ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
ROAD AND TRANSPORT ENGINEERING

EFFECT OF MARBLE CHIPS FILLERS ON HOT MIX ASPHALT PERFORMANCE

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A Thesis Submitted to the School of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

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Approved by Board of Examiners

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DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Eng. Efrem Gebre-egziabher and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

Michael Aseged	____________	May 2017
Name	Signature	Date

ABSTRACT

Hot Asphalt Mixtures (HMA) is particulate composite material consisting of mineral aggregates, asphalt binder and air voids. Asphalt binder is considered as the most expensive and economically variable material. In road construction, different kinds of alternative materials are used for different purpose. Among them the very common are crushed concrete, crushed glass fines, rubber modifiers, plastic modifiers and different type of fillers. These materials have their own drawbacks such as high cost, availability (recycled by their own sector) and ease for use.

The use of locally available materials in road construction is a key part in road construction. Hot Mix Asphalt is composed of Aggregates, Bitumen and Fillers. For Hot Mix Asphalt (HMA), fillers play a crucial role in the mix strength. This study evaluates the effects locally available filler, Marble Chips, have on HMA as compared to the conventional crushed fillers. The Marble Chips are used separately and blended with crushed filler at different percentages (0, 4, 5.5 and 7.5 percent). The study will make use of Marshall Method of mix design to evaluate the volumetric properties as well as film thickness and try to determine the moisture susceptibility of the mix.

The research concludes that all mixes prepared satisfy all the criteria of the Marshall Mix design requirements set in ERA 2013 PDM except for a marginally lower Stability values. An optimum Marble chips content of 4 – 5.5% was also determined. The economic analysis also showed an 8 – 10 percent birr/m^2 saving in the production of Asphalt concrete.

Key Words: Hot Mix Asphalt Performance, Marble Chips Filler, Filler, Film Thickness, Moisture Susceptibility, Marshall Mix Design, Economic Analysis

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LIST OF ABBREVIATIONS

AASHTO – American Associates of State Highway and Transport Officials

AC – Asphalt Concrete

DSR – Dynamic Shear Rheometer

ERA – Ethiopian Roads Authority

HMA – Hot Mix Asphalt

MS-2 – Asphalt Institute's Manual Series – 2

MTD – Maximum Theoretical Density

NP – Non-Plastic

OBC – Optimum Binder Content

PDM – Pavement Design Manual

SANS – South African National Standards

STS – Standard Technical Specification

VFA – Voids Filled with Asphalt

VMA – Voids in Mineral Aggregate

VTM – Voids in Total Mix synonymous with air voids

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ANNEX

1 INTRODUCTION

1.1 Background

Since the start of recorded history, roads have underpinned economic growth. Roads are multifunctional and can be readily accessed by a wide range of users. It is because of their high and diverse functionality and wide range of beneficiaries that roads have become such an essential component of all national transport systems, usually consuming thee greatest proportion of public and private investment resources in both infrastructure and service (The World Bank Group, 2008).

In the context of Ethiopia's geography, pattern of settlement and economic activity, transport plays a vital role in facilitating economic development (ERA, 2013). The government of Ethiopia has therefore, undertaken ambitious projects and is currently working hard to meet them. One of these projects is the Road Sector Development Program that aims to construct new roads and maintain the existing ones.

The Ethiopian road network has approximately 27 thousand kilometers of roadway, of which almost 49 percent are paved. Flexible pavements support loads through bearing rather than flexural action, as rigid pavements do (Druta, 2006).

Surface dressings were initially used as surfacing for paved roads. The main use being a barrier against moisture ingress and dust control in paved roads. However, due to its very fast failure rate in the ever increasing traffic loads in Ethiopia it was replaced with Asphalt Concrete (AC). The AC as compared to the surface dressing has several advantages, the main point being AC is a structural layer while surface dressing is not. The design of an AC mix is done by combining aggregates of different sizes and mixing them with the optimum amount of bitumen.

Fillers in the hot mix asphalt are fine particles passing the No. 200 sieve added in the asphalt mix to a maximum of 10% by mass in accordance with ERA 2013 design manuals. Mineral fillers serve a dual purpose when added to asphalt mixes, the portion of the mineral filler that is finer than the thickness of the asphalt film blends with asphalt cement binder to form a mortar or mastic that contributes to improved stiffening of the mix. Particles larger than the thickness of the asphalt film behave as mineral aggregate and hence contribute to the contact points between individual aggregate particles (Meininger, 1992), (Mehari, 2007) and (Abed & Eyada, 2013). Furthermore, fillers affect the workability, moisture sensitivity, stiffness and ageing characteristics of hot mix asphalt (Muniandy, et al., 2012). In order to improve the pavement performance and durability it is necessary to prepare a good mix which is highly influenced on the components viz. filler. In this regard understanding the effect of fillers on the Asphalt concrete mix is essential.

In this study marble chip fillers by-products of ceramic factories will be studied. The study is aimed at understanding: the nature of this material, reaction it has with bitumen, effect on the Marshall Mix properties and moisture sensitivity.

Since this material is directly brought from ceramic factories, there will be no need to crush filler fraction aggregate. The main requirement is that the marble chips should have the required gradation and plasticity index specified in the manuals. This reduces the time and cost required to produce crushed fillers, which requires a lot of time and cost to produce and is cheaper to buy when compared to Portland cement and Lime.

The study is aimed at understanding the effect marble chips have on hot mix asphalt performance, Marshall Properties and Moisture Sensitivity, and in this regard reduce the need to crush aggregates and produce fillers. Then conclusions will be drawn on appropriateness of marble chips filler followed by economic analysis in the last chapter. Finally, conclusions and recommendations are given along with suggestions for further studies on the topic.

1.2 Problem Statement

In road construction industry, there is much need for the suitable materials for the construction of pavements. One of the construction material is HMA. One of the crucial components of the HMA is filler. Fillers are crushed aggregates passing the No. 200 (0.075mm) sieve. These fillers require a lot of time and cost to produce as it involves many re-crushing cycles. The current trend in HMA preparation involves the use of fillers from crushed rocks, or cement and lime bought from factories. This study is undertaken to use the locally available material fillers from Marble Chips, which is a by-product of ceramic factory and using it a filler for HMA. Which will reduce the time and cost required for the production.

The aim of this research is to understanding the effect of using Marble Chip Filler on Hot Mix Asphalt.

1.3 Research Questions

This research is aimed to answer the following research questions:

- Is it possible to use the ceramic factory by-product Marble Chips for HMA?
- Is it possible to blend the Marble Chips with crushed filler to produce an optimum mix?
- What composition of Marble Chips and crushed filler optimally fulfill the wearing course requirement?
- What is the effect of moisture on the Marble Chips HMA mix?

1.4 Research Objectives

1.4.1 General Objective

The general objective of this research is to investigate the effect of Marble chips filler in hot mix asphalt performance

1.4.2 Specific Objectives

The specific objectives of this research are as follows:

- To study the effect of marble chips on the volumetric properties of HMA mix
- To evaluate the performance of the mix using Marshall method and moisture sensitivity of the mix
- To evaluate the economic advantages of the mix

1.5 Research Limitation

The results of the study depends on set of limitations and criteria that were taken into account during the experimental work. The limitations include

- Because of budget constraints the number of samples were limited
- Due to time and budget constraints the type of bitumen used in the experiment is limited

1.6 Research Organization

Chapter one discuss about the overall importance of the problem and an introduction to the project. Chapter two deals with literature review on the basic pavement concepts, materials, mixture design and past studies and works on Marble chips in the construction industry. Chapter three describes how the experimental work is done with detailed procedures. Chapter four discusses in detail about the results of the experimental works. The conclusions and recommendations regarding this experimental work are described clearly in chapter five.

2 LITERATURE REVIEW

2.1 Introduction

Asphalt mixes are used as surfacing layers of road and airfield pavements (AL-Saffar, 2013). Pavement constitutes of capping layer, sub-base, base and surface layer altogether. The sub-grade or sometime improved subgrade is the natural soil on which the road is constructed. The sub-base is the tertiary load-spreading layer underlying the base course and surfacing and of lower bearing strength. The sub-base also acts as a separating layer preventing contamination of the base course by the sub-grade. The base course is the main layer in terms of providing additional strength and load bearing capacity to the road. This layer mainly consists of crushed stone or gravel. The surface layer, surfacing, comprises of the top layer(s) of the pavement. This include either bituminous surface dressing or one or two layers of premixed bituminous material. When premixed bituminous materials are laid in two layers, it is known as wearing course and binder course (ERA, 2013). Figure 2-1 below shows pavement layers with two layer premixed bituminous material.

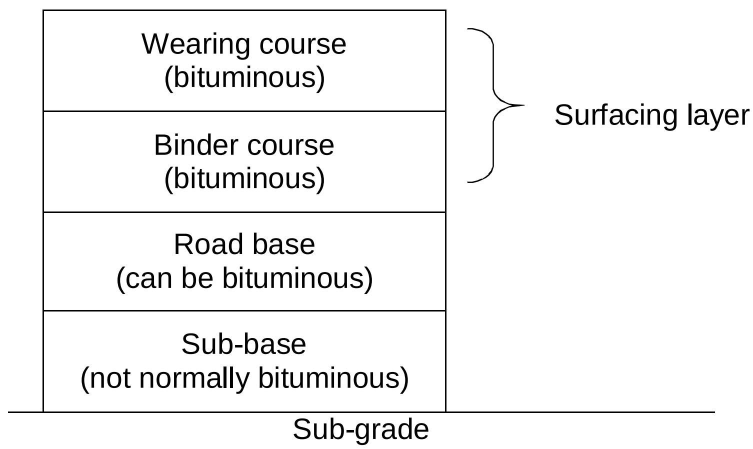

Figure 2-1 Pavement Layers

This research will discuss about a premixed bituminous surface layer, Asphalt Concrete, in particular the wearing course.

2.2 Asphalt Concrete

Asphalt concrete, cement is defined a dark brown to black cementitious material in which the predominating constituents are bitumen, which occurs in nature or are obtained in petroleum processing. Asphalt Concrete is mainly composed of bitumen and aggregates, fine and coarse. A schematic of asphalt mixture is shown in the figure below

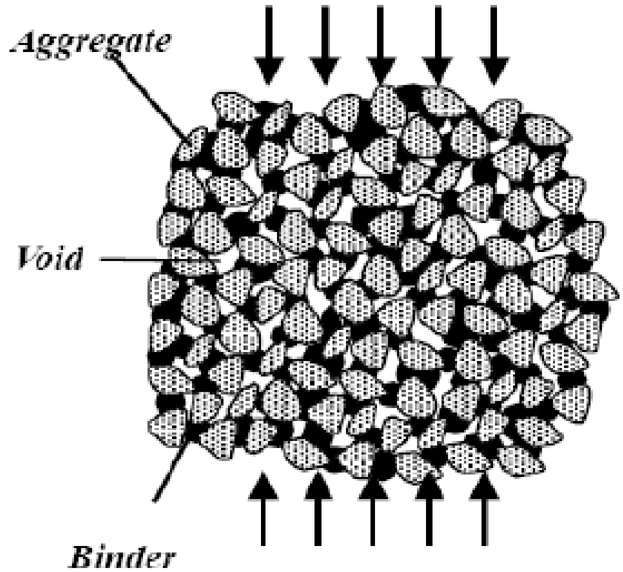

Figure 2-2 Schematic of Asphalt Mixture Materials (Druta, 2006)

2.2.1 Bitumen

ASTM further defines asphalt cement as a fluxed or unfluxed asphalt specially prepared as to quality and consistency for direct use in the manufacture of bitumen pavements (Lavin, 2003).

Asphalt/bitumen according to Traxler (1936), Romber et al., (1959) and Traxler and Coombs (1936) as cited by (Hunter, et al., 2015) is largely composed of hydrocarbon molecules, with some hetrocyclic species and functional groups containing sulfur, nitrogen and oxygen atoms.

Chromatographic techniques classify the constituents of bitumen as saturates, aromatics, resins and asphaltenes. Saturates are non-polar viscous oils that are straw colored or colorless. The fraction forms 5 – 20% of bitumen

Aromatics constitute 40-65% of the total bitumen and are dark-brown viscous liquids. They consist of non-polar carbon chains attached to unsaturated ring systems.

Resins are dark brown in color, solid or semi-solid and strongly adhesive. Resins are dispersing agents or peptisers for the asphaltenes. The ratio of resins to asphaltenes, to a degree, governs the solution (sol) or gelatinous (gel) character of the bitumen.

Asphaltenes are insoluble black or brown amorphous solids that significantly affect the rheology of bitumen. In addition to carbon and hydrogen, some nitrogen, sulfur and oxygen atoms are present. Increasing asphaltene produces a harder, more viscous, bitumen with lower penetration and higher softening point and consequently higher viscosity (Hunter, et al., 2015). Asphaltenes constitute 5 – 25% of the bitumen.

The table below shows a typical analysis of the four groups of bitumen with a penetration value of 100.

Table 2-1 Typical elemental analysis of bitumen with a penetration value of 100 dmm (Chipperfield, 1984) cited by (Hunter, et al., 2015)

	Yield on bitumen [%]	Carbon [%]	Hydrogen [%]	Nitrogen [%]	Sulfur [%]	Oxygen [%]	Atomic ratio: H/C
Aspaltenes	5.7	82.0	7.3	1.0	7.8	0.8	1.1
Resins	19.8	81.6	9.1	1.0	5.2	-	1.4
Aromatics	62.4	83.3	10.4	0.1	5.6	-	1.5
Saturates	9.6	85.6	13.2	0.05	0.3	-	1.8

2.2.1 Bitumen Characteristics

Asphalt binder has the following key characteristic properties.

- Adhesion

Bitumen has excellent adhesive qualities provided the conditions are favorable. However, in the presence of water the adhesion does create some problems. Most of the aggregates used in road construction possess a weak negative charge on the surface. The bitumen aggregate bond is because of a weak dispersion force. Water is highly polar and hence it gets strongly attached to the aggregate displacing the bituminous coating.

- Elasticity

Elasticity is the ability of a deformed material body to return to its original shape and size when the forces causing the defamation are removed. The response to relatively small stress results in a directly proportional strain as described by Robert Hooke in Hooke's law in 1660 (Hunter, et al., 2015).

- Plasticity

When temperatures are raised, as well as when a load is applied to bitumen, the bitumen will flow, but will not return to its original position when load is removed. This condition is referred to as plastic behavior.

- Visco-elasticity

Asphalt binder has a viscoelastic character. Its behavior may be either viscous or elastic depending on the temperature or the load it is carrying. Visco-elasticity differs from plasticity in that visco-elastic materials exhibit a time-related recovery when a load is removed: this is often referred to as a delayed elastic response. At low temperature the elastic property dominates, while at high temperature the material behaves as a viscous fluid. Visco-elasticity is measured by transient flow, creep and relaxation test, and dynamic flow, oscillatory test esp. DSR (Hunter, et al., 2015).

- Aging

Aging refers to changes in the properties of asphalt binder over time, which is caused by external condition. There are two stages of a pavement's life where oxidation can occur in the field.

Hot mixing and construction: During the mixing and placement process the asphalt binder is exposed to elevated temperatures and is in very thin films can lead to rapid aging by volatilization and oxidation. The aging mechanism which includes the loss of volatiles and chemical oxidation that result from elevated mixing and placement temperatures falls under the primary process which is followed by oxidation in a secondary process during long term service.

In-service: After the HMA pavement has cooled and opened to traffic ageing continues at a slower rate for the first 2 – 3 years until the pavement reaches its limiting density under traffic. Thereafter, the rate of ageing is further reduced . Ageing in-service takes place at an accelerated rate if the HMA pavement has a higher air void content than originally designed (Roberts, et al., 1996).

The factors contributing to ageing of asphalt during mixing and/or in-service are Oxidation, Volatilization, Polymerization, Thixotropy, Syneresis and Separation.

2.2.2 Bitumen Grading System

The first specification for asphalt in the Untied States was bsed on the appearance of the crude Trindad asphalt and analytical test to determine amount of bitumen (soluble in carbon disulfide) and insoluble organic and inorganic matter (Roberts, et al., 1996).

a. Penetration Grading System

As the HMA industry grew in the 1900's standardized methods were needed to determine the consistency of the paving binders. After several trials in 1918 the Bureau of Public Roads introduced the penetration grading system. AASHTO published standard specifications for penetration grade asphalt cements in 1931.

The grading system is presented as for example 40-50 for a minimum penetration of 40dmm and maximum penetration of 50dmm. The unit of penetration rate is one tenth of a millimeter (0.1mm) or dmm and usually the unit is omitted when the results are reported.

