Weight of passing (g)	% Passing	Average cumm. Passing (%)
25	0.0	0.0	0.0	3800.0	100.0	0.0	0.0	0.0	4000.0	100.0	100.0
19	0.0	0.0	0.0	3800.0	100.0	0.0	0.0	0.0	4000.0	100.0	100.0
12.5	0.0	0.0	0.0	3800.0	100.0	0.0	0.0	0.0	4000.0	100.0	100.0
9.5	0.0	0.0	0.0	3800.0	100.0	0.0	0.0	0.0	4000.0	100.0	100.0
4.75	36.2	1.0	1.0	3763.8	99.0	48.1	1.2	1.2	3951.9	98.8	98.9
2.36	224.4	5.9	6.9	3539.4	93.1	238.1	6.0	7.2	3713.8	92.8	93.0
1.18	852.1	22.4	29.3	2687.3	70.7	895.7	22.4	29.5	2818.1	70.5	70.6
0.6	683.8	18.0	47.3	2003.5	52.7	720.1	18.0	47.6	2098.0	52.5	52.6
0.3	665.1	17.5	64.8	1338.4	35.2	698.5	17.5	65.0	1399.5	35.0	35.1
0.15	456.0	12.0	76.8	882.4	23.2	480.2	12.0	77.0	919.3	23.0	23.1
0.075	294.5	7.8	84.5	587.9	15.5	300.6	7.5	84.5	618.7	15.5	15.5
Pan	105.1	2.8	87.3	0.0	0.0	150.0	3.8	0.0	0.0	0.0	0.0
W.Loose	482.8					468.7					
Total	3800.0					4000.0					

Table A4: Aggregate gradation for 5% CSD filler

Aggregate Type	9.5 - 25mm		2.36 - 9.5mm		0 - 2.36mm		Total Blend	Middle Value	Specification Limit
Blending,(%)	30		36		34				
Sieve size,mm	% Pass	% Blend A	% Pass	% Blend B	% Pass	% Blend C	A+B+C		
25	100.0	30.0	100.0	36.0	100.0	34.0	100.0	100.0	100
19	78.0	23.4	100.0	36.0	100.0	34.0	93.4	95.0	90-100
12.5	27.7	8.3	100.0	36.0	100.0	34.0	78.3	79.5	……..
9.5	3.8	1.1	85.4	30.7	100.0	34.0	65.9	68.0	56-80
4.75	1.1	0.3	36.6	13.2	98.9	33.6	47.2	50.0	35-65
2.36	0.6	0.2	6.7	2.4	93.0	31.6	34.2	36.0	23-49
1.18	0.4	0.1	4.0	1.4	70.6	24.0	25.5	26.0	……..
0.6	0.3	0.1	1.4	0.5	52.6	17.9	18.5	19.0	……..
0.3	0.2	0.1	0.7	0.3	35.1	11.9	12.3	12.0	5–19
0.15	0.0	0.0	0.5	0.2	23.1	7.9	8.0	8.5	……..
0.075	0.0	0.0	0.0	0.0	15.5	5.3	5.3	5.0	2–8

Table A5: Aggregate gradation for 5.5% CSD filler

Aggregate Type	9.5 - 25mm		2.36 - 9.5mm		0 - 2.36mm		Total Blend	Middle Value	Specification Limit
Blending,(%)	28.8		36		35.2				
Sieve size,mm	% Pass	% Blend A	% Pass	% Blend B	% Pass	% Blend C	A+B+C		
25	100.0	28.8	100.0	36.0	100.0	35.2	100.0	100.0	100
19	78.0	22.5	100.0	36.0	100.0	35.2	93.7	95.0	90-100
12.5	27.7	8.0	100.0	36.0	100.0	35.2	79.2	79.5	……..
9.5	3.8	1.1	85.4	30.7	100.0	35.2	67.0	68.0	56-80
4.75	1.1	0.3	36.6	13.2	98.9	34.8	48.3	50.0	35-65
2.36	0.6	0.2	6.7	2.4	93.0	32.7	35.3	36.0	23-49
1.18	0.4	0.1	4.0	1.4	70.6	24.8	26.4	26.0	……..
0.6	0.3	0.1	1.4	0.5	52.6	18.5	19.1	19.0	……..
0.3	0.2	0.1	0.7	0.3	35.1	12.4	12.7	12.0	5–19
0.15	0.0	0.0	0.5	0.2	23.1	8.1	8.3	8.5	……..
0.075	0.0	0.0	0.0	0.0	15.5	5.4	5.4	5.0	2–8

Table A6: Aggregate Gradation for 6% CSD filler

Aggregate Type	9.5 - 25mm		2.36 - 9.5mm		0 - 2.36mm		Total Blend	Middle Value	Specification Limit
Blending,(%)	27.6		34.9		37.5				
Sieve size,mm	% Pass	% Blend A	% Pass	% Blend B	% Pass	% Blend C	A+B+C		
25	100.0	27.6	100.0	34.9	100.0	37.5	100.0	100.0	100
19	78.0	21.5	100.0	34.9	100.0	37.5	93.9	95.0	90-100
12.5	27.7	7.6	100.0	34.9	100.0	37.5	80.0	79.5	……..
9.5	3.8	1.0	85.4	29.8	100.0	37.5	68.3	68.0	56-80
4.75	1.1	0.0	36.6	12.8	98.9	37.1	49.9	50.0	35-65
2.36	0.6	0.6	6.7	2.3	93.0	34.9	37.9	36.0	23-49
1.18	0.4	0.3	4.0	1.4	70.6	26.5	28.2	26.0	……..
0.6	0.3	0.1	1.4	0.5	52.6	19.7	20.3	19.0	……..
0.3	0.2	0.0	0.7	0.3	35.1	13.2	13.4	12.0	5–19
0.15	0.0	0.0	0.5	0.2	23.1	8.7	8.8	8.5	……..
0.075	0.0	0.0	0.0	0.0	15.5	5.8	5.8	5.0	2–8

Table A7: specific gravity and water absorption of coarse aggregate (9.5-25 mm)

Test method AASHTO T85-91

Trial No	1	2	Average
A= Weight of oven dry sample in air, gm	2471.3	2469.9	
B=Weight of SSD sample in air, gm	2500.0	2500.0	
C=Weight of saturated sample in water,gm	1551.7	1550.9	
Bulk sp.gravity(oven dry) ,Gsb=A/(B-C)	2.6	2.6	2.604
Bulk sp.gravity(SSD), Gss=B/(B-C)	2.6	2.6	2.635
Apparent specific gravity ,Gsa=A/(A-C)	2.7	2.7	2.688
Water Absorption ,%=(B-A)/A*100	1.2	1.2	1.191

Table A8. Specific gravity and water absorption of intermediate aggregate (2.36-9.5 mm)

Test method AASHTO T85-91

Trial No	1	2	Average
A= Weight of oven dry sample in air, gm	1972	1971.09	
B=Weight of SSD sample in air, gm	2000	2000	
C=Weight of saturated sample in water,gm	1244.5	1245.53	
Bulk sp.gravity(oven dry) ,Gsb=A/(B-C)	2.610	2.613	2.611
Bulk sp.gravity(SSD), Gss=B/(B-C)	2.647	2.651	2.649
Apparent specific gravity ,Gsa=A/(A-C)	2.711	2.717	2.714
Water Absorption ,%=(B-A)/A*100	1.419	1.467	1.443

Table A9: specific gravity and water absorption of fine aggregate (0-2.36 mm)

Test method AASHTO T84-95

Trial No	1	2	Average
A= Weight of oven dry sample in air, gm	247.78	249.22	
B= Weight of Pycnometer+ Water,gm	696.76	697.98	
C=Weight of Pycnometer + water + sample,gm	857.73	853.21	
S=Weight of SSD sample,gm	252	253	
Bulk Sp.gravity(oven dry) ,Gsb=A/(B+S-C)	2.722	2.549	2.636
Bulk sp.gravity(SSD), Gss=S/(B+S-C)	2.768	2.588	2.678
Apparent specific gravity ,Gsa=A/(A+B-C)	2.854	2.652	2.753
Water Absorption ,%=(S-A)/A*100	1.703	1.517	1.610

Appendix B: Bitumen Test Results

Table B1: Penetration test (Test method: AASHTO T49)

Test No.	Test Temp. °C	Time of test (s)	Test Load (g)	Reading, (0.1mm)			Average (0.1mm)
				1st time	2nd time	3rd time	
1	25	5	100	65.79	64.88	64.71	65.13
2	25	5	100	65.69	67.55	65.34	66.19
3	25	5	100	66.32	65.71	67.15	66.39
Average Penetration							65.90

Table B2: Ductility test (Test method AASHTO T51)

Test No.	Test Temp. °C	Test Load(g)	Ductility(cm)	Average (cm)
1	25	5	110	109
2	25	5	108	
3	25	5	109	

Table B3: Softening point (Test method AASHTO T53)

Test No.	Temp. When starting to heating (°C)	Record of liquid temp.in beaker			Softening Point (°C)
		4min	5min	6min	
1	25	34	42	48	48.11
2	25	34	42	48	48.71
Average					48.41

Table B4: Specific Gravity of bitumen (Test Method ASTM D70-97 or AASHTO T-228)

Group	Wt.of Pycnometer (g)=A	Wt. Of Pycnometer + distilled Water (g) =B	Wt. of pycno +Partially filled with Bitumen (g)=C	Wt. of pycno + Water + Bitumen (g)=D	Relative Density (gm/cm³) = (C-A)/((B-A)-(D-C))	Specific Gravity= Relative Density*Density of Water (0.997gm/cm³)
1	31.81	131.89	109.26	133.33	1.019	1.016
2	32.1	130.58	108.91	132.57	1.027	1.024
Average						1.020

Appendix C: Mineral Filler Test Results

Table C1: Particle size distribution of CSD filler (Test method: AASHTO T 11)

Material	Crushed Stone Sand, <0.075 mm								
Dry Wt, g	340				350				
Washed, g	0				0				
Sieve size, mm	Weight Ret., g	% Ret.	Cumm. % Ret.	% Pass	weight Ret., g	% Ret.	Cumm. % Ret.	% Pass	Av. cumm. Pass,%
1.18	0	0	0	100	0.0	0	0	100	100
0.6	0	0	0	100	0.0	0	0	100	100
0.3	0	0	0	100	0.0	0	0	100	100
0.15	0	0	0	100	0.0	0	0	100	100
0.075	0	0	0	100	0.0	0	0	100	100
Pan	0				0.0				
W.loose	340				350.0				
Total	340				350.0				