Table 2-2 gives the requirements for penetration graded asphalt cements as per ASTM D946.

Table 2-2 ASTM Requirements for Penetration Grade Asphalt (Roberts, et al., 1996)

	Penetration Grade									
	40-50		60-70		85-100		120-150		200-300	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Penetration at 77°F (25°C), 100 g, 5 s	40	50	60	70	85	100	120	150	200	300
Flash point, °F (Cleveland open cup)	450	—	450	—	450	—	425	—	350	—
Ductility at 77°F (25°C), 5 cm/min, cm	100	—	100	—	100	—	100	—	100	—
Solubility in trichloroethylene, %	99.0	—	99.0	—	99.0	—	99.0	—	99.0	—
Retained penetration after thin-film oven test, %	55+	—	52+	—	47+	—	42+	—	37+	—
Ductility at 77°F (25°C), 5 cm/min, after thin-film oven test, cm	—	—	50	—	75	—	100	_	100*	—

***If ductility at 77°F (25°C) is less than100 cm, material will be accepted if ductility at 60°F (15.5°C) is 100 cm minimum at the pull rate of 5 cm/min.**

The penetration grade system has the following advantages (Roberts, et al., 1996):

- Grading is based on the consistency of asphalt cement at 25^{0}c, which is close to the average pavement service temperature. Provides a better correlation with low temperature properties.
- Testing time is relatively short
- It is adaptable to field conditions
- Equipment cost is low
- Precision limits are well established
- Temperature susceptibility of the asphalt cement can be determined by measuring penetration at temperatures other than 25^{0}c. Temperature susceptibility is the rate at which the consistency of an asphalt cement changes with a change in temperature. Asphalt cements highly susceptible to temperature change are not desirable.

The disadvantages of the penetration grading system are as follows (Roberts, et al., 1996):

- Penetration is an empirical test and does not measure consistency
- Shear rate is high during the test
- Shear rate is variable because it depends on consistency of the asphalt
- Similitude at 250c can be deceptive to performance a higher and lower service temperatures
- No viscosity is available to establish mixing and compaction temperatures

b. Viscosity Grading system

In the early 1960s different state highway departments, wanted asphalt cement to be graded based on viscosity at 60^0c. The objectives were to replace the empirical penetration tests with rational scientific viscosity test and to measure consistency at 60^0c rather than 25^0c, which approximates asphalt pavement maximum surface temperature during summer in the United States.

Viscosity graded asphalt cements are delignated as AC followed by a number. The number represents the viscosity. The unit of viscosity is poise and as such a AC-2.5 describes an asphalt cement with a viscosity of 250 poise at 60^0c.

Advantages of viscosity grading system are as follows (Roberts, et al., 1996):

- Viscosity is a fundamental property therefore is independent of the test system and sample size.
- It is suitable for wide range of environments (pavement temperature 25 – 600c)
- Based on viscosity at 600c which is close to the maximum pavement surface temperature and is critical for pavement performance during hot days
- Reduced overlap with other grading systems
- Wide range of test instruments
- Test standards are available with established precision limits
- Temperature susceptibility can be determined since consistency is measured at three temperatures

Disadvantages of the viscosity grading system (Roberts, et al., 1996):

- Grading at 60^0c is deceptive to performance at average or low service temperatures
- It is not adequate to safeguard against low temperature cracking.
- The test system is slightly more expensive than the penetrometer
- Testing time is longer
- Thin Film Oven Test residue viscosity can vary considerably within the same grade.

2.2.3 Aggregate

Aggregates make up about 92 – 96% by mass of the asphalt concrete. As such, the type of aggregate, its mineralogy and physical and chemical properties have significant effect on the performance of the mix.

Rocks are formed from plate tectonics, erosion, weathering and chemical and biological actions. This formation of rocks is known as rock cycle and forms three rock types of rocks namely, igneous, metamorphic and sedimentary rocks. All three types of rocks can be used as aggregate for asphalt concrete.

The types of rocks suitable for the production of asphalt concrete from the three groups are presented below. From igneous rocks basalt, dolerite, granite and andesite are suitable for asphalt concrete production. From sedimentary rocks limestone, dolomite and sandstone (gritstone) are ideal sources of aggregate for asphalt concrete. Finally from metamorphic rocks meta-quartzite are suitable for the production of asphalt concrete.

Hard rock deposits are usually processed initially by drill and blast method. This uses holes of 115 – 150mm diameter to be drilled and filled with ammonium nitrate fuel oil explosive. The rock mass is then blasted and the pieces collected. For weaker rocks excavation with the help of bull dozers with ripper attachments or excavators with jack hammer attachments will be enough.

The large rock sizes obtained by blasting or ripping are crushed to a more conforming sizes, typically 75mm or less. This is achieved by re-crushing the rock pieces into different crushers until the desired size is obtained (Hunter, et al., 2015).

Aggregates for asphalt concrete are comprised of coarse, fine and filler. Coarse aggregate are aggregates that are substantially retained on 2.36mm sieve. Fine aggregates have a substantial amount passing sieve size 2.36mm. Fillers are fine particles with at least 75% passing sieve size 0.075mm (Hunter, et al., 2015). The physical properties of aggregates that are important to the asphalt pavement are described below.

Grading

Aggregate grading, also known as gradation, is the most important property that an aggregate can contribute to the performance of asphalt concrete. Gradation is the distribution of the particle size expressed as a percentage of the total weight. It is determined by passing the aggregate through a series of sieves stacked with a progressively smaller opening. The weight of the aggregate in each sieve is weighed and percent retained to the total weigh is computed.

The grading results are generally recorded in a table or shown graphically. When the gradation result are graphed, the grading can easily be identified as dense graded, gap graded or open graded. Figure 2-2 depicts the different grading types.

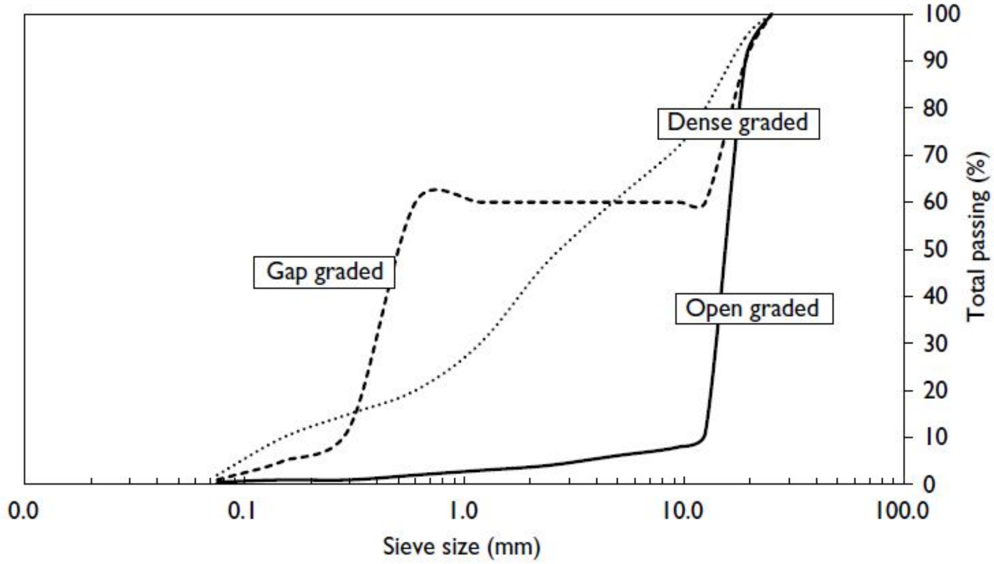

Figure 2-3 Aggregate Grading (Lavin, 2003, p. 42)

Aggregate gradation graphs can either be semi-log chart as shown in Figure 2-2 or 0.45 power chart. The 0.45 power chart was developed in 1962 by the United States Bureau of Public Roads that uses an arithmetic scale of the sieve size raised to the 0.45 power. The chart was developed on the assumption that the best aggregate grading for asphalt mixture is the one that gives the densest particle packing. The maximum density gradation is a line drawn from the maximum aggregate size through the origin as shown in Figure 2-3 below.

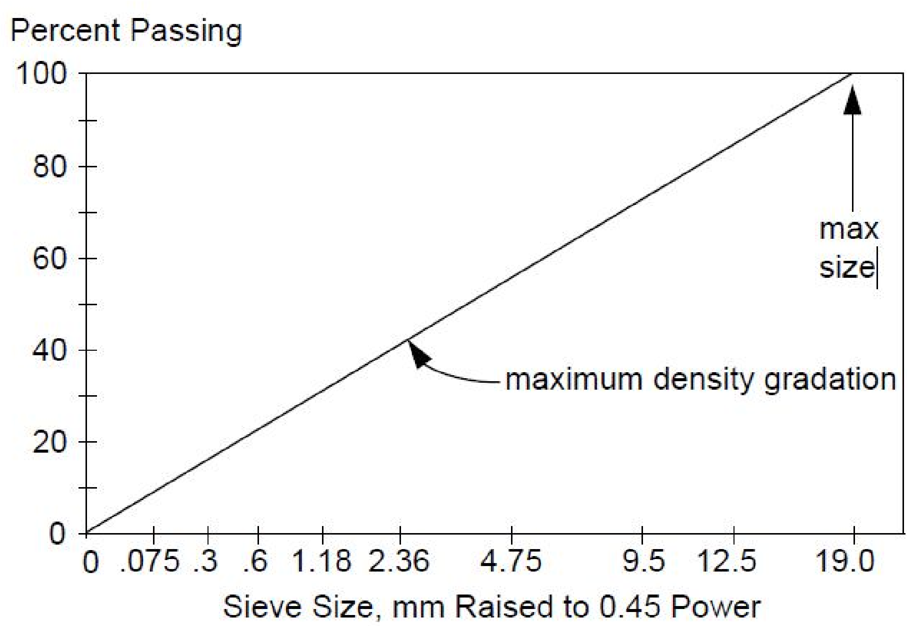

Figure 2-4 0.45 Power Chart (USDoT-FHA)

Gradation of the material is compared to universal specification like ASTM D3515 or local specifications like ERA STS Table 6403.

Particle Shape

For coarse aggregate, the shape of the aggregate is another crucial property. Cubical shaped aggregates provides a better interlock and denser particle packing. In order to rid out flaky and elongated particles flakiness and shape indices have been developed. Flakiness index (FI) is the percentage of particles that have thickness of less that one-half of the nominal size using specific bar sieves, and is expressed as a percentage of the mass of test portion. Shape index (SI) is the measure of the individual particle in a shape of aggregates on the basis of the ratio of the length to the thickness using a measuring gauge. An aggregate to be suitable for asphalt concrete shall have a FI value of 35 or less.

Toughness and Durability

Toughness is the resistance of an aggregate to abrasion and degradation. Degradation occurs during the production and compaction of an asphalt mix while abrasion is due to traffic and loading. This value is computed by measuring the mass percent loss of material during a test known as Los Angeles Abrasion (LAA). In order to be suitable for asphalt concrete an aggregate shall have a maximum LAA value of 35%.

Durability is similar to toughness with the addition of resistance of aggregate to weather like freezing and thawing. Durability is measured by mass of percent loss of material from an aggregate during sodium or magnesium sulfate soundness test. The loss encountered during the sodium sulfate test shall be 16 or less for coarse and 10 or less of fine aggregate in order to be accepted for asphalt concrete.

Cleanliness

The absence of deleterious materials from an aggregate is known as cleanliness. Deleterious material is vegetation, clay lumps, clay coating, shale, mica and other objectionable material (Lavin, 2003). Different tests like sand equivalent – AASHTO T176-86, Clay Lumps and Friable gravel – ASTM C142 and Plasticity Index – BS 1377 Part 2 (1990) are used to evaluate this criteria. For an aggregate to be acceptable for asphalt concrete it should have a sand equivalent value in excess of 40 and a plasticity index of 4 or less.

Absorption

Absorption is the amount of water an aggregate will absorb when soaked in water. Due to the viscosity of asphalt binder and since most aggregates are hydrophilic the aggregate will absorb less asphalt binder than water. If an aggregate is highly absorptive, it will continue to absorb the binder after mixing in plant leaving less film on its surface. Absorption is tested based on BS 812, Part 2 1975. A water absorption value of 2% or less is recommended for asphalt concrete.

Adhesion

Adhesion is the affinity of an aggregate to asphalt. Asphalt cement must coat the aggregate surface and must not be degraded in the presence of water. Aggregates that have high affinity to water may allow the removal of asphalt film from their surface, known as stripping. The affinity of an aggregate to bitumen can be tested by a means of static immersion test as described in D. Whiteoak (1990). As such, more than 95% of the coating is required for asphalt aggregate.

2.3 Fillers

Mineral filler is an inert material passing the No. 200 sieve, occupies the void space between coarse aggregate particles and pores within the aggregate particle (AL-Saffar, 2013).

Fillers by their action can be grouped into two: active and inert fillers. Inert fillers are used to fill voids between aggregates and form mastics while active fillers have properties that manifest at the interface between the filler and the asphalt. The level of interaction between active filler and asphalt strongly affect high temperature rheology in certain compatible asphalt binders to a much higher degree than other inert fillers (Liao, et al., 2013).

Mineral filler serves a dual purpose when added to asphalt mixes, the portion of the mineral filler that is finer than the thickness of the asphalt film blends with the asphalt cement binder to form a mastic that contributes to improved stiffening of the mix. Larger particles, larger than the thickness of asphalt film, behave as mineral aggregates hence contribute to the contact points between individual aggregate particles. Mineral filler can also greatly affect the mix strength, plasticity, voids, resistance to action of water and resistance to the forces of weathering (Lee, 1964).

In addition to physical mechanism, the chemical mechanism of “active” mineral filler should be taken into account. Because of chemical composition, filler may serve as an active material (Liao, et al., 2013). Active fillers also improve the adhesion properties of the aggregate. Active fillers include Portland cement, hydrated lime, blast furnace slag, Portland blast furnace cement, fly-ash or a mixture of any of the above materials (ERA, 2002).

The use of waste materials such as: glass cullet (Nigatu, 2014), brick dust and silica fume (Tomar, et al., 2013) have been studied. The result of each of these researches indicate that the waste materials can be utilized in the use as fillers. The results might not produce a better performance as compared to conventional fillers but still fulfills all the requirements.

2.4 Marble Chips

Marble is a crystalline, compact variety of metamorphosed limestone transformed through the heat and pressure into a dense, variously colored, crystallized rock (Zewde, 2011). Marble is composed primarily of calcite mineral ($CaCO_3$) and usually contains other minerals such as: clay minerals, micas, quarts, pyrite, iron oxides and graphite.

In Ethiopia, marble deposits are found in western part of Wellega (Daleti) and Gojam (Mora, Bulen, Mankush and Baruda) (Walle, et al., 2000). Marble deposits are also found in the northern Ethiopia. These marble deposits are different from that of the west in age, grain size and color (Zewde). The location map of known marble deposits in Ethiopia is shown in Figure 2-4 below.

Figure 2-5 Marble Locations in Ethiopia after (Zewde)

Marble blocks are cut into smaller blocks in-order to give the required smooth shape. During the cutting process about 20% – 25% marble is resulted into dust, chips (Karasahin & Terzi, 2005) (Jain, et al., 2014) (Kumar, et al., 2016). Dust is a material passing sieve No. 200, 0.075mm. This waste comes from the production of marble tiles and marble powder used in mosaic tiles (Abed & Eyada, 2013). Marble Chips have been used for different purposes. These include the use of marble chips, dust, for concrete and concrete blocks.

The use of such by-products also has an impact to the environment. Marble dusts are settled by sedimentation which results in ugly appearance and cause dust in the summer to threat both agriculture and health (Karasahin & Terzi, 2005). Hence, the re-use of these materials is important.

2.4.1 Use of Marble in Concrete and Concrete Blocks

Marble has been used as a replacement of fine sand for use in concrete in its dust form. The Marble dust in addition to silica fume, fly ash, pumice powder and ground blast furnace slag are used as admixtures instead of cement (Demirel, 2010). From the study it was observed that unit weight and compressive strength of the concrete increased with the addition of waste marble dust as a substitute for fine sand aggregate.