Table C2: Particle size distribution of polyvinyl chloride pipe powder (PVC-PP) filler

Material	Polyvinyl chloride pipe powder			Specification (ASTM D242)
Sieve size, mm	Mass Retained (g)	% Retained	% Pass	
2.36	0	0.0	100.0	-
1.18	0	0.0	100.0	-
0.6	0	0.0	100.0	100
0.3	6.15	0.6	99.4	95 - 100
0.15	105.7	10.6	89.4	70 - 100
0.075	357.4	35.7	64.3	-
Pan	530.75			-
Total	1000			-

Table C3: Specific gravity of CSD mineral fillers (Test method: AASHTO T84-95)

Material type	Crushed Sand Stone	
Pycnometer No.	1	2
Mass of dry clean & calibrated pycnometer, g	30.72	26.74
A = Mass of oven dry sample in air, g	25	25
B = Mass of pycnometer + water, g	127.35	125.42
C = Mass of pycnometer + water + sample, g	143.03	141
Observed of Temp.H2O, g	22	23
Temp.of contents of pycnometer when Mpsw was taken, Tx	22	23
K for TX	1.007	1
Apparent specific gravity Gsa =A* K/(A+ B-C)	2.701	2.654
Average	2.678	

Table C4: Specific gravity of polyvinyl chloride pipe powder as a mineral fillers

Material type	PVC Pipe Powder as a Filler	
Pycnometer No.	1	2
Mass of dry clean & calibrated pycnometer, g	30.5	31.81
A = Mass of oven dry sample in air, g	25	25
B = Mass of pycnometer + water, g	123.72	127.67
C = Mass of pycnometer + water + sample, g	138.62	142.54
Observed of Temp.H2O, Ti	22	23
Temp.of content of pycnometer when Mpsw was taken, Tx	23	23
K for TX	1.0005	1
Apparent specific gravity Gsa =A* K/(A+ B-C)	2.476	2.468
Average	2.472	

Appendix D: Maximum Theoretical Density

Test Method: ASTM Designation: D 2041 -90

Table D1: Theoretical maximum specific gravity of un-compacted mixture with 5 % CSD

BC %	4		4.5		5		5.5		6	
Trial No	1	2	1	2	1	2	1	2	1	2
A	1226.67	1225.80	1219.89	1218.45	1221.70	1220.97	1219.50	1221.45	1228.83	1229.61
B	2415.80	2377.50	2425.40	2371.40	2377.50	2415.80	2425.40	2371.40	2377.50	2415.80
C	3136.90	3094.70	3139.67	3104.02	3100.90	3138.32	3139.00	3099.87	3101.23	3128.78
Gmm= A/(A+B-C)	2.426	2.410	2.413	2.508	2.452	2.450	2.411	2.478	2.433	2.380
Average Gmm	2.418		2.460		2.451		2.444		2.406	

Table D2: Theoretical maximum specific gravity of un-compacted mixture with 5.5 % CSD

BC %	4		4.5		5		5.5		6	
Trial No	1	2	1	2	1	2	1	2	1	2
A	1217.78	1220.45	1218.21	1217.34	1218.46	1217.48	1217.57	1218.34	1219.67	1221.00
B	2377.50	2425.40	2371.40	2415.80	2425.40	2377.50	2415.80	2371.40	2425.40	2377.50
C	3101.34	3153.76	3091.21	3139.26	3144.39	3098.98	3133.69	3091.78	3132.67	3091.00
Gmm= A/(A+B-C)	2.465	2.480	2.444	2.465	2.440	2.455	2.437	2.447	2.380	2.406
Average Gmm	2.473		2.455		2.447		2.442		2.393	

Table D3: Theoretical maximum specific gravity of un-compacted mixture with 6% CSD

BC %	4		4.5		5		5.5		6	
Trial No	1	2	1	2	1	2	1	2	1	2
A	1218.34	1217.76	1217.20	1217.56	1218.12	1218.65	1218.43	1218.81	1221.67	1222.80
B	2425.40	2377.50	2371.40	2415.80	2425.40	2377.50	2371.40	2415.80	2377.50	2371.40
C	3150.23	3098.89	3092.76	3135.34	3139.87	3101.23	3090.00	3130.65	3091.50	3087.54
Gmm= A/(A+B-C)	2.469	2.453	2.455	2.445	2.419	2.462	2.438	2.418	2.406	2.413
Average Gmm	2.461		2.450		2.440		2.428		2.410	

Table D4: Theoretical maximum specific gravity of un-compacted mixture of LDPE as additive.