Marble dust powder, passing IS-90 micron sieve, has also been used in concrete works as a partial substitute of cement. Marble has been used at a proportion of 5%, 10%, 15% and 20% as a partial replacement of cement. At 10% replacement of cement, compressive strength of the M40 concrete increased. Replacement less or in excess of 10% showed a lower compressive strength than the target mean strength of M40 concrete (Jain, et al., 2014). A partial replacement of marble by 5% – 10% has an increased compressive strength for M20 concretes. The increase in marble dust content from 10% showed a reduction in the compressive strength. As such, a partial replacement of cement by 5 – 10% of marble dust improves the compressive strength of M20 grade concrete (Kumar, et al., 2016).

The combination of marble dust and water in the proportion of 70% and 30% respectively is known as sludge. The sludge is a by-product of semi-processed slab. The sludge has been used in metal contaminated soil remediation as toxicological evaluation to decrease the amount of heavy metal polluted sediment (Aukour, 2009). Incorporating the marble sludge in building blocks has also been investigated. The results indicate the marble sludge mix is environmentally friendly and fulfills all the standards and can be used as a raw material in block production.

2.4.2 Use of Marble in Asphalt Concrete

Marble chips have been used as fillers in asphalt concrete. Researches carried out in Iraq and Turkey suggest the material can be used for filler in HMA. The results indicate an increase in air voids, flow, Marshall Stability and decrease in density of the mix when compared with limestone dust. Dust refers to the material passing No. 200 sieve, 0.075mm. This increase in stability is associated with the specific gravity of the filler. Low specific gravity means high volume of filler. This increment in volume may be responsible for the ability of the mix to resist the applied load. Increasing the aggregate volume increases the friction angle between marble mixes. This also decreases the density with respect to limestone dust and as such increases the air voids (Abed & Eyada, 2013).

The result showed that adding Marble waste to a mix reflects a good effect on the cohesion of mix due to high values of Indirect Tensile Strength while showing high effectiveness to change in temperature with high temperature susceptibility as well as a reduced in the moisture attack of the mix. (Abed & Eyada, 2013).

The use of Marble chips filler decreases deformation for up to 7% filler/bitumen ratio. Void ratio for marble dust is slightly higher as compared to limestone dust and the plastic defamation is slightly higher (Karasahin & Terzi, 2005). Nevertheless, the material fulfils all the specification.

In addition to strength, with an increase in marble content a reduction in optimum binder content has been found. This shows that the filler acts as a bitumen extender also (Choudhary & Chandra, 2008).

2.5 Asphalt Mixture Design

Significant research has been and is still being conducted on asphalt mix design and evaluation. The reason for this continuing research is that adjustments are required to accommodate the changing parameters that affect asphalt pavement performance, e.g., new loading conditions, new construction materials, and analytical methods. Therefore, asphalt mix design has to be an adaptable process to meet renewed challenges facing the paving industry. Various studies have been conducted to investigate causes and remedies to distresses like early rutting, cracking and stripping all of which lead to reduced pavement service life. The recent Asphalt Aggregate Materials and Mixture Study (AAMAS) focused on laboratory evaluation of asphaltic concrete mixtures for such distress in developing an improved mix design procedure.

A mix design should be required for every mix. The mix design will typically include material proportions and characteristics as well as select mixture properties (volumetric, strength tests, etc.). There are three common procedures for designing HMA mixtures. These are Hveem, Marshall and most recently Superpave. All these mix design procedures can be used to design quality mixtures.

2.5.1 Hveem method

The Hveem method was created by Francis Hveem in 1927. After joining the California Division of Highways in 1917, he was asked to develop a method to determine the appropriate amount to of bitumen to add to aggregate to produce a ‘hard and smooth’ road surface that would not deform under traffic.

The basic philosophy surrounding the Hveem method can be summarized in the following three points (Roberts, et al., 1996):

- HMA requires enough asphalt binder to coat each aggregate particle to an optimum film thickness (allowing for its absorption into the aggregate).
- HMA requires sufficient stability to resist traffic loading. This stability is generated by internal friction between aggregate particles and cohesion (or tensile strength) created by the binder.
- HMA durability increases with thicker asphalt binder film thicknesses.

Hveem method of mix design is carried out by the use of Centrifuge Kerosene Equivalent, CKE, method to determine the ‘approximate’ asphalt content. With a calculated surface area and factors obtained from CKE the approximate asphalt content is determined by using a series of charts. Four samples are then prepared two above the CKE in 0.5 increments and one below the CKE in 0.5 increment. Additional two test specimen are prepared for swell tests. The samples are then placed in the Hveem stabilometer to determine the strength and swell in the swell test apparatus. The results are plotted in a chart containing asphalt content and stability on x and y-axis respectively.

The suitability of the mix is then checked by comparing the results obtained to the criteria set for different traffic categories. The advantages and disadvantages of the Hveem mix design methods are presented below.

The Hveem method has the following advantages.

- The kneading compactor of laboratory compaction is thought by most engineers to simulate the densification characteristics of HMA in the field.
- The Hveem stability is a direct measurement of the internal friction component of shear strength. It measures the ability of a test specimen to resist lateral displacement from application of a vertical load.

The disadvantage of the Hveem procedure

- The testing equipment is that the equipment is expensive - particularly the kneading compactor and stabiliometer.
- Durability is not considered as the main parameter
- Mostly used for researches
- Longer period is required for mixture design

2.5.2 Marshall Method

This method was developed by Bruce Marshall around 1939 in Mississippi. Marshall used many of the principles of Hubbard Field method with some modifications. The modifications include the hammer size to cover the entire sample, weight and drop of hammer to maintain the same energy, orientation of the test specimen and the computation of air voids and VMA.

The Marshall Mix Design method is the most commonly used mix design method in the World although criteria and practice vary in the selection of the optimum asphalt content. The popularity of the Marshall method stems from its simplicity and portability. Even though it is an empirical method, in the absence of other effective methods, the Marshall method serves as an effective guide in setting initial plant mix parameters and monitoring mix production uniformity (Roberts, et al., 1996)

A brief description of the Marshall method, the complete test procedure can be found in MS-2, is as follows:

Aggregate that meet the gradation and other quality test to determine the suitability for asphalt mix design are selected.

Binder that meet the local specifications either based on penetration, absolute viscosity or Superpave performance grading are selected.

Laboratory specimens are prepared by computing the design bitumen content and preparing two samples 0.5% below the OBC and three 0.5% above the OBC. Three samples are prepared for each binder content. The samples are then mixed at temperature which attains a kinematic viscosity of 170+20 cSt and 280+30 cSt for compaction. The samples are then loaded into Marshall compactor where the hammer imparts a fixed number of blows, usually 75 for high traffic volume.

Samples are tested for stability and flow as well as density and void analysis: average bulk density of the specimen, average specific gravity of the binder, theoretical maximum specific gravity of the mix are computed.

One of the strengths of the Marshall method is its attention to density/voids analysis. This ensures that the important volumetric properties of the mix are at their optimum levels to achieve a durable HMA pavement. The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen until failure, and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) as a result of the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded

Finally, data are interpreted by computing an acceptable range which fulfills all the volumetric and strength parameters. An optimum binder content is selected based on the average asphalt content that produces 4% air voids, maximum stability and maximum density. The final mix design that is economical and meets all the criteria is selected.

The Marshall method has enjoyed widespread usage all over the world because of its ease to use, ease to transport, replicability and the result in the laboratory conform the findings on the field (Hunter, et al., 2015).

Advantages of the Marshall design are related to the ease for use and the portability of the machines. Disadvantages of this mix design are as follows. The impact compaction does not simulate actual condition, it does not measure shear strength and does not estimate permanent deformation.

2.5.3 Superpave method

The Strategic Highway Research Program (SHRP) Asphalt Research Program came up with the Superpave method. The SHRP was developed in USA because of an increasing number of premature asphalt pavement failures. The SHRP came up with Superior Performing Asphalt Pavements (Superpave) which encompasses the performance-based tests and performance prediction models using mixture volumetric. This method was first developed in 1991 and still researches are undertaken to predict other performance models.

The goals of the first new mix design procedure for HMA pavements in over 50 years were to have a procedure that would simulate the real world. Since the Marshall and Hveem procedures used 100 mm molds in which courser aggregates were discarded, it was needed to have a new procedure to represent the actual site conditions. Superpave mix design is an improved method of mix design used to rationally design for various traffic volumes, axle loads and environment using larger aggregates than Marshall and Hveem.

The Superpave mixture design and analysis system uses increasingly rigorous degrees of testing and analysis to provide a well performing mixture for a given pavement project. The Superpave mix design procedure involves careful material selection and volumetric proportioning as a first approach in producing a mix that will perform successfully. The four basic steps of Superpave asphalt mix design are materials selection, selection of the design aggregate structure, selection of the design asphalt binder content, and evaluation of the mixture for moisture sensitivity.

The Superpave asphalt mix design procedure consists of the following four key steps. First selection of appropriate performance grade (PG) binder meeting AASHTO M320 requirements is undertaken.

Secondly, a combined aggregate with a nominal aggregate size in the range of 4.75 – 19.0mm is taken. Control points for the specific nominal size conforming to AASHTO M323 is adopted and plotted on 0.45 power chart.

The third step is the selection of design binder content. This is achieved by using the $N_{inintial}$, N_{design} and N_{max} parameters with four asphalt contents. N is the number of gyration to which the asphalt specimen is subjected as shown in Figure 2-5 below. One at design asphalt content, one 0.5% below the design asphalt content and two 0.5% and 1% above the design asphalt content. The objective is to determine the binder content that produces the target, 4%, air void content at N_{design}.

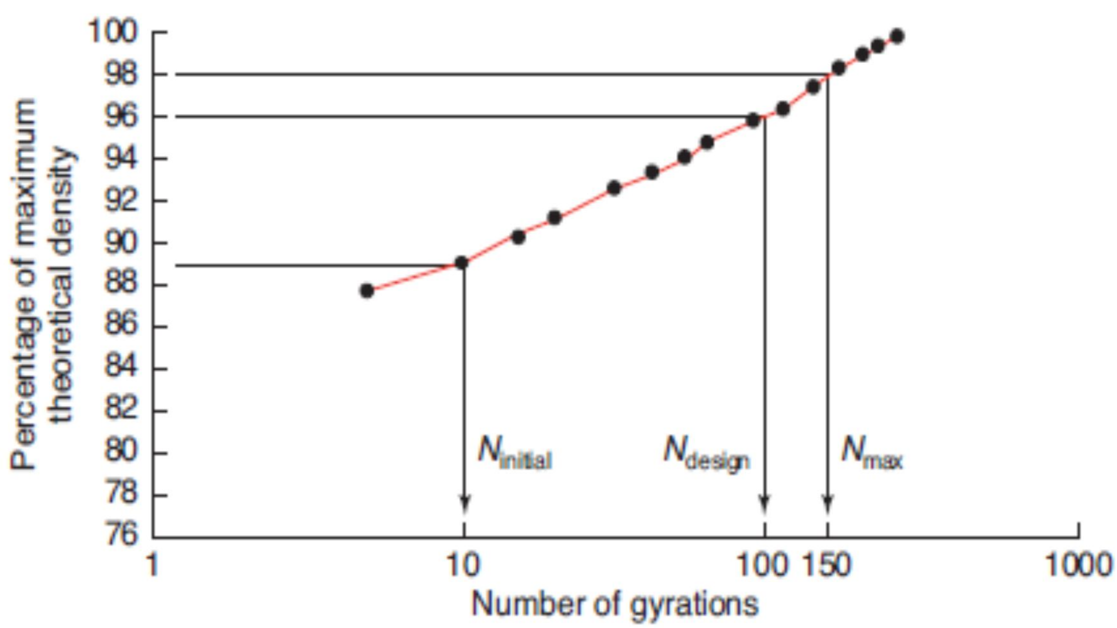

Figure 2-6 Densification Curves using the Superpave Gyratory Compactor

Finally, moisture sensitivity of the asphalt is evaluated in accordance with AASHTO T283. Advantages and shortcomings of the Superpave mix design method is presented below.

Advantages of Superpave mix design

- Predict the permanent deformation
- Predict fatigue cracking
- Predict possible thermal cracking

Shortcomings of Superpave mix design

- More sample required
- Require more space in the oven
- Sophisticated equipment is required
- Advanced personnel is necessary
- Still under research to complete the mechanical behavior

2.6 Moisture Sensitivity of Asphalt Mix

A mix design is not complete without some discussion of moisture susceptibility or the deterioration of the HMA due to detrimental influences of moisture, called stripping. Stripping reduces the strength by weakening the bond between asphalt cement and aggregate. As such, the asphalt peels off the aggregate, the cohesion of the mix is lost, and distress develops rapidly.

To combat stripping, proper mix design is essential but it is still possible for a properly designed mix to strip if the field compaction produces higher air voids to permit water into the Asphalt layer. Therefore moisture susceptibly shall be determined for each mixture in case water penetrates into the asphalt 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 (Roberts, et al., 1996). 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.

a. **Boiling Water Test (ASTM D3625)** – Loose HMA mix is added to boiling water. ASTM specifies 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%.

b. **Static-Immersion Test (AASHTO T182)** – HMA mix is immersed in distilled water at 250c 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%.

c. **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 -18^{0}c for 15hours and thaw for 24 hours at 60^{0}c. All nine specimen are tested for resilient modulus or indirect tensile strength. Retained tensile strength (TSR) is the quotient of ITS of conditioned specimen to ITS of control specimen. A minimum TSR of 0.7 is used as a guideline.

d. **Modified Lottman Test (AASHTO T283)** – is proposed by Kandhal. It 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 – 8 percent air void. Group 1 is a control specimen while group 2 are vacuum saturated (55 to 80 percent saturation) with water and then subjected to one cycle freeze and thaw. All specimen are tested for ITS at 25^{0}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.

e. **Marshall Immersion Test (ASTM D1075)** – Six Marshall specimen are prepared for this test. The specimen are grouped into two groups, each with three specimen. Group 1 is the control specimen maintained in air at 25^{0}c while group 2 is immersed in water for 24 hrs. at 60^{0}c or at 49^{0}c for four days. Group 2 specimen are then transferred to 25^{0}c water bath for 2hours and compressive strength of both group 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. Superpave design guideline requires a minimum of 80% retained strength.

3 RESEARCH METHODOLOGY

3.1 Introduction

For this research work, experimental method has been used. There are two parts to this experiment. The first part includes preparation of mix design for asphalt binder, aggregate and different quantities of Marble chips. The second part investigates the sensitivity of the mix at optimum asphalt content to moisture.

The guidelines and manuals used for this study are taken from ERA 2013 manuals specifically Flexible Pavement Design Manual and Standard Technical Specification, Asphalt Institute MS-2, AASHTO Standard Technical Specifications M20-70 and South African Speciation for Penetration Grade Bitumen SABS-307.

3.2 Study Design

This research was designed to answer the research questions and meet its objectives based on experimental findings.

The first step in the research work was sample collection. At this stage, the samples of the component materials viz. crushed aggregate, bitumen, and Marble chips were collected.

The second step was laboratory testing. This step is comprised of three major phases: Phase I-Quality testing, Phase II-Mix design and Phase III-Moisture sensitivity. Quality tests were undertaken on each of the component materials so that their physical and/or chemical properties are identified. During the mix design phase, four types of mixtures were designed and their properties were assessed to check whether they are suitable as wearing course material. One of the four mixtures was bituminous mixtures that was composed of crushed filler, normal mix. The remaining mixes were composed of Marble chips at different percentages with crushed filler as well as one sample without any crushed filler. The bituminous mixtures were tested and evaluated according to Marshall method of mix design.

The third step of the research was analyses and interpretation of the laboratory test data. In this step, the laboratory test data were analyzed and interpreted. This includes discussing the effects of Marble chips on the volumetric and Marshall properties of the mix. This include the effect Marble chips has on Stability, Flow, unit weight, VTM, VMA, VFA, effective asphalt content, optimum asphalt content and on the film thickness of the mix. Effect of the Marble chips on the moisture sensitivity and the selection of an optimum marble content are also discussed. Further, in this step, the bituminous mixtures were compared, based on economic criteria, with normal mix and the three mixes so as to identify the cheaper option.

The fourth and final step was declaration of the research findings and recommendations based on those findings.

The entire research process is shown by the flow chart in Figure 3-1.

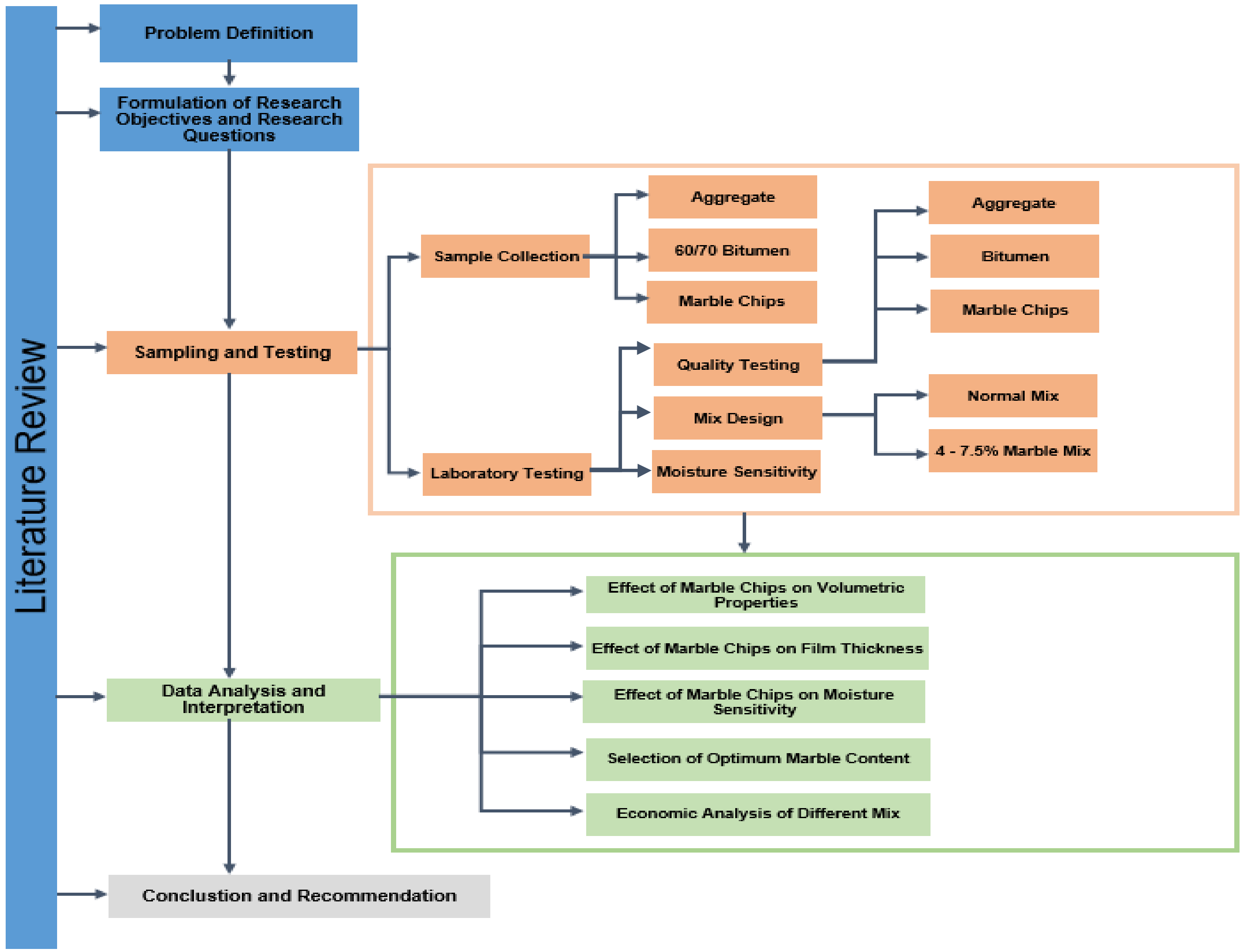

Figure 3-1 Research Design Flow Chart

3.3 Material Properties

The materials used for this experimental study are bitumen, crushed aggregate and Marble chips. The sources of these materials are:

Bitumen – CORE Consulting Engineers Asphalt Laboratory

Crushed Aggregate – CRBC/IFH

Marble chips – Adwa marble factory

3.3.1 Bitumen

The bitumen used for this experiment is 60/70 penetration grade bitumen. In order to evaluate the bitumen properties laboratory test were conducted. The bitumen quality tests conducted include:

- Penetration (ASTM D 5)
- Specific gravity (ASTM D 70)
- Ductility (ASTM D 113)
- Flash point (ASTM D 92)
- Softening point (ASTM D 36)
- Solubility in Trichloroethylene (ASTM D 2042)

3.3.2 Aggregate

The aggregate quality test was undertaken to check the suitability of the crushed source. The sources obtained from CRBC/IF. The samples include four different aggregate sizes: 14-25, 6-14, 3-6, and 0-3. In order to define the properties of these aggregates, a number of laboratory tests have been conducted. These tests include:

- Sieve Analysis (AASHTO T 27)
- Sand Equivalent (AASHTO T 176)
- Plasticity Index (AASHTO T 89)
- Specific gravity (AASHTO T 85)
- Water absorption (AASHTO T 85)
- Los Angles abrasion (AASHTO T 96)
- Flakiness Index (%) (BS 812 Part 105)
- Soundness loss by $NaSO_4$ (AASTO T 104)
- Aggregate Crushing Value (BS 812 Part 110)
- Ten Percent Fines Value (BS 812 Part 111)

3.3.3 Marble Chips Filler

For this research Marble Chips were collected from Adwa Marble Factory. To evaluate the marble chips a number of quality tests were performed. The tests include:

- Sieve Analysis (AASHTO T 27)
- Hydrometer Analysis (AASHTO T 88)
- Specific Gravity (AASHTO T 00)
- Lithium Metaborate Fusion ($LiBO_2$)
- Hydrofloric Acid (HF) Attack

- Gravimetric Analysis
- Atomic Absorption Spectroscopy (AAS)

3.4 Mix Evaluation based on Marshall Method

The choice of the Marshall method of mix design to Hveem and Superpave has been discussed in the previous sections. The resistance to plastic deformation of a compacted cylindrical specimen loaded in semicircular plates with a deformation rate of 50mm per minute is studied.

For this experimental work four scenarios/conditions were considered. The first one is the mix is prepared without any Marble chips, normal mix, 0%. The remaining three mixes were done by varying the content of Mable chips. As such, one mix is prepared with only Marble chips i.e. no fine crushed basaltic aggregate 7.5% Marble chips by mass. Another mix is done by reducing the crushed fine by 9%, 4% Marble chips by mass, and the last mix design is prepared by reducing the crushed fine by 19%, 5.5% Marble chips by mass.

Blending of the aggregates was done by trial and error adjusting each aggregate size percentage to meet the specification. An optimum aggregate proportion that meets both criteria was then selected. Table 3-1 below shows the mix proportions, blending, of the different aggregate sizes to produce the desired combined gradation.

Table 3-1 Aggregate Blending

Mix	14-25	6 – 14	3 – 6	0 – 3	Marble Chips	Combined
0%	25.0%	28.0%	18.0%	29%	-	100%
4%	22.0%	21.0%	33.0%	20%	4.0%	100%
5.5%	22.0%	21.0%	41.5%	10%	5.5%	100%
7.5%	19.5%	20.0%	53.0%	0%	7.5%	100%

The table and charts below will show the four different gradations employed for the four scenarios. Note that the aggregate gradation has been plotted on Superpave gradation curve in order to satisfy the VMA requirements. This is done as the Superpave design procedure implements control points in which the gradation must pass through in order to achieve sufficient VMA. The gradation and the specifications criteria is given in Tables 3-2 and Figures 3-2 to 3-5 below.

Table 3-2 Blended Aggregate Gradation

Sieve Size (mm)	0%	4%	5.5%	7.5%	Specification Limits
25	100.00	100.00	100.00	100.00	100
19	100.00	100.00	100.00	100.00	90 – 100
12.5	79.62	82.10	82.10	84.12	-
9.5	69.06	73.48	73.45	76.11	56 – 80
4.75	48.65	56.90	56.31	58.93	35 – 65
2.36	33.22	32.91	27.34	23.14	23 – 49
1.18	18.45	17.73	13.67	10.25	-
0.6	10.13	11.02	9.16	7.82	-
0.3	6.43	8.19	7.45	7.18	5 – 19
0.15	4.52	6.61	6.35	6.53	-
0.075	3.51	5.83	5.89	6.39	2 – 8

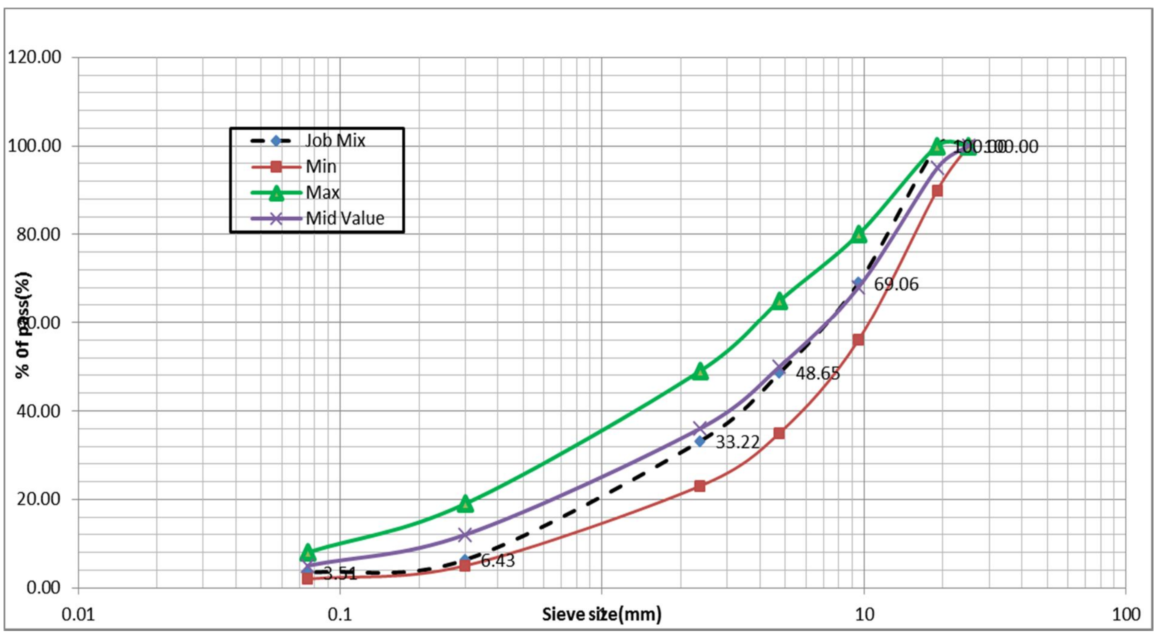

Figure 3-2 Gradation for 0% Mix

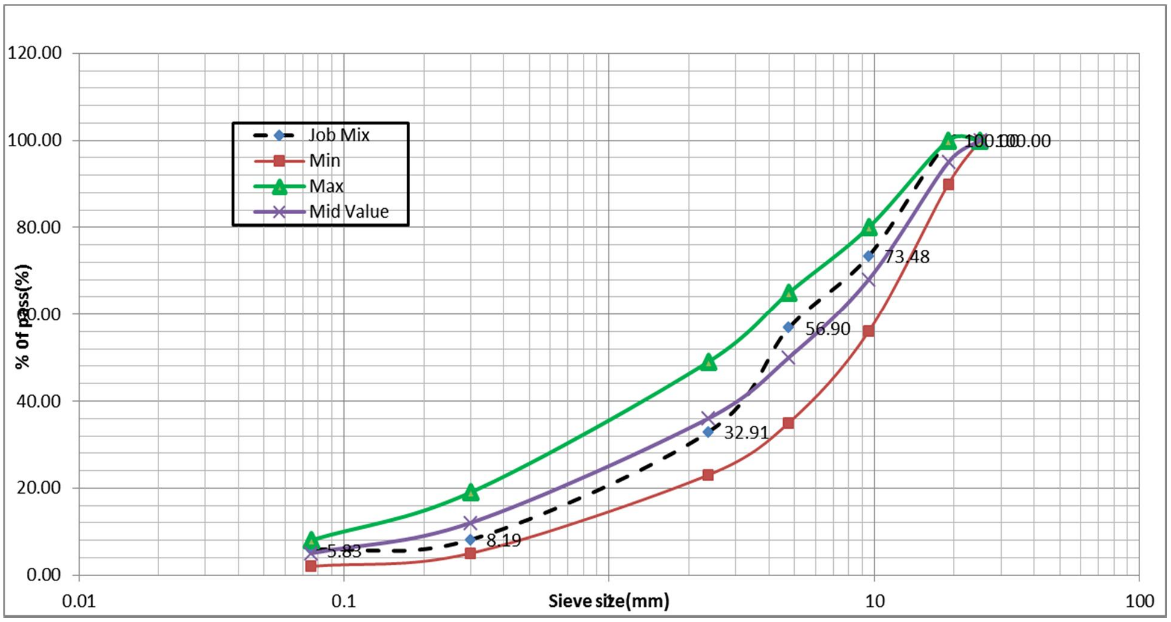

Figure 3-3 Gradation for 4% Mix

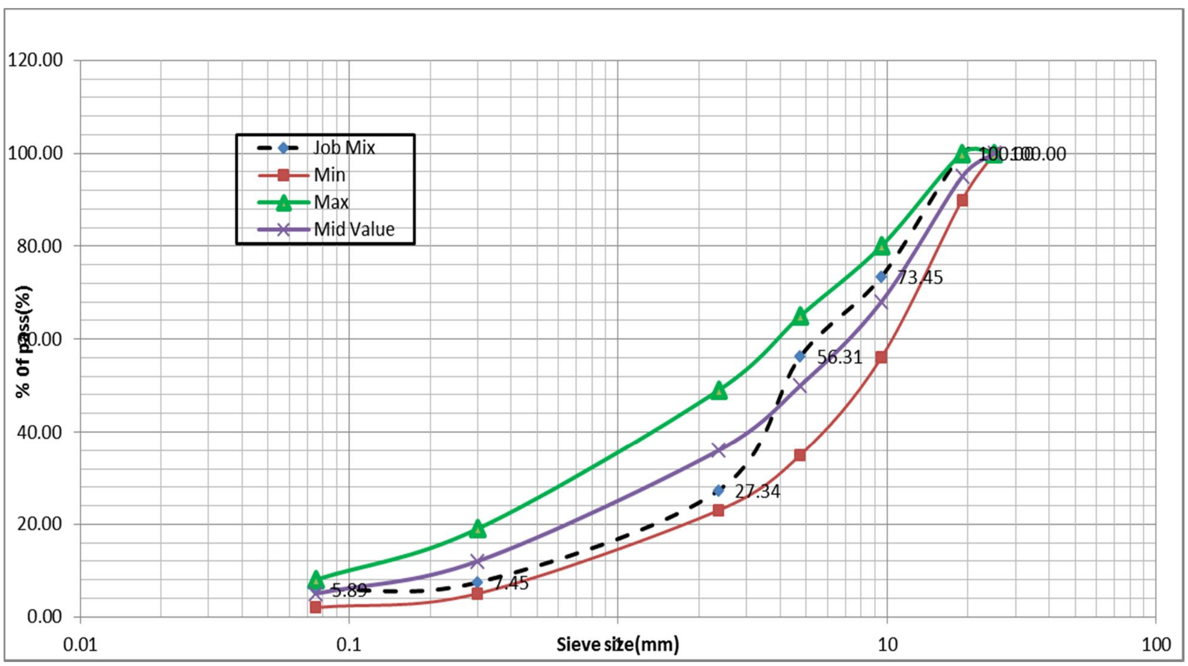

Figure 3-4 Gradation for 5.5% Mix

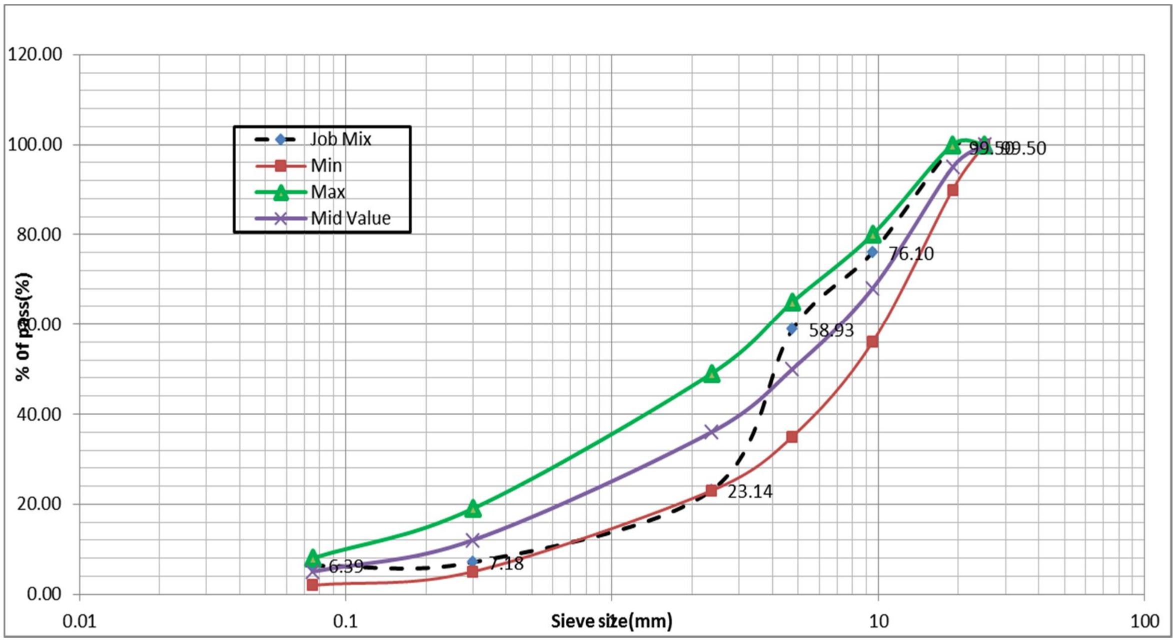

Figure 3-5 Gradation for 7.5% Mix

As it can be seen from Table 3-2 and Figures 3-2 to 3-5 the gradation of the combined aggregate was blended to meet both specification criteria.