LDPE, %	0		2		4		6		8		10	
Trial No	1	2	1	2	1	2	1	2	1	2	1	2
A	1216.82	1218.76	1214.90	1217.10	1219.50	1218.42	1216.93	1217.97	1218.78	1217.56	1218	1220.34
B	2425.40	2371.40	2415.80	2377.50	2371.40	2377.50	2425.40	2415.80	2377.50	2425.40	2371	2377.50
C	3144.70	3088.20	3133.80	3091.90	3089.80	3093.90	3141.12	3132.27	3092.80	3140.01	3086	3090.06
Gmm= A/(A+B-C)	2.446	2.428	2.445	2.421	2.434	2.427	2.428	2.429	2.421	2.421	2.419	2.403
Average Gmm	2.437		2.433		2.430		2.428		2.421		2.411	

Table D5: Theoretical maximum specific gravity of un-compacted mixture of PVC-PP as a filler.

PVC - PP, %	0		25		50		75		100	
Trial No	1	2	1	2	1	2	1	2	1	2
A	1222.50	1225.90	1212.43	1213.80	1212.78	1211.23	1214.21	1213.43	1200.90	1211.21
B	2377.50	2425.40	2371.40	2415.80	2425.40	2377.50	2415.80	2371.40	2425.40	2371.40
C	3088.40	3130.12	3066.80	3122.45	3133.65	3069.50	3116.56	3068.20	3116.06	3068.20
Gmm= A/(A+B-C)	2.390	2.352	2.345	2.393	2.404	2.333	2.365	2.349	2.354	2.355
Average Gmm	2.371		2.369		2.368		2.357		2.354	

Where; A=Mass of Dry Sample in Air, B=Mass of Jar filled with water (@ 25 ºC and C=Mass of Jar + Sample + Water (@ 25 ºC

Appendix E: - Marshall Mix Design Test Results for Control Mix.

Table E1: - Marshall mix Properties of Asphalt mix with **5% CSD filler** for different bitumen content

Project : MSc Thesis
Location : Jimma University,JIT
Sample : Asphalt Concrete Mix
Tested by : Abdissa Nagara
Test Name: ____________________
Test Number: ____________________
Date Tested: ____________________
Checked by: ____________________
Bulk specific gravity of Aggregate: 2.590
Bitumen Grade: 60/70 penetration grade
Filler Material: Crushed stone dust
Test Method: ASTM D1559/AASHTO T 245

Spec. No	% AC	Spec. height (mm)	Weight of specimen (g)			Volume of spec. (cc)	Bulk Density (g/cc)	Unit Weight (kg/m3)	Gmm	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
			in Air	in Water	in SSD									
1	4	69.5	1228	699.9	1229.5	529.6	2.318	2318		6.0	14.1	56.9	9.3	2.58
2		70.0	1209	695.2	1220.7	525.5	2.300	2300		6.8	14.7	54.1	10.1	2.60
3		68.7	1227	698.6	1228.3	529.7	2.316	2316		6.2	14.2	56.4	10.6	2.57
Mean ± St.Dev.		69.4	1221.1	697.9	1226.2	528.3	2.311±0.01	2311	2.468	6.3±0.34	14.3±0.4	55.8±1.4	10±0.7	2.58±0.02
1	4.5	70.0	1220	695.1	1220.5	525.4	2.322	2322		5.6	14.4	60.3	10.8	2.75
2		70.5	1220	692.2	1215.7	523.5	2.330	2330		5.3	14.1	61.3	11.1	2.69
3		69.5	1220	692.7	1214.1	521.4	2.340	2340		4.9	13.7	62.4	11.9	2.58
Mean ± St.Dev.		70.0	1219.9	693.3	1216.8	523.433	2.331±0.01	2331	2.459	5.2±0.35	14.1±0.32	61.3±1.1	11.3±0.6	2.67±0.09
1	5	68.0	1226	695.1	1216.6	521.5	2.351	2351		4.1	13.8	66.9	12.9	3.18
2		68.5	1225	694.2	1215.3	521.1	2.350	2350		4.1	13.8	66.9	12.7	3.22
3		68.4	1218	696.3	1219.1	522.8	2.329	2329		5.0	14.6	65.8	12.8	3.37
Mean ± St.Dev.		68.3	1222.7	695.2	1217.0	521.8	2.343±0.01	2343	2.451	4.4±0.50	14.1±0.45	66.5±0.6	12.8±0.1	3.26±0.10
1	5.5	70.5	1208	695.1	1209.5	514.4	2.349	2349		3.9	14.3	72.7	11.6	3.21
2		70.0	1210	692.2	1210.7	518.5	2.333	2333		4.6	14.9	69.3	11.2	3.32
3		70.5	1209	692.7	1209.1	516.4	2.341	2341		4.2	14.6	71.0	11.4	3.34
Mean ± St.Dev.		70.3	1208.9	693.3	1209.8	516.4	2.341±0.01	2340.9	2.444	4.2±0.33	14.6±0.23	71±1.70	11.4±0.2	3.29±0.07
1	6	67.6	1218	698.4	1220.4	522.0	2.334	2334		3.2	16.3	80.0	9.8	3.43
2		67.9	1217	695.7	1218.2	522.5	2.329	2329		3.2	16.2	79.9	9.6	3.47
3		67.2	1220	699.2	1221.2	522.0	2.336	2336		2.9	16.2	81.9	8.9	3.46
Mean ± St.Dev.		67.6	1218.1	697.8	1219.9	522.2	2.333±0.00	2332.8	2.406	3.1±0.18	16.2±0.05	80.6±1.1	9.4±0.47	3.45±0.02