The mix design was processed by preparing three samples for each bitumen content. For all mixes, six different bitumen contents were selected on 0.5% increment. Hence, a total of seventy two Marshall specimen were prepared and tested for this research. To evaluate the MTD one specimen for each bitumen content was tested. As such a total of 24 MTD tests were conducted.

One mold, mix, consists of a combined aggregate weighing 1200gm. The aggregate and the asphalt are then mixed with a temperature of 160^0c – 170^0c. The mixed samples are placed into a mold and compacted with 75 blows on each side by a 4.5kg hammer falling from 457mm height.

3.4.1 Volumetric Properties

Mix design is meant to determine the volume of bitumen binder 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 the theoretical maximum specific gravity G_{mm}, the bulk specific gravity G_{mb}, percentage of voids in total mix VTM, percentage volume of bitumen V_b, percentage void in mineral aggregate VMA, percentage voids filled with asphalt VFA, Effective asphalt content P_{be} and film thickness. Figure 3-10 below will show a phase diagram of the bituminous mix.

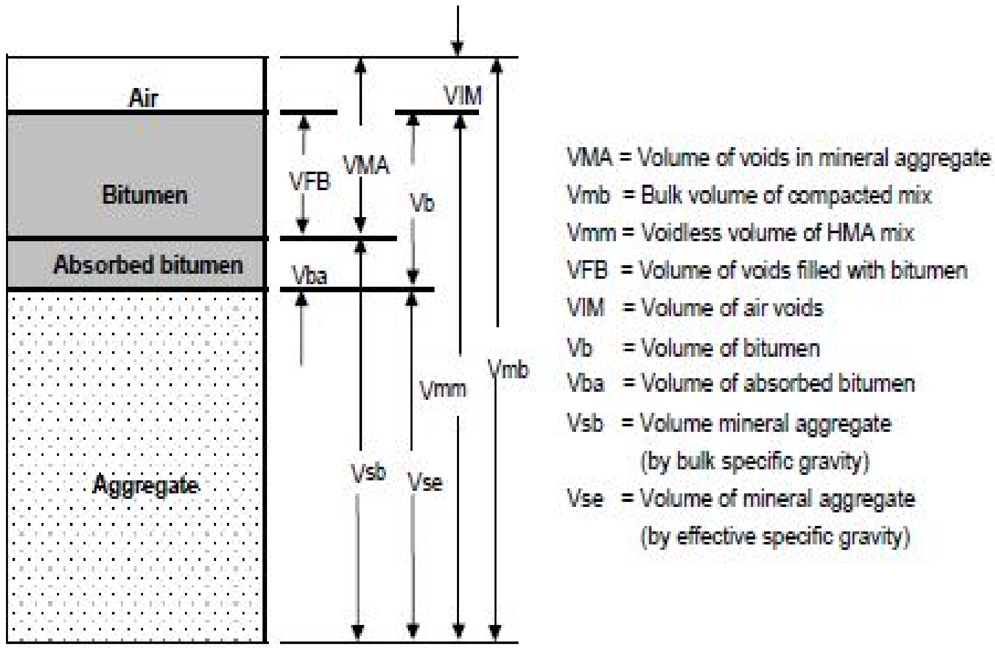

Figure 3-6 Phase Diagram of Bituminous Mix (ERA, 2013)

Percent Air Void in Total Mix – It is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture. It is computed as:

$$VTM = 100 * \frac{Gmm - Gmb}{Gmm}$$

Percent Voids in Mineral Aggregate – is the volume of intergranular void space between the aggregate particles of a compacted paving mixture. It includes the air voids and the volume of bitumen not absorbed in to the aggregate. It is expressed as a percentage of the total mix. It is calculated as:

$$VMA = 100 - \frac{Gmb}{Gsb} * Ps$$

Percentage Voids Filled with Asphalt – is the voids in the mineral aggregate framework filled with bitumen binder. This represents the volume of the effective bitumen content. It is inversely related to air voids. It is calculated as:

$$VFA = 100 * \frac{VMA - Va}{VMA}$$

Effective Asphalt Content of a Mix – is total asphalt content of the HMA less the portion of asphalt binder that is lost by absorption into the aggregate (Pavement Interactive, 2010). 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:

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

Where; P_{be} = effective asphalt content, percent by total weight of the mix

P_b = asphalt content, percent by total weight of mix

P_s = aggregate content, percent by total weight of mixture

P_{ba} = absorbed asphalt, percent by weight of aggregate given by the formula

$$P_{ba},\% = 100 * \frac{Gse - Gsb}{Gse * Gsb} * G_b$$

Where; G_{sb} = bulk specific gravity of total aggregate

G_b = specific gravity of bitumen

G_{se} = is the effective specific gravity of aggregate given by the equation

$$G_{se} = \frac{100 - Pmb}{\frac{100}{Gmm} * \frac{Pb}{Gb}}$$

Where P_b = bitumen content at which G_{mm} was performed

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

G_b = specific gravity of bitumen

Film Thickness – It refers to the average of binder coating aggregate particles in the mixture. It is a computed value that defines the thickness of the effective asphalt binder coating on each particle in the mixture and is use to ensure that the HMA has adequate asphalt binder to achieve a desired level of mix durability (Krishamurty, et al., 2012). Film thickness is calculated by:

$$F = \frac{P_{be}}{100 - P_b} * \frac{1}{A} * \frac{1}{S} * 10^6$$

Where; F = Film thickness (µm)

P_{be} = effective asphalt content, percent by total weight of the mix

P_b = asphalt content, percent by total weight of mix

A = surface area of aggregate blend (m^2/kg)

S = density of bitumen at 25^0C (kg/m^3)

In addition, the surface area of the aggregate blend is computed by:

A = (2+0.02a+0.04b+0.08b+0.14d+0.3e+0.6f+1.6g)*0.20482

Where; a = percentage passing 4.75mm sieve

b = percentage passing 2.36mm sieve

c = percentage passing 1.18mm sieve

d = percentage passing 0.600mm sieve

e = percentage passing 0.300mm sieve

f = percentage passing 0.150mm sieve

g = percentage passing 0.075mm sieve

3.5 Moisture Susceptibility

It is known that presence of moisture in a bituminous mix is a critical factor, which leads to premature failure of the flexible pavement. The loss of adhesion of aggregates with bitumen is studied by utilizing Retained stability test to examine the effect of additive on resistance to moisture induced damage. The test measures the stripping resistance of a bituminous mixture. The test is conducted as per ASTM D1075-94 specification. Compressive strength of compacted specimen is determined after conditioning them by keeping in water bath maintained at 60^0c for 24 hours prior to testing. This compressive strength, expressed as a percentage of the compressive strength of Marshall Specimens determined under standard conditions, is the retained stability of the mix. A higher value indicates lower moisture susceptibility (higher moisture damage resistance).

$$Index\ of\ retained\ strengt, \% = \frac{S_2}{S_1} * 100$$

Where, S_1 = compressive strength of dry specimen

S_2 = compressive strength of immersed specimen

The material at an optimum asphalt content is subjected to moisture sensitivity test. This is accomplished for the 0%, 4%, 5.5% and 7.5% mixes. The results are then tabulated and plotted.

4 RESULTS AND ANALYSIS

This chapter discusses about the laboratory test results and the interpretations of the results. These interpretations are then used to draw up a conclusion on the mix design and provide a recommendation.

4.1 Quality Test Results

4.1.1 Bitumen

The bitumen quality tests were conducted before the start of the mix design and compared to the specifications set in ERA 2013 PDM, AASHTO Standard Technical Specifications M20-70 and SABS-307. The result of the quality tests are presented in Table 4-1 below.

Table 4-1 Bitumen Quality Specification and Test Results

Test	Test Method (ASTM)	Specification	Test Result
Penetration at 25°C	D 5	60 – 70	65
Softening point (°C)	D 36	42-51	51.6
Flash point (°C) Min	D 92	232	310
Solubility in Trichloroethylene (%) Min	D 2042	99	99.8
Thin Oven Film Test heating for 5hours at 163°C			
Loss by mass (%) Max	D 1754	1.0	-0.02
Penetration (% of original) Min	D 5	50	91
Ductility at 25°C Min	D 113	75	100^+
Specific Gravity (kg/m^3)	D 70	-	1.022

The other criteria for bitumen is temperature susceptibility. This test is used to check the consistency of the bitumen with changes in temperature. The formula is given as:

$$PI = \frac{1952 - 500\ \log Pen - 20SP}{50 \log\ Pen - SP - 120}$$

where, PI – Penetration Index

pen – Penetration at 25^0c

SP – Softening point

By substituting the required inputs

$$PI = \frac{1952 - 500\ \log 65 - 20 * 51.6}{50 \log\ 65 - 51.6 - 120} = -0.16$$

From this value it can be seen that the bitumen is slightly lower than the optimum range for temperature susceptibility and therefore it is of fair quality. Here it can be seen that since the bitumen fulfills the PI and Penetration requirements the softening point is also satisfied.

The test result for the bitumen is attached in **Annex I.**

4.1.2 Aggregate

The aggregate quality tests conducted were compared to the specifications set in ERA 2013 PDM and STS. The results of the quality tests are presented in the tables below. The test results for the aggregates is also attached in **Annex I**.

Table 4-2 Aggregate Quality Specification and Test Results

Property	Test	Test Method	Specification as per ERA 2013 PDM	Aggregate Test Results
Cleanliness	Sand equivalent: for < 4.75mm fraction >1.5 x 10^6 ESA	AASHTO T-176	> 40	95
	(Material passing 0.425mm sieve) Plasticity Index	AASHTO T-89	< 4	NP
Particle shape	Flakiness Index	BS 812:Part 105	< 35	17
Strength	Aggregate Crushing Value (ACV)	BS 812:Part 110	< 25	15
	10% FACT (dry) kN	BS 812:Part 111	>160	260
	Los Angeles Abrasion (LAA)	AASHTO T-96	< 35	13
Water Absorption	Water absorption	AASHTO T-85	<2	2.0
Soundness (5 cycles, % loss)	Sodium Sulphate Test: Coarse Fine	AASHTO T-104	< 10 < 16	2
Bitumen affinity	Static Immersion Test	AASHTO T-182	> 95% coating retained	> 95%

The gradation for the different aggregate sizes is shown in the Tables 4-3 to 4-6 below.

Table 4-3 Aggregate Gradation for Coarse Aggregate (14-25)

Sieve Size	Percentage Passing (%)
25	100
20	100
12.5	19.6
9.5	0.4
4.75	0
Bulk sp.gr	2.591
Bulk sp.gr(SSD)	2.631
Apparent sp.gr	2.700
Water Absorption	1.560

Table 4-4 Aggregate Gradation for Medium Aggregate (6-14)

Sieve Size	Percentage Passing (%)
20	100
12.5	99
9.5	78.7
4.75	10.2
2.36	0.8
Bulk sp.gr	2.585
Bulk sp.gr(SSD)	2.626
Apparent sp.gr	2.695
Water Absorption	1.580

Table 4-5 Aggregate Gradation for Fine Aggregate (3-6)

Sieve Size	Percentage Passing (%)
9.5	100
4.75	93.3
2.36	29.6
1.18	6
0.6	1.8
Bulk sp.gr	2.500
Bulk sp.gr(SSD)	2.621
Apparent sp.gr	2.725
Water Absorption	2.0

Table 4-6 Aggregate Gradation for Fine Aggregate (0-3)

Sieve Size	Percentage Passing (%)
4.75	100
2.36	95.4
1.18	59.9
0.6	33.8
0.3	21.6
0.15	15.6
0.075	12.1
Bulk sp.gr	2.509
Bulk sp.gr(SSD)	2.572
Apparent sp.gr	2.677
Water Absorption	2.0

4.1.3 Marble Chips

Besides the conventional filler tests additional quality tests were performed on the Marble chips to clearly know the inherent property of the material. The gradation, hydrometer analysis as well as the chemical composition results are presented below.

Table 4-7 Aggregate Gradation for Marble Chips Filler

Sieve Size	Percentage Passing (%)
9.5	100
4.75	99.15
2.36	97.25
1.18	94.3
0.6	91.58
0.3	89.39
0.15	87.125
0.075	85.145
Specific Gravity	2.709

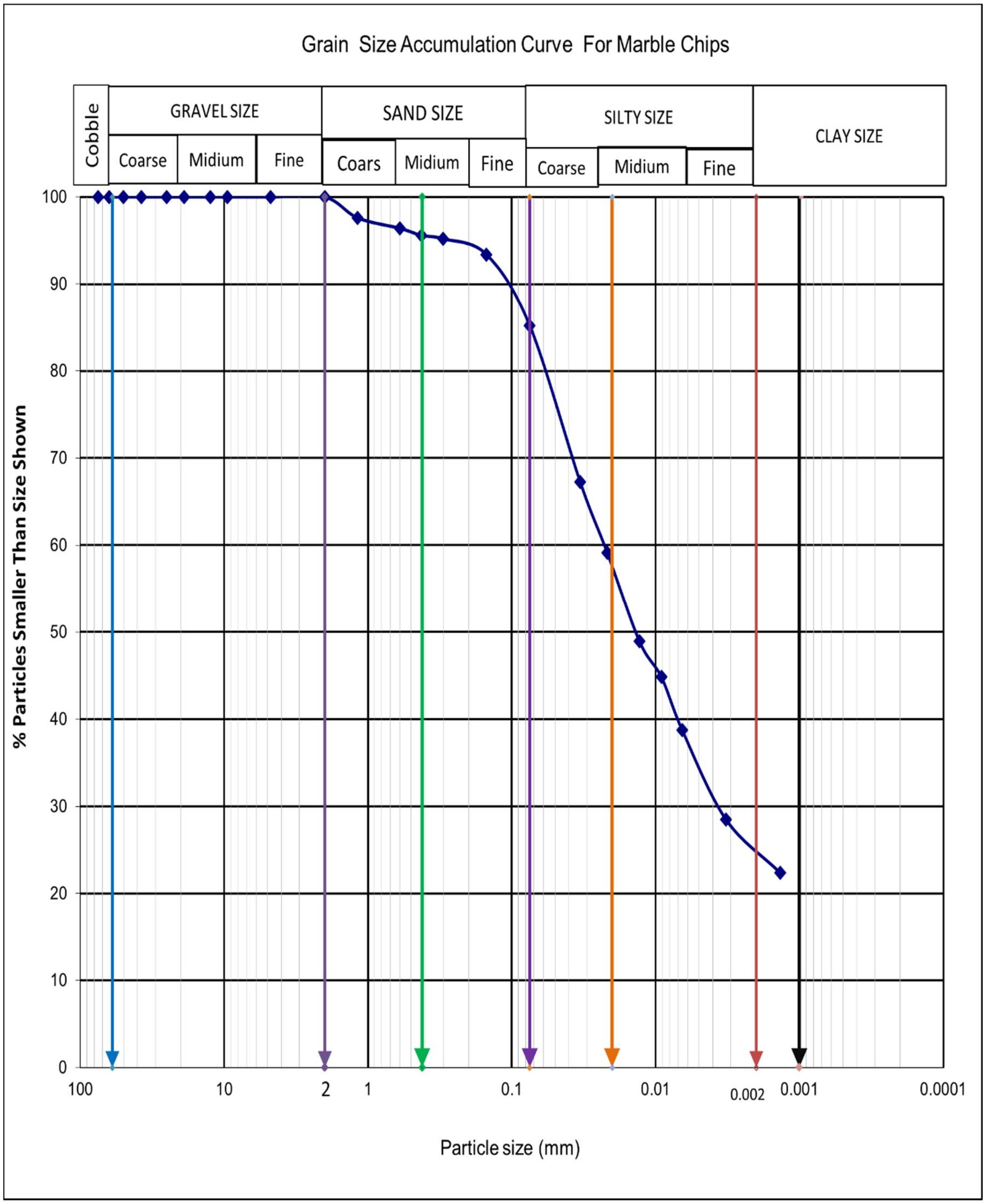

Figure 4-1 Hydrometer Analysis of Marble Chips

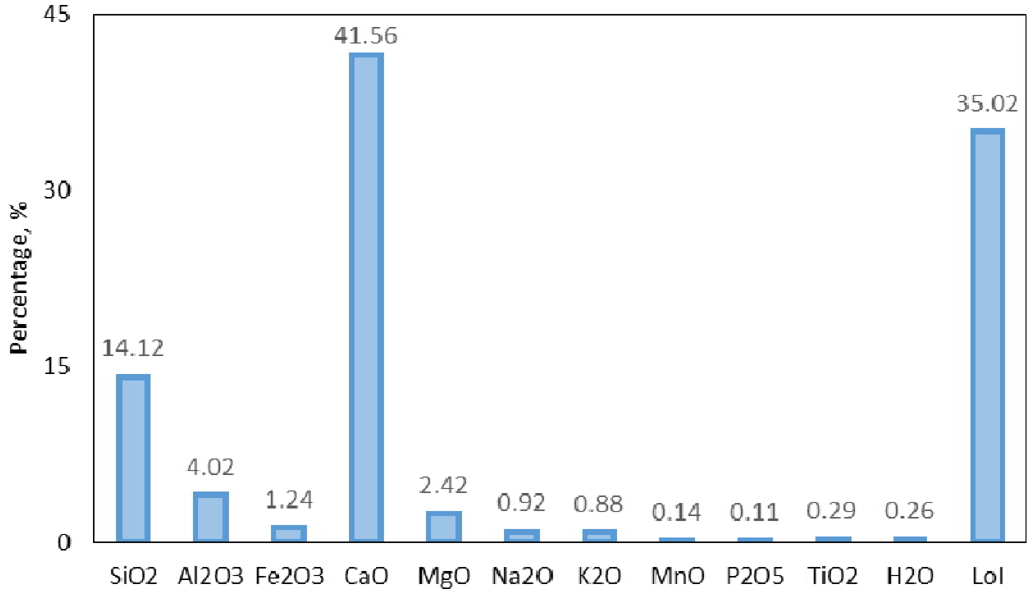

Figure 4-2 Chemical Composition of Marble Chips

From the chemical analysis, it can be seen that the material has a higher calcium oxides content indicating the Marble is of good quality. The higher Loss on Ignition (LoI) indicates the materials degree of weathering. The higher LoI value can also be attributed to the amount of graphite present in the chips. The presence of Dolomite, Clay minerals and Micas in the marble is small as seen in the results of MgO, Na_2O, K_2O, MnO and SiO_2. It can be said that from the chemical analysis that the material is good source but the higher degree of weathering has reduced the calcium oxides content.

4.2 Effect of Marble Chips Filler on Marshall Properties of HMA

The effect of the Marble chips on the HMA mix is evaluated by using the Marshall mix design. The Marshall tests are prepared at various Marble chips contents. Table 4-8 shows the properties of the mix with different Marble chips content. The effect of the Marble chips on each property will be discussed in the sections below.

Table 4-8 Volumetric Properties of All Mixes

Mix	% AC by wt. of mix	VTM [%]	VMA [%]	VFA [%]	Marshall Stability [kN]	Flow [mm]	Unit weight kg/m^3]
0%	4	11.50	17.75	35.22	9.20	2.51	2187
	4.5	8.06	15.79	48.98	11.10	2.62	2252
	5	5.82	14.98	61.14	10.71	2.73	2287
	5.5	4.03	14.58	72.35	10.12	2.80	2311
	6	2.20	14.76	85.11	9.12	2.90	2303
	6.5	1.55	14.95	87.65	8.80	3.20	2250
4%	3.5	11.54	17.51	34.06	7.60	2.60	2195
	4	9.60	16.47	41.68	9.30	2.70	2220
	4.5	7.66	16.02	52.16	8.67	3.10	2245
	5	5.66	15.57	63.67	8.14	3.15	2270
	5.5	3.61	15.14	76.13	7.86	3.50	2295
	6	2.10	15.85	78.65	7.20	3.80	2265
5.5%	3.5	10.45	16.69	37.37	7.80	2.25	2218
	4	7.73	14.56	46.90	9.49	2.65	2273
	4.5	5.30	14.29	62.91	9.38	2.90	2293
	5	4.38	14.10	68.94	8.99	3.30	2311
	5.5	3.33	14.18	76.47	8.04	3.60	2323
	6	2.22	14.55	78.56	7.50	3.95	2288
7.5%	3.5	10.10	18.91	28.23	8.10	1.85	2159
	4	8.10	17.70	36.16	9.42	2.05	2189
	4.5	6.20	17.07	47.24	9.07	2.25	2218
	5	4.10	16.41	59.75	8.04	2.50	2249
	5.5	2.60	15.80	73.65	7.49	2.75	2279
	6	1.40	17.20	77.50	7.11	3.02	2251

4.2.1 Effect of Marble Chips on Stability of Mix

The stability of the mix is the maximum load required to produce failure. The effect of Marble chips on the stability is shown in Figure 4-3 below. The Marshall stability is the highest for 0% Marble chips, Normal mix. The 5.5% mix has a higher stability value as compared to 4.0% and 7.5% mixes. The stability of the 7.5% mix is the lowest after 4.0% asphalt content.

The results indicate that the stability of the mix increases with an increase in marble content for 4% and 5.5% mixes. However, the lowest stability value is recorded for 7.5% mix. Researches conducted on Mable fillers and crushed filler indicate a lower stability value for the marble fillers.

The result are then compared to the available specification. At optimum asphalt content the all the samples fulfil the minimum stability value of 8kN for high traffic volume as per MS-2. This value however is increased to 9kN in ERA 2013 PDM. As such, 0% and 5.5% mix fulfill the requirement as per ERA manual. The stability of the 4% and 7.5% mixes is slightly lower, 8.6 and 8.7kN respectively, than 9kN. If the remaining volumetric properties are satisfied then the marginally lower stability will not pose significant problem.

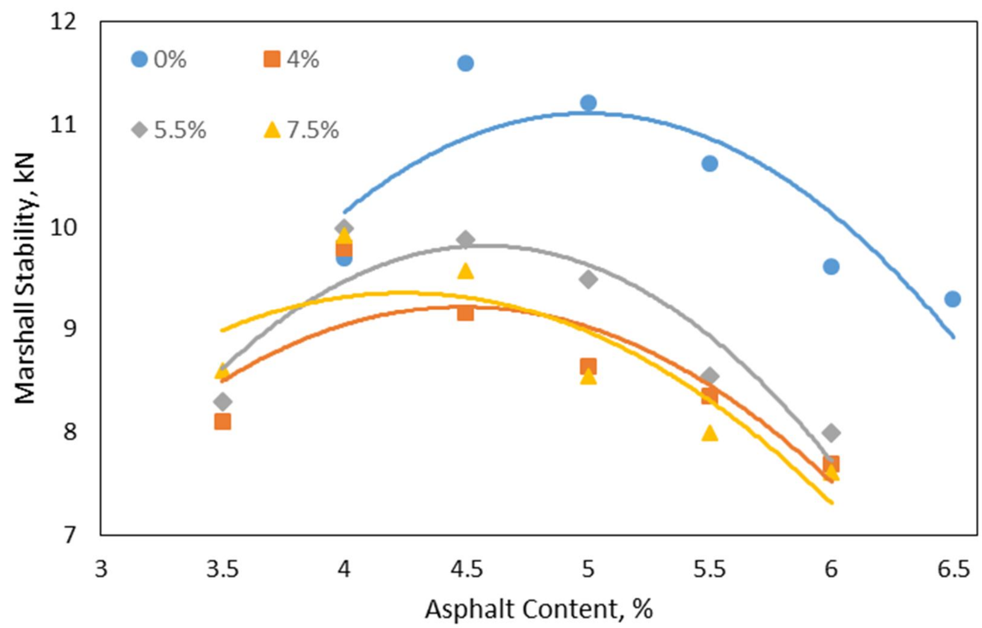

Figure 4-3 Effect of Marble Chips on Marshall Stability

4.2.2 Effect of Marble Chips on Flow of Mix

The Marshall flow is the vertical deformation of the specimen at the failure point. The flow value is within the range of the specification set in ERA 2013 PDM. The manual suggests the flow value for a heavy traffic to be within a range of 2 – 3.5mm. The trend suggests that the 4% and 5.5% mixes have a slightly higher flow values at after 5.5% asphalt content. The flow value for 7.5% mix is on the lower side of the specification for a lower, 3%, asphalt content and is generally smaller than all three mixes.

The filler content of is the greatest for 7.5% mix as such the deformation will be lower when compared with the rest. For 5.5% and 4% mixes with an increase in Marble content an increase in flow is expected. Findings of (Abed & Eyada, 2013) also suggest that with an increase in marble content up to 5.5% an increase in flow value is expected.

However, for very high filler content since the filler stiffens the mixture the flow is expected to decrease.

At an optimum asphalt content, all four mixes fulfill the requirements set in ERA Pavement Design Manual 2013.

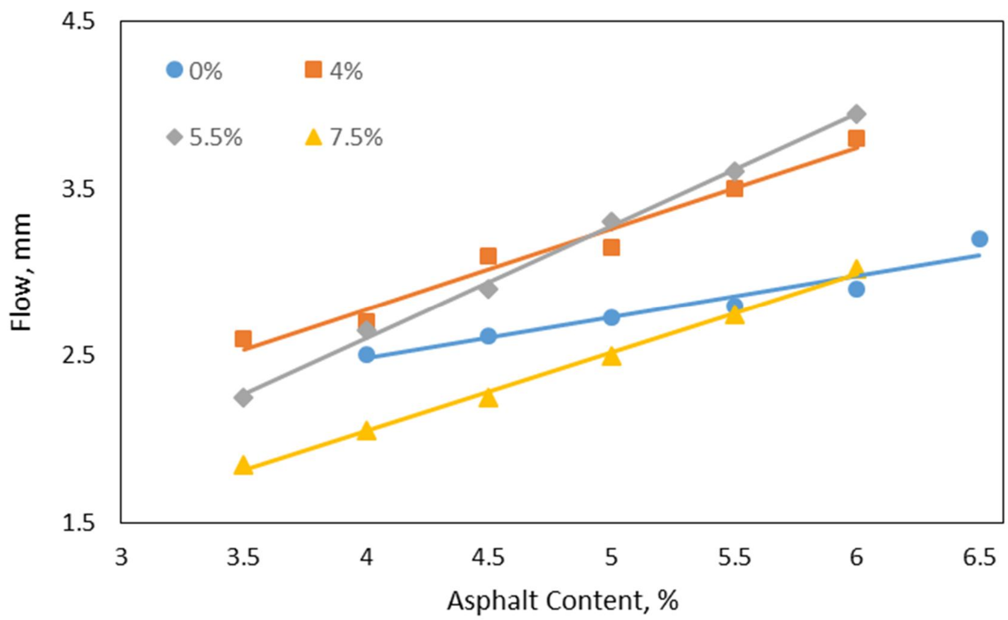

Figure 4-4 Effect of Marble Chips of Flow

4.2.3 Effect of Marble Chips on Unit Weight of Mix

The unit weight of the mix is not affected by the amount of Marble chips significantly. The heavier, densest, mix is the 5.5%. The remaining unit weights are somehow follow similar trend are in the same vicinity.

The results indicate that the substitution of crushed filler with Marble chips shows slight variation in unit weight of the mix because the unit weight of the individual materials is in the same range. For crushed filler the unit weight is around 2.510g/cm3 where as for marble chips it is 2.710g/cm3. This slight increase has increased the unit weight of 5.5% mix. The slight increase in unit weight of the fillers has also reduced the difference among all four mixes.

Figure 4-5 below shows the effect of Marble chips on unit weight of the mix.

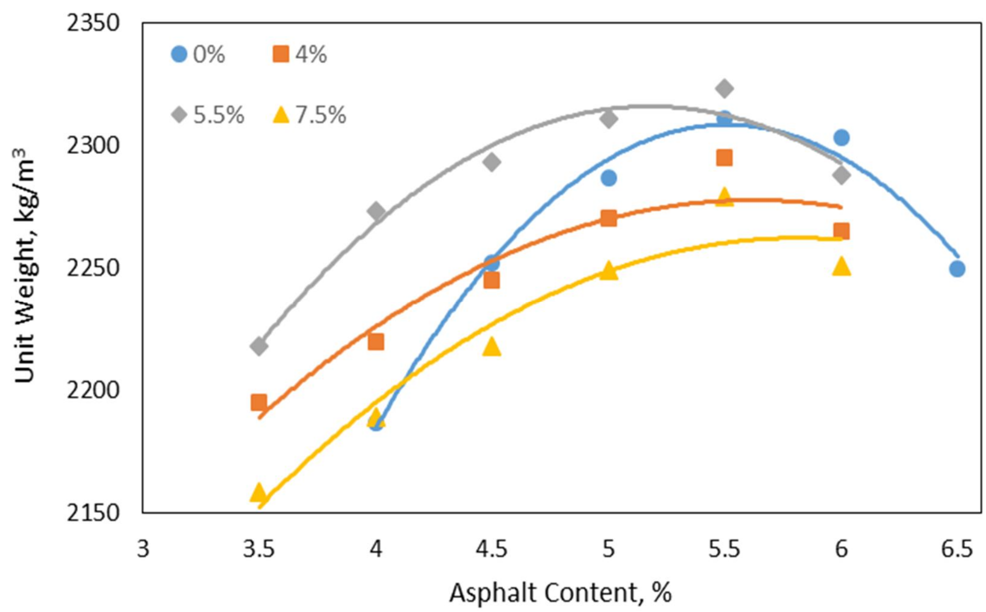

Figure 4-5 Effect of Marble Chips on Unit Weight of Mix

4.2.4 Effect of Marble Chips on Voids in Total Mix (VTM)

The voids in total mix refer to the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture. All the mixes follow a general trend that with an increasing asphalt content the voids in the total mix decrease.

The effect of the Marble chips in the mix suggest that all the mix contains less voids as compared to 0%, Normal, mix. With an increase in marble chips content, the voids in the total mix decrease. The outlier to this is the VTM value for an asphalt content in the range of 4 – 5% for 7.5% mix. As the amount of filler, increases all the voids in the mix instead of being filled with air will be filled with fine fractions, fillers.

In addition, the marble chips have a tendency to break under the weight of the Marshall hammer. The marble chips used for this research have some amount of slightly coarser particle retained on 1.18mm to 4.75mm sieve. This disintegration into finer particles reduces the voids in the mix.

At optimum asphalt content, the VTM of the mix fulfills the requirements set in ERA 2013 PDM specifications, 3 – 5%. Figure 4-6 below shows the effect of different proportions of Marble chips on the VTM.

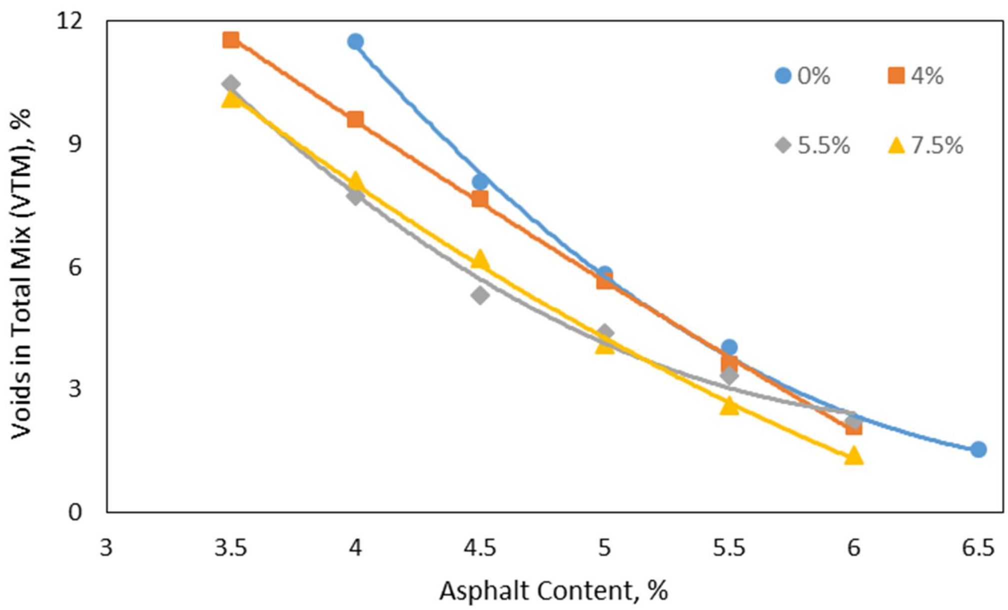

Figure 4-6 Effect of Marble Chips on Voids in Total Mix (VTM)

4.2.5 Effect of Marble Chips on Voids in Mineral Aggregate (VMA)

The VMA is the volume of intergranular void space between the aggregate particles of a compacted paving mixture. All four mixes fulfil the criteria set in ERA 2013 PDM for VMA requirements, 13%.