Table E2: - Marshall mix Properties of Asphalt mix with **5.5% CSD filler** for different bitumen content

Project : MSc Thesis	**Test Name:** ____________	**Bulk specific gravity of Aggregate:2.592**
Location : Jimma University,JIT	**Test Number:** ____________	**Bitumen Grade: 60/70 penetration grade**
Sample : Asphalt Concrete Mix	**Date Tested:** ____________	**Filler Material: Crushed stone dust**
Tested by : Abdissa Nagara	**Checked by:** ____________	**Test Method: ASTM D1559/AASHTO T 245**

Spec. No	% AC	Spec. height (mm)	Weight of specimen (g)			Volume of spec. (cc)	Bulk Density (g/cc)	Unit Weight (kg/m3)	Gmm	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
			in Air	in Water	in SSD									
1	4	70.2	1216	695.2	1225.7	530.5	2.292	2292		7.3	15.1	51.2	8.9	2.58
2		70.3	1214	696.7	1224.9	528.2	2.299	2299		7.0	14.8	52.4	8.7	2.65
3		70.0	1217	694.8	1224.7	529.9	2.296	2296		7.2	14.9	52.0	9.5	2.61
Mean ± St.Dev.		70.2	1215.5	695.6	1225.1	529.5	2.295±0.00	2295	2.473	7.2±0.14	14.9±0.13	51.9±0.6	9±0.42	2.61±0.04
	4.5	70.0	1230	704.0	1235.5	531.5	2.313	2313		5.8	14.7	61.6	10.8	2.65
		70.5	1230	701.3	1233.6	532.3	2.310	2310		5.9	14.8	60.3	10.4	2.66
		69.5	1230.9	703.5	1234.3	530.8	2.319	2319		5.5	14.5	61.7	10.9	2.58
Mean ± St.Dev.		70.0	1230.0	702.9	1234.5	531.5	2.314±0.00	2314.1	2.455	5.7±0.18	14.7±0.16	61.2±0.8	10.7±0.3	2.63±0.04
1	5	70.2	1217	697.1	1217.5	520.4	2.338	2338		4.5	14.2	69.4	11.98	3.06
2		71.3	1215	693.3	1215.7	522.4	2.325	2325		5.0	14.7	64.9	11.7	3.23
3		69.5	1219	694.7	1220.1	525.4	2.320	2320		5.2	14.9	65.6	12.1	3.03
Mean ± St.Dev.		70.3	1216.8	695.0	1217.8	522.7	2.328±0.01	2328	2.447	4.9±0.38	14.6±0.35	66.6±2.4	11.9±0.2	3.11±0.11
1	5.5	70.5	1229	713.1	1241.5	528.4	2.325	2325		4.8	15.2	68.4	11.6	3.26
2		70.0	1228	712.6	1240.3	527.7	2.327	2327		4.7	15.1	68.9	12.2	3.29
3		70.0	1229	711.8	1242.2	530.4	2.318	2318		5.1	15.4	67.3	11.4	3.34
Mean ± St.Dev.		70.2	1228.5	712.5	1241.3	528.8	2.323±0.00	2323	2.442	4.9±0.19	15.2±0.17	68.2±0.8	11.7±0.4	3.30±0.04
1	6	68.7	1217	698.1	1224.5	526.4	2.312	2312		3.4	16.1	78.9	10.6	3.35
2		69.5	1217	696.2	1222.7	526.5	2.311	2311		3.4	16.1	78.9	10.5	3.39
3		69.7	1215	695.7	1220.1	524.4	2.317	2317		3.2	15.9	80.1	10.4	3.31
Mean ± St.Dev.		69.3	1216.2	696.7	1222.4	525.8	2.313±0.00	2313	2.393	3.3±0.13	16.0±0.11	79.3±0.7	10.5±0.1	3.35±0.04

Table E3: - Marshall mix Properties of Asphalt mix with **6% CSD filler** for different bitumen content

Project : MSc Thesis | **Test Name:** ________ | **Bulk specific gravity of Aggregate: 2.591**
Location : Jimma University,JIT | **Test Number:** ________ | **Bitumen Grade: 60/70 penetration grade**
Sample : Asphalt Concrete Mix | **Date Tested:** ________ | **Filler Material: Crushed stone dust**
Tested by : Abdissa Nagara | **Checked by:** ________ | **Test Method: ASTM D1559/AASHTO T 245**