The normal trend for VMA curve is to decrease with an increasing asphalt content up to a certain point after which the asphalt will start to take the place of the aggregate and increase the VMA. This trend is followed by all the samples.

The VMA of the 7.5% mix is the highest and 5.5% mix is the lowest. The use of medium aggregates for the compensation of fine aggregates have increased the voids in 7.5% mix. For the 4 and 5.5% mix, however as the amount of filler increase the voids in the mix decrease which follows the general trend.

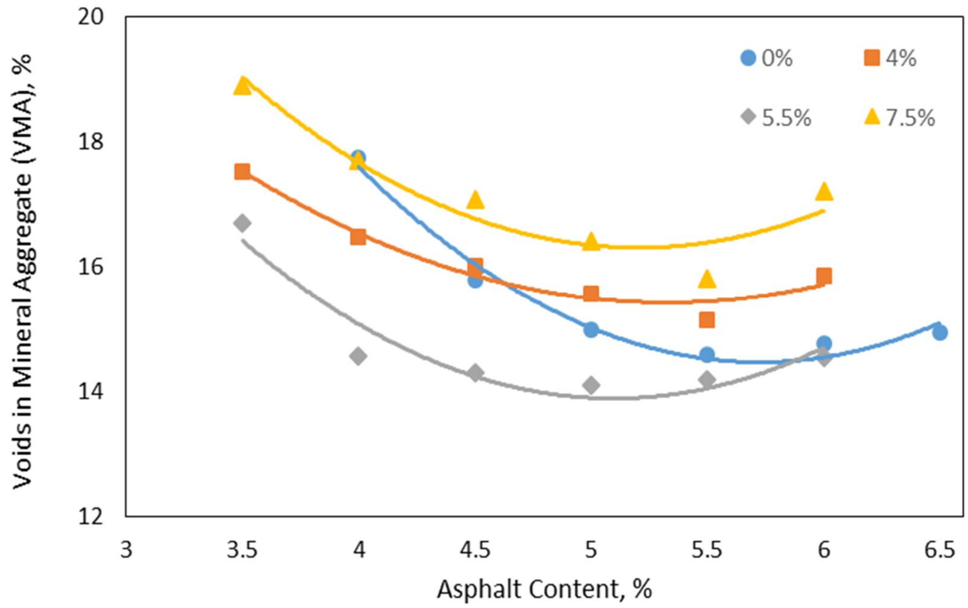

Figure 4-7 Effect of Marble Chips on the Voids in the Mineral Aggregate (VMA)

4.2.6 Effect of Marble Chips on Voids Filled with Asphalt (VFA)

The Voids Filled with Asphalt, VFA, is the portion of the voids in the mineral aggregate that contain asphalt binder. The VFA has a direct relation to the asphalt content and inverse relation to the VTM, air voids.

As the asphalt content increases the amount of voids filled with asphalt increases and the voids in the total mix, VTM, decreases. The VFA criteria limits the effects of maximum levels of VMA. In other words the VFA criterial limits the maximum levels of asphalt content.

At optimum asphalt content the voids in the total mix of 5.5% mix is the lowest indicating a higher VFA for the mix. At lower asphalt contents the VFA of the 0% mix is the lowest and correspondingly it has the higher VTM. The VFA for the Normal mix is lower than the 4% and 5.5% mix. This indicates that the samples with Marble chips reach the to the required VFA value with less asphalt content. The effect of Marble chips on the VFA of the mix is shown in Figure 4-8 below.

All mixes fulfill the VFA criteria, 65 – 75%, at their respective optimum asphalt contents.

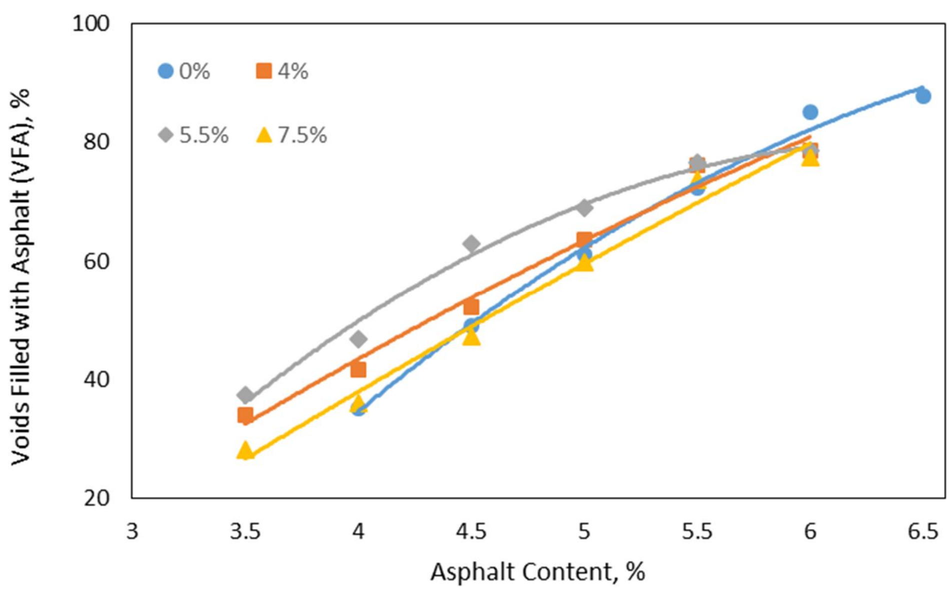

Figure 4-8 Effect of Marble Chips on the Voids Filled with Asphalt (VFA)

4.2.7 Effect of Marble Chips on the Effective Asphalt Content (P_{be})

The effective asphalt content of a mix is the total asphalt content minus the quantity of asphalt lost by absorption into the aggregate particles. It is the portion of the total asphalt content that remains as a coating on the outside of the aggregate particles. Consequently, the effective asphalt content governs the performance of the asphalt mix.

The method used to compute the effective asphalt content has been given in Section 3.3.1. Table 4-9 and Figure 4-9 below shows all the required parameters for the computation and the effective asphalt content.

Table 4-9 Effective Asphalt Content of the Mix

	% AC by wt. of mix	G_{mm}	G_{se}	G_{sb}	P_{ba}	P_{be}
0%	4	2.471	2.626	2.548	1.193	**2.854**
	4.5	2.449	2.621		1.124	**3.426**
	5	2.428	2.618		1.065	**3.988**
	5.5	2.408	2.614		1.018	**4.538**
	6	2.372	2.590		0.657	**5.383**
	6.5	2.347	2.579		0.490	**6.042**
4%	3.5	2.481	2.616	2.547	1.065	**2.472**
	4	2.456	2.609		0.946	**3.092**
	4.5	2.431	2.600		0.816	**3.720**
	5	2.406	2.591		0.676	**4.358**
	5.5	2.381	2.581		0.524	**5.004**
	6	2.356	2.570		0.361	**5.661**
5.5%	3.5	2.477	2.612	2.549	0.965	**2.569**
	4	2.463	2.617		1.038	**3.004**
	4.5	2.421	2.588		0.603	**3.924**
	5	2.417	2.604		0.848	**4.194**
	5.5	2.403	2.608		0.909	**4.641**
	6	2.384	2.606		0.872	**5.181**
7.5%	3.5	2.498	2.636	2.549	1.324	**2.222**
	4	2.468	2.623		1.125	**2.920**
	4.5	2.438	2.608		0.911	**3.630**
	5	2.408	2.593		0.682	**4.352**
	5.5	2.378	2.577		0.436	**5.088**
	6	2.348	2.560		0.172	**5.838**

The effective asphalt content of the mix increases with an increase in asphalt content for all mix. This value is bound on the lower side by 0% mix and on the upper side by 7.5% Marble mix after the 4.8% asphalt content. From this result, it can be said that the performance of the mix is not different from the 0% mix.

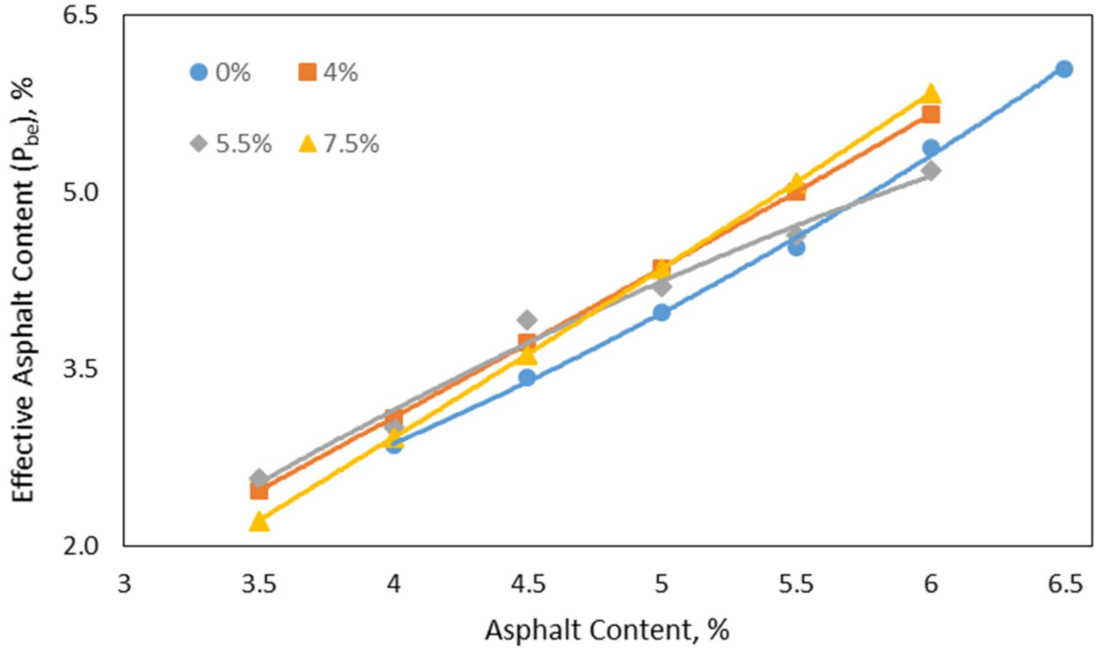

Figure 4-9 Effect of Marble Chips on Effective Asphalt Content

4.2.8 Effect of Marble Chips on the Optimum Asphalt Content

The optimum asphalt content of the mix is selected based on the procedures outlined on MS-2. The asphalt content at the mid-point of the VTM, maximum stability and maximum density were selected and averaged. From Table 4-10 and Figure 4-10 below it can be seen that with an increase in Marble chips there is a decrease in the optimum asphalt content.

Researches conducted on the optimum asphalt content using different amounts of Marble indicate the same. With an increase in the amount of Marble chips a decrease in the optimum asphalt content is expected. This makes marble chips as bitumen extenders.

Table 4-10 below shows the determination of the optimum asphalt content.

Table 4-10 Optimum Asphalt Content

Mix	Asphalt Content at Maximum Density [%]	Asphalt Content at Maximum Stability [%]	Asphalt Content at mid-point of VTM [%]	Optimum Asphalt Content [%]
0%	5.50	4.50	5.50	**5.17**
4%	5.50	4.10	5.40	**5.00**
5.5%	5.50	4.00	5.20	**4.90**
7.5%	5.50	3.90	5.00	**4.80**

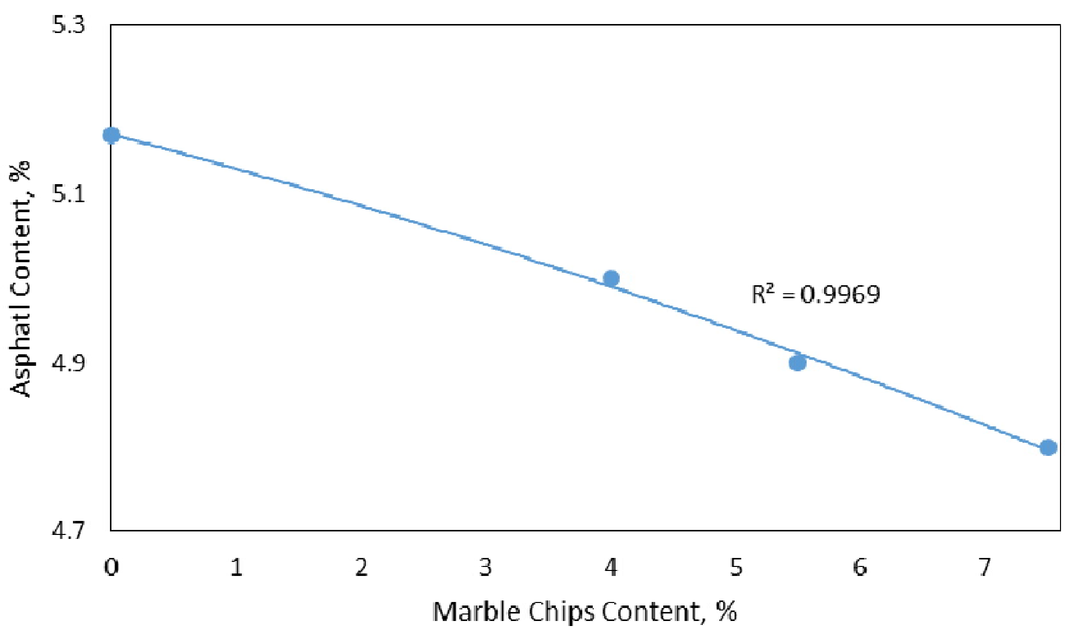

Figure 4-10 Optimum Asphalt Content for Different Marble Chips Content

4.2.9 Effect of Marble Chips on the Film Thickness of the Mix

The film thickness of an asphalt mix describes the amount of bitumen coating the aggregates. The value of the film thickness for an asphalt mix is in the range of 8 – 15µm (Heitzman, 2007).

The film thickness is calculated for the optimum asphalt content of the respective mix. The effective asphalt content for the optimum asphalt content was interpolated from the Table 4-11 Effective Asphalt Content of Mix.

The film thickness revealed that all the mix are within acceptable range of film thickness. The increase in film thickness for the 0% mix is attributed to the higher optimum asphalt content and lower surface area of the mix.

The data used to compute the film thickness is presented in Table 4-11 while the film thickness with varying marble content is plotted in Figure 4-11.