Spec. No	% AC	Spec. height (mm)	Weight of specimen (g)			Volume of spec. (cc)	Bulk Density (g/cc)	Unit Weight (kg/m3)	Gmm	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
			in Air	in Water	in SSD									
1	4	69.5	1228	699.8	1230.7	530.9	2.312	2312		6.1	14.3	57.7	8.8	2.59
2		69.0	1226	699.6	1228.5	528.9	2.317	2317		5.8	14.1	58.6	8.9	2.53
3		69.0	1227	698.5	1229.5	531.0	2.310	2310		6.1	14.4	57.3	8.8	2.58
Mean ± St.Dev.		69.2	1226.6	699.3	1229.6	530.3	2.313±0.00	2313.1	2.461	6.0±0.14	14.3±0.13	57.9±0.6	8.8±0.06	2.57±0.03
1	4.5	70.2	1225	704.1	1229.7	525.6	2.331	2331		4.8	14.0	65.6	9.7	2.62
2		70.4	1224	701.2	1227.8	526.6	2.324	2324		5.1	14.3	64.1	9.9	2.64
3		69.7	1225	703.7	1228.1	524.4	2.335	2335		4.7	13.9	66.3	10.7	2.58
Mean ± St.Dev.		70.1	1224.6	703.0	1228.5	525.5	2.330±0.00	2330	2.450	4.9±0.23	14.1±0.21	65.3±1.1	10.1±0.5	2.61±0.03
1	5	68.0	1219	701.1	1220	518.9	2.349	2349		3.8	13.9	72.8	11.5	2.98
2		68.5	1218	697.5	1218.5	521.0	2.337	2337		4.2	14.3	70.4	11.2	3.04
3		68.5	1218	699.6	1219.1	519.5	2.345	2345		3.9	14.0	72.0	11.4	3.11
Mean ± St.Dev.		68.3	1218.2	699.4	1219.2	519.8	2.344±0.01	2344	2.440	4.0±0.23	14.0±0.21	71.8±1.2	11.4±0.2	3.04±0.02
1	5.5	70.4	1241	713.1	1245.3	532.2	2.332	2332		3.9	14.9	76.2	11.3	3.25
2		69.7	1240	712.8	1242.2	529.4	2.342	2342		3.6	14.6	75.6	11.9	3.29
3		70.2	1239	711.7	1241.1	529.4	2.340	2340		3.6	14.6	75.2	11.4	3.35
Mean ± St.Dev.		70.1	1239.8	712.5	1242.9	530.3	2.338±0.00	2338	2.428	3.7±0.20	14.7±0.18	75.7±0.5	11.5±0.3	3.3±0.05
1	6	67.5	1218	698.1	1220.1	522.0	2.334	2334		3.2	15.3	79.2	9.9	3.4
2		68.0	1218	695.2	1218	522.8	2.329	2329		3.4	15.5	78.1	9.8	3.5
3		67.0	1219	699.0	1221	522.0	2.336	2336		3.1	15.2	79.6	9.6	3.45
Mean ± St.Dev.		67.5	1218.3	697.4	1219.7	522.3	2.333±0.00	2333	2.410	3.2±0.15	15.3±0.13	79.0±0.8	9.8±0.2	3.5±0.02

Appendix F: - Marshall Mix Design Test Results for Replacement

Table F1: - Marshall Mix Properties of Asphalt mix with LDPE at 5.43% OBC and 5% FC

Project : MSc Thesis	**Test Name:** ____________	**Bulk specific gravity of Aggregate: 2.592**
Location : Jimma University,JIT	**Test Number:** ____________	**Bitumen Grade: 60/70 penetration grade**
Sample : Asphalt Concrete Mix	**Date Tested:** ____________	**Binder additve Material: LDPE**
Tested by : Abdissa Nagara	**Checked by:** ____________	**Test Method: ASTM D1559/AASHTO T 245**

Spec . No	% LDPE	Spec. height (mm)	Weight of specimen (g)			Volume of spec. (cc)	Bulk Density (g/cc)	Unit Weight (kg/m3)	Gmm	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
			in Air	in Water	in SSD									
1	0	69.5	1223.10	683.40	1224.7	541.30	2.260	2260		4.96	17.50	68.08	11.22	3.76
2		70.3	1222.80	680.60	1223.1	542.50	2.254	2254		4.97	17.70	67.54	11.38	2.98
3		70.2	1223.02	682.50	1225.0	542.51	2.254	2254		4.98	17.68	66.32	11.05	2.65
Mean ± St.Dev.		70.0	1222.97	682.17	1224.3	542.10	2.256±0.00	2256	2.437	4.97±0.13	17.63±0.11	67.31±0.5	11.22±0.2	3.13±0.6
1	2	70.4	1217.8	681.3	1220.4	539.10	2.259	2259		4.87	17.52	69.98	11.90	3.2
2		69.5	1216.6	679.2	1217.2	538.00	2.261	2261		4.89	17.43	66.45	11.40	2.92
3		69.7	1218.2	684.7	1221.3	536.60	2.270	2270		4,67	17.11	67.59	11.81	2.96
Mean ± St.Dev.		69.9	1217.53	681.73	1219.6	537.90	2.264±0.01	2264	2.433	4.88±0.24	17.35±0.22	68.01±0.9	10.81±0.1	3.05±0.0
1	4	69.5	1251.2	708.1	1254.7	546.60	2.289	2289		4.81	16.42	67.74	11.65	2.87
2		69	1250.1	705.5	1253.5	548.00	2.281	2281		4.93	16.71	68.97	11.91	2.93
3		69.5	1249.5	702.9	1256.8	553.90	2.256	2256		4.78	17.63	67.78	11.83	2.98
Mean ± St.Dev.		69.3	1250.3	705.5	1255.0	549.5	2.275±0.02	2275	2.430	4.84±0.71	16.92±0.63	68.16±2.8	10.80±0.1	3.03±0.1
1	6	66	1201.1	685.3	1205.6	520.30	2.308	2308		4.91	15.71	68.76	12.46	2.87
2		66.2	1200.9	679.7	1205.1	525.40	2.286	2286		4.85	16.54	68.98	11.20	2.93
3		67	1201.5	685.3	1205.9	520.60	2.308	2308		4.70	15.73	70.12	11.98	2.98
Mean ± St.Dev.		66.4	1201.2	683.4	1205.5	522.1	2.301±0.01	2301	2.428	4.82±0.54	15.99±0.48	68.8±2.3	11.55±0.8	2.93±0.2
1	8	69.0	1254.5	715.6	1259.7	544.10	2.306	2306		4.75	15.81	69.99	12.91	2.88
2		68.0	1252.3	712.5	1255.3	542.80	2.307	2307		4.69	15.76	70.27	12.21	2.97
3		70.0	1250.2	710.7	1251.9	541.20	2.310	2310		4.56	15.65	70.84	11.89	2.89
Mean ± St.Dev.		69.0	1252.3	712.9	1255.6	542.7	2.308±0.00	2308	2.421	4.67±0.09	15.74±0.08	70.37±0.4	12.34±0.5	2.91±0.1
1	10	68.4	1208.3	696.4	1219.1	522.70	2.312	2312		4.12	15.59	73.56	11.11	2.90
2		69.3	1203.4	688.1	1214.2	526.10	2.287	2287		5.13	15.50	66.91	11.00	2.89
3		68.3	1200.5	695.1	1216.1	521.00	2.304	2304		4.43	15.86	72.07	11.20	2.92
Mean ± St.Dev.		68.7	1204.1	693.2	1216.5	523.3	2.301±0.01	2301	2.411	4.56±0.09	15.65±0.45	70.84±2.4	11.10±0.2	2.90±0.0

Table F2: - Marshall Mix Properties of Asphalt mix with PVC-PP at 5.43% OBC and 5% FC

Project : MSc Thesis | **Test Name:** ________________ | **Bulk specific gravity of Aggregate:** 2.592

Location : Jimma University,JIT | **Test Number:** ________________ | **Bitumen Grade:** 60/70 penetration grade

Sample : Asphalt Concrete Mix | **Date Tested:** ________________ | **Filler Material:** Polyvinyl chloride pipe powder

Tested by : Abdissa Nagara | **Checked by:** ________________ | **Test Method:** ASTM D1559/AASHTO T 245

Spec . No	% PVC-PP	Spec. height (mm)	Weight of specimen (g)			Volume of spec. (cc)	Bulk Density (g/cc)	Unit Weight (kg/m3)	Gmm	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
			in Air	in Water	in SSD									
1	0	69.0	1246.6	699.1	1251.0	551.93	2.259	2259		4.73	17.53	73.04	10.99	3.11
2		69.3	1247.8	699.2	1252.8	553.65	2.254	2254		4.93	17.71	72.16	10.20	3.10
3		69.5	1246.9	699.2	1251.9	552.70	2.256	2256		4.84	17.62	72.56	9.42	3.20
Mean ± St.Dev.		69.3	1247.10	699.15	1251.9	552.76	2.256±0.00	2256	2.371	4.83±0.10	17.62±0.09	72.59±0.4	10.20±0.8	3.14±0.1
1	25	66.0	1189.2	663.5	1191.8	528.30	2.251	2251		4.99	17.81	71.99	10.60	3.13
2		66.0	1190	663.9	1192.6	528.70	2.251	2251		5.00	17.82	71.96	10.62	3.12
3		66.0	1190.6	664.8	1193.3	528.50	2.253	2253		4.91	17.74	72.32	10.64	3.14
Mean ± St.Dev.		66.0	1189.93	664.07	1192.6	528.50	2.252±0.00	2252	2.369	4.97±0.05	17.79±0.04	72.09±0.2	10.62±0.0	3.13±0.0
1	50	69.0	1245.50	695.20	1249.7	554.50	2.246	2246		5.14	17.98	71.42	12.90	3.21
2		69.5	1248.25	695.40	1250.2	554.80	2.250	2250		4.98	17.85	72.08	12.40	3.10
3		70.0	1251.00	697.60	1252.7	555.10	2.254	2254		4.82	17.71	72.76	12.60	3.10
Mean ± St.Dev.		69.5	1248.25	696.07	1250.9	554.80	2.250±0.00	2250	2.368	4.98±0.16	17.85±0.14	72.09±0.7	12.63±0.3	3.14±0.1
1	75	66.0	1188.70	660.20	1191.7	531.50	2.237	2237		5.12	18.34	72.05	10.70	3.22
2		66.0	1190.10	659.50	1192.6	533.10	2.232	2232		5.30	18.49	71.34	11.20	3.12
3		66.0	1191.50	662.10	1194.8	532.70	2.237	2237		5.12	18.33	72.09	11.37	3.11
Mean ± St.Dev.		66.0	1190.10	660.60	1193.0	532.43	2.235±0.00	2235	2.357	5.18±0.10	18.38±0.09	71.83±0.4	11.09±0.4	3.15±0.1
1	100	65.3	1187.70	660.50	1193.7	533.20	2.227	2227		5.38	18.67	71.16	9.50	3.22
2		66.0	1189.80	661.30	1193.9	532.60	2.234	2234		5.11	18.43	72.28	10.02	3.13
3		66.3	1191.80	660.20	1194.7	534.50	2.230	2230		5.29	18.58	71.55	10.10	3.12
Mean ± St.Dev.		65.9	1189.77	660.67	1194.1	533.43	2.230±0.00	2230	2.354	5.26±0.10	18.56±0.12	71.67±0.6	9.87±0.3	3.16±0.1

Appendix G: - Tensile Strength Ratio Test

Table G1 : - Effect of LDPE on Moisture Susceptibility of HMA (Test Method: - ASTM C 618)

Sample Type	Binder Type	Specimen Height (mm)	Weight of specimen (gm)			Bulk density (g/cm3)	Maximum load (kN)	Indirect Tensile Strength (kpa)	TSR (%)
			in air	in water	SSD				
Control	60/70-PG	65.20	1195.4	668.5	1205.7	2.225	12.76	1.271	83.03
		65.60	1198.7	669.2	1208.8	2.221	11.56	1.272	
		65.30	1197.9	669.6	1207.1	2.229	11.93	1.250	
Average		65.37	1197.32	669.08	1207.20	2.225	12.08	1.264	
Conditioned	60/70-PG	66.80	1192.2	667.8	1194.4	2.264	10.07	1.010	
		66.01	1193.5	669.2	1195.4	2.268	9.94	1.020	
		66.00	1190.8	665.4	1194.7	2.250	10.09	1.120	
Average		66.27	1192.17	667.45	1194.83	2.261	10.03	1.050	
Control	LDPE	64.00	1191.21	676.74	1191.19	2.316	14.69	1.480	92.08
		64.00	1188.96	675.50	1190.88	2.307	13.98	1.440	
		64.00	1191.03	676.36	1191.05	2.314	14.89	1.340	
Average		64.00	1190.40	676.20	1191.04	2.312	14.52	1.420	
Conditioned	LDPE	64.00	1194.90	676.90	1197.62	2.295	13.37	1.390	
		64.50	1195.55	676.21	1196.22	2.299	12.89	1.280	
		63.50	1195.45	675.79	1196.56	2.296	13.85	1.260	
Average		64.00	1195.30	676.30	1196.80	2.296	13.37	1.310	

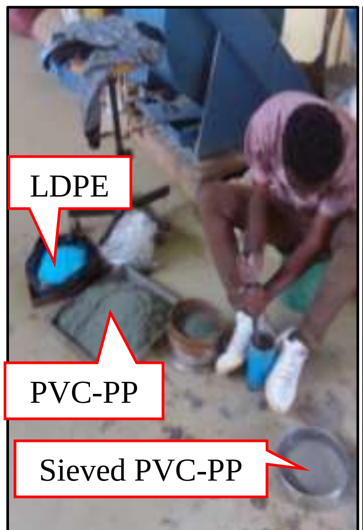
Table G2: - Effect of LDPE on Moisture Susceptibility of HMA (Test Method: -ASTM C 618)

Sample Type	Filler Type	Specimen Height (mm)	Weight of specimen (gm)			Bulk density (g/cm3)	Maximum load (kN)	Indirect Tensile Strength (kpa)	TSR (%)
			in air	in water	SSD				
Control	CSD	64.00	1199.4	668.5	1200.7	2.254	12.36	1.270	83.98
		64.60	1197.7	669.2	1201.8	2.249	12.56	1.272	
		65.00	1195.0	669.6	1200.1	2.253	12.71	1.250	
Average		64.53	1197.35	669.08	1200.87	2.252	12.54	1.264	
Conditioned	CSD	64.80	1189.2	667.8	1190.4	2.276	10.57	1.022	
		65.01	1190.5	669.2	1193.4	2.271	10.74	1.032	
		65.00	1190.8	665.4	1192.7	2.258	10.29	1.131	
Average		64.94	1190.17	667.45	1192.17	2.268	10.53	1.062	
Control	PVC-PP	65.00	1192.98	664.50	1196.57	2.242	13.24	1.267	93.63
		64.10	1191.78	665.88	1194.12	2.256	13.36	1.259	
		63.89	1195.23	665.22	1194.01	2.260	13.74	1.256	
Average		64.33	1193.33	665.20	1194.90	2.253	13.45	1.261	
Conditioned	PVC-PP	65.00	1189.79	655.78	1192.23	2.218	12.59	1.165	
		65.00	1190.90	654.94	1193.01	2.213	12.99	1.178	
		65.00	1190.20	655.78	1190.76	2.225	12.19	1.198	
Average		65.00	1190.30	655.50	1192.00	2.219	12.59	1.180	

Appendix H: - Sample Photos during the Study

Pictured by Asrat Bekele on 7/26/2021

Pictured by Fares Bogale



Pictured by Dejene Dereje on 8/23/2021

Pictured by Fares Bogale on 8/22/2021

Pictured by Dejene Dereie on 8/24/2021

Pictured by Fares Bogale on 08/28/2021

Pictured by Fares Bogale on 8/30/2021

Pictured by Dejene Dereje on 09/01/2021

Pictured by Fares Bogale on 9/19/2021

Pictured by Dejene Dereje on 10/09/2021

Pictured by Fares on 10/9/2021