Table 4-11 Film Thickness of Mix

Mix	0%	4%	5.5%	7.5%
A [m^2/kg]	3.574723	4.744983	4.519312	4.570558
P_{be} [%]	4.208	4.358	4.140	4.063
P_b [%]	5.2	5.0	4.9	4.8
F [µm]	**12.15**	**9.46**	**9.43**	**9.14**

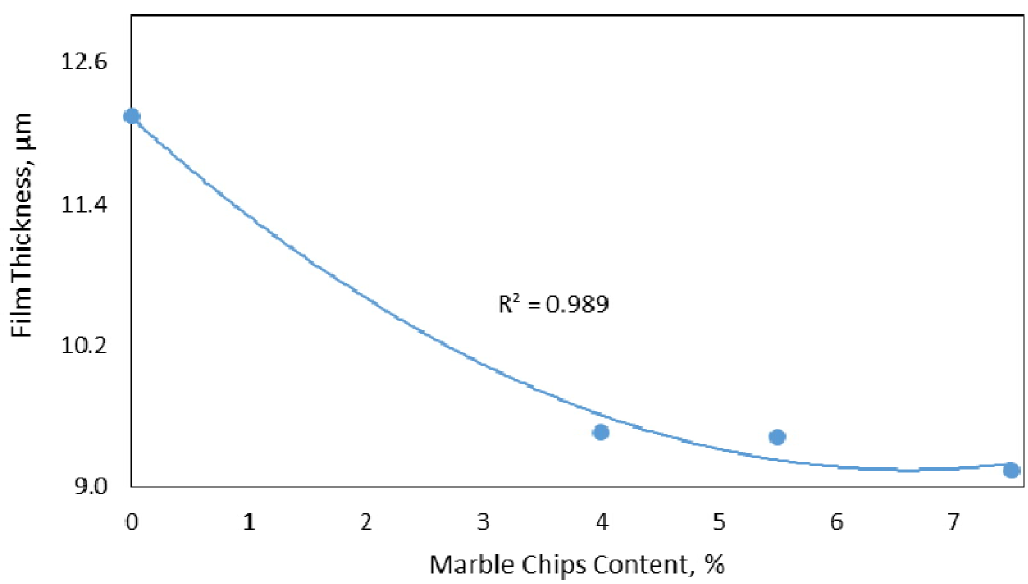

Figure 4-11 Effect of Marble Chips on Film Thickness

4.3 Effect of Marble Chips on Moisture Susceptibility of Mix

The moisture susceptibility of the mix was conducted by the use of Marshall Immersion. The test was conducted by preparing six Marshall specimen for each mix at optimum asphalt content. The six samples are then divided into two groups of three specimen each as control and test. The control group was stored at room temperature for four hours before the compressive strength was undertaken. The test group were immersed in water at 60^0c for 24 hours and then moved to a water bath at 25^0c for two hours before the compressive strength test was performed.

The test results for the moisture susceptibility indicates that the retained compressive strength of the mix which is the quotient of test group to the control group. The retained compressive strength has to satisfies the minimum requirement of 80%, minimum requirement for Superpave design method. Figure 4-12 below shows the retained strength of the test specimen. Hence, all of the specimen are not sensitive to the action of water.

Table 4-12 Index of Retained Strength

Mix	Compressive Strength of Control Mix [mPa]	Compressive Strength of Test Mix [mPa]	Index of Retained Strength
0%	3.29	2.91	**88.4**
4%	3.01	2.50	**82.8**
5.5%	3.2	2.76	**86.3**
7.5%	2.75	2.58	**93.7**

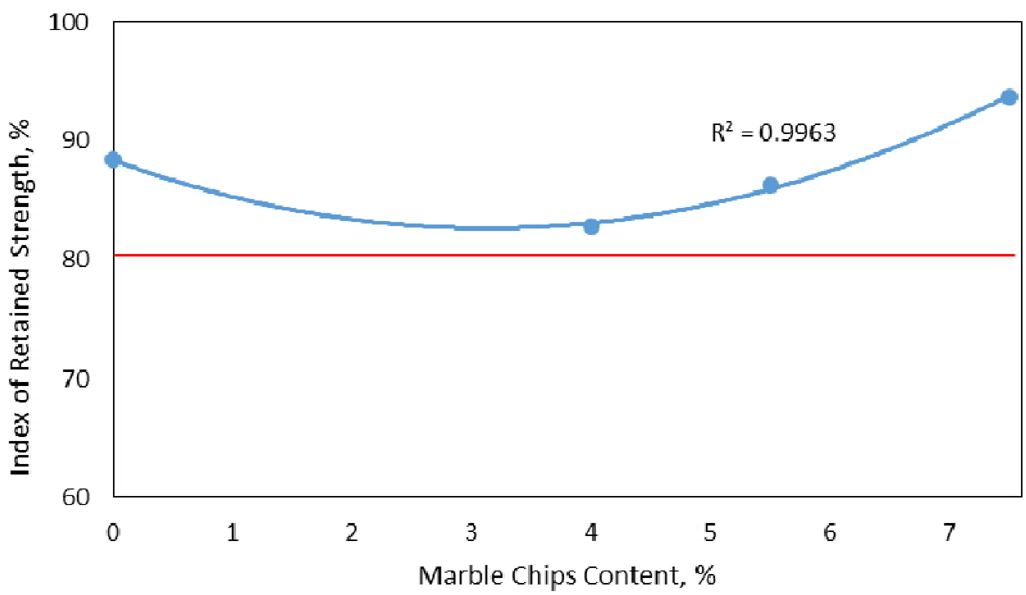

Figure 4-12 Index of Retained Strength for different Marble Chips Content

4.4 Selection of Optimum Marble Chip Content

The selection criteria is not only for the strength parameters but also for the economy of the mix. In terms of the mix design criteria all the mixes satisfy the requirements set in MS-2 and ERA for heavy traffic with the exception of Marshall Stability which is slightly lower than the specification set in ERA.

The 7.5% mix, Mix 1, gradation is on the lower side of the charts as seen in Table 3-10 and Figure 3-3 but fulfils all the requirements. The volumetric properties like VMA, VFA and VTM of the 4% and 5.5% mix follow the general trend described in other researches and literatures. In terms of the effective asphalt content the values of 4 and 5.5% mixes is ideal. Even though the range of film thickness is 8-15µm researches have shown that a film thickness in the range of 6 - 8µm are ideal (Hmoud, 2011) (Krishamurty, et al., 2012). The results of 4% and 5.5% mix is near to this value.

Hence, using an optimum marble chips content in the range of 4 – 5.5% will be optimal for an asphalt concrete mix and the saving in total mix and bitumen also makes this range acceptable.

4.5 Economic Analysis

The economic benefit of the marble chips was analyzed by considering utilization of crushed filler mix as base case scenario. The cost per m^2 of a 50mm asphalt concrete with crushed filler was compared against the same cost of asphalt concrete with Marble chips filler.

For the sake of economic evaluation, all the proposed mix scenarios are compared against the base case scenario.

The analysis is carried out on two fronts. The first takes into consideration the material cost of producing an asphalt concrete while the second approach considers the cost of materials, manpower and equipment that will be invested during the production, haulage and placement.

The unit rates used for the computation is shown in Table 4-13 below.

Table 4-13 Summary of Unit Rates for Economic Analysis

Material Type	Unit	Rate
Bitumen 60/70	Ton	21000.0
19mm Aggregate for surfacing	m^3	160.00
10mm Aggregate for surfacing	m^3	200.00
Crushed Filler for surfacing	m^3	300.00
Marble Chips	m^3	12.23

The analysis is conducted for the unit cost of preparing one m^2 of 50mm asphalt concrete. The analysis was carried out for all the mix and then the values compared to the 0% mix. The assumptions for the analysis are as follows:

- Asphalt plant is located near to the crusher
- The production rate of 4,000 – 5,000 m^3/day of AC
- The cost of Marble chips is taken as the hauling cost of one m^3 sample up to the time the analysis was conducted.

The detail of the complete analysis is given under Annex II.

From the analysis results, it was obtained that the cost of production for m^2 of asphalt concrete for the different mixes is given table and figure below. The difference in cost for the three mix with respect to the 0% mix is also shown in the table below.

Table 4-14 Cost Analysis of Different Mixes

AC Mix	Cost of Production [birr/m^2]	Difference from Normal Mix [%]
0%	312.80	0%
4%	286.32	8%
5.5%	282.15	10%
7.5%	277.91	11%

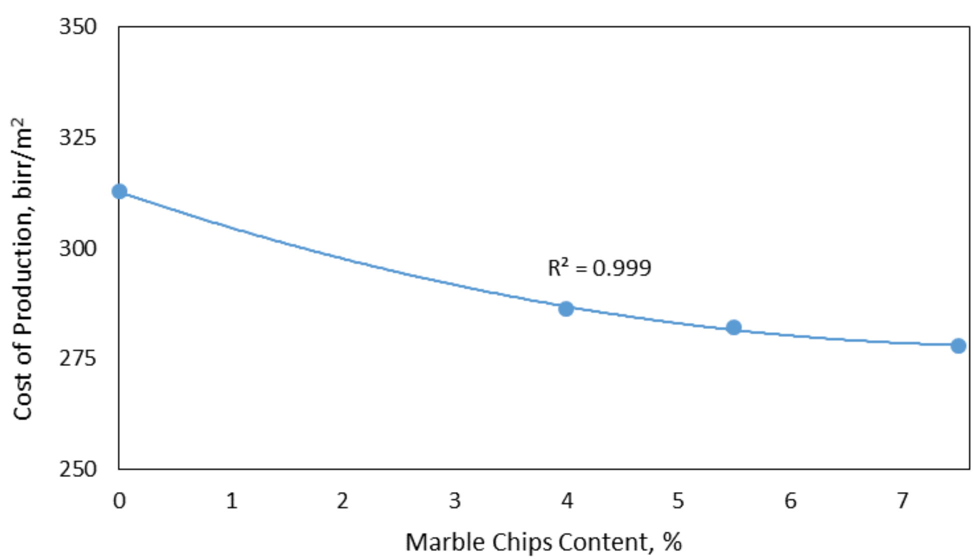

Figure 4-13 Cost of Production for Different Marble Chips Content

From the analysis, it can be seen that there is considerable saving in AC production. For the "optimum" marble content between 4 – 5.5%, there is a saving in asphalt production from 8 – 10% birr/m^2. The difference in cost is due to the decrease in the requirement of the asphalt content and the crushed filler.

The cost saving related to only the bitumen saving is in the range of 4 – 6%. This solely because of the saving in the optimum asphalt content. This value might seem small but considering the fact that bitumen is imported into this country the reduction in cost in foreign currency saves the country a great deal of money.

5 CONCLUSION AND RECOMMENDATIONS

The main goal of this research study was to analyze the effect of Marble Chips filler on hot mix asphalt performance to have a more economical pavement and use the locally available by-product. Accordingly, it is found that the use of Marble chips filler has influenced the overall property of the mix.

5.1 Conclusions

This study tries to study the effect of Marble chip filler on hot mix asphalt performance based on Marshall mix design and moisture sensitivity tests. Based on the results of the research the following conclusions are drawn.

- The use of factory by products Marble chips filler can be used for Asphalt Concrete production either fully replacing the need for crushed fillers or used in combination with the crushed fillers.
- The use of Marble chips filler at different contents to Hot Mix Asphalt satisfied all the requirements for mix design set in ERA PDM 2013 with the marginally lower Marshall stability.
- All the mix fulfill the requirements for moisture sensitivity but the 4% and 5.5% mix have a lower moisture resistance compared to the 0%.
- An optimum mix can be produced by combining crushed filler with Marble chips filler. The amount of Marble chips has to be in the range of 4 – 5.5% to produce an optimum mix.
- Marble chips facilitate the coating process and as such reduce the amount of optimum bitumen required. As such Marble chips are bitumen extenders.
- The economic analysis of the mix resulted in saving of Asphalt Concrete cost in the range of 8 – 10% with the use of Marble chips in the range of 4 – 5.5%.

5.2 Recommendations

Based on the findings of this research the following recommendations are made:

- Marble chips can be used as a filler in hot mix asphalt
- Marble chips can either be used alone or in combination with crushed fillers at 4 – 5.5% to produce an "optimum" mix
- It may be possible to use relatively lower bitumen content when Marble chips are used as filler.
- The use of Marble chips has an economical and environmental advantage.

5.3 Further Study

In order to further validate the findings of this research, additional researches have to be conducted. Here are some of the research topic recommended:

1. Performance testing of HMA with Marble Chips Fillers

The performance analysis of the Marble chips filler is a limitation for this study. In order to strengthen this research the performance of the mix has to be evaluated.

2. Economic Analysis of Marble Chips Haulage for HMA

The economic analysis presented here describes the economic advantage of using the Marble chips in the vicinity of the project. Identifying a haulage distance that is economical for the use in HMA production is beneficial not only for the saving of crushed aggregates but the import of bitumen as well.

3. Rheological properties of Bitumen – Marble Mixture

Understand the effect marble dusts have on bitumen is also another research topic. Detailed analysis on the rheological properties of bitumen marble mixture have to be studied using various tests by making use of Dynamic Shear Rheometer (DSR).

4. Marble Chips Filler Quality on the Performance of Hot Mix Asphalt

The quality of marble is determined by the amount of impurities present such as clay, mica, quarts graphite and so on. The degree of weathering also affects the quality of the marble chips. Examining the Marble chips filler quality on the HMA mix will help in a more economical mix.

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APPENDICES

Appendix – I
Laboratory Test Results

Aggregate Quality Test Results

SUMMARY OF CRUSHED AGGREGATE TEST RESULTS

Project : **Thesis**

Lab No.:

Client :

Date :

Sample of : **Crushed Aggregate**

Reported to :

Submitted by :

Reported by

Station	AASHTO T 85 Specific Gravity, (Oven-dry)	AASHTO T 85 Water Absorption (%)	AASHTO T 104 Soundness loss by Na_2SO_4 (%)	BS 812 : Part 110 ACV (%)	BS 812 : Part 111 TFV Dry (KN)	AASHTO T 96 LAA (%)	AASHTO T 182 Coating and Stripping	AASHTO T 176 Sand Equivalent (%)	BS 812: Part 105-1 Flakiness Index (%)	AASHTO T 182 Coating and Stripping
1	2.591	2.0	2	15	260	13.0	>95	95	17	NP

Remark:

Sieve Analysis AASHTO Designation : T 27

Project : **Thesis** Lab No.: ______

Client : ______ Date Tested: ______

Sample of : **Aggregate** Date Reported: ______

Station : ______ Reported To: ______

Submitted by: ______ Reported By: ______

Wet Gradation

Wt. of Oven Dry Sample Before Washing (gm):- **4638**

Wt. of Oven Dry Sample After Washing (gm):- **4638**

Sieve Size (mm)	Wt. of Sample Retained	% Retained	% Passing
25			**100.0**
20		0.0	**100.0**
12.5	3728.9	80.4	**19.6**
9.5	890.5	19.2	**0.4**
4.75	18.6	0.4	**0.0**
Passing 0.075	0.1	0.0	

Remark : ______

Sieve Analysis AASHTO Designation : T 27

Project :	**Thesis**	Lab No.:	
Client :		Date Tested:	
Sample of :	**Aggregate**	Date Reported:	
Station :		Reported To:	
Submitted by:		Reported By:	

Wet Gradation

Wt. of Oven Dry Sample Before Washing (gm):- **4427**

Wt. of Oven Dry Sample After Washing (gm):- **4392**

Sieve Size (mm)	Wt. of Sample Retained	% Retained	% Passing
20			**100.0**
12.5	44.3	1.0	**99.0**
9.5	898.7	20.3	**78.7**
4.75	3032.4	68.5	**10.2**
2.36	416.1	9.4	**0.8**
Passing 0.075	35.4	0.8	

Remark :

Sieve Analysis AASHTO Designation : T 27

Project :	**Thesis**	Lab No.:	
Client :		Date Tested:	
Sample of :	**Aggregate**	Date Reported:	
Station :		Reported To:	
Submitted by:		Reported By:	

Wet Gradation

Wt. of Oven Dry Sample Before Washing (gm):- **3218**

Wt. of Oven Dry Sample After Washing (gm):- **3160**

Sieve Size (mm)	Wt. of Sample Retained	% Retained	% Passing
9.5			**100.0**
4.75	215.6	6.7	**93.3**
2.36	2049.6	63.7	**29.6**
1.18	759.4	23.6	**6.0**
0.600	135.2	4.2	**1.8**
Passing 0.075	57.8	1.8	

Remark :

Sieve Analysis AASHTO Designation : T 27

Project :	**Thesis**		Lab No.:	
Client :			Date Tested:	
Sample of :	**Aggregate**		Date Reported:	
Station :			Reported To:	
Submitted by:			Reported By:	

Wet Gradation

Wt. of Oven Dry Sample Before Washing (gm):- **4072**

Wt. of Oven Dry Sample After Washing (gm):- **3579**

Sieve Size (mm)	Wt. of Sample Retained	% Retained	% Passing
4.75			**100.0**
2.36	187.3	4.6	**95.4**
1.18	1445.5	35.5	**59.9**
0.600	1062.7	26.1	**33.8**
0.300	496.7	12.2	**21.6**
0.150	244.3	6.0	**15.6**
0.075	142.5	3.5	**12.1**
Passing 0.075	492.7	12.1	

Remark :

Sieve Analysis AASHTO Designation : T 27

Project :	**Thesis**		Lab No.:	
Client :			Date Tested:	
Sample of :	**Marble Chips**		Date Reported:	
Station :			Reported To:	
Submitted by:			Reported By:	

Wet Gradation

Wt. of Oven Dry Sample Before Washing (gm):- **1000**

Wt. of Oven Dry Sample After Washing (gm):- **149**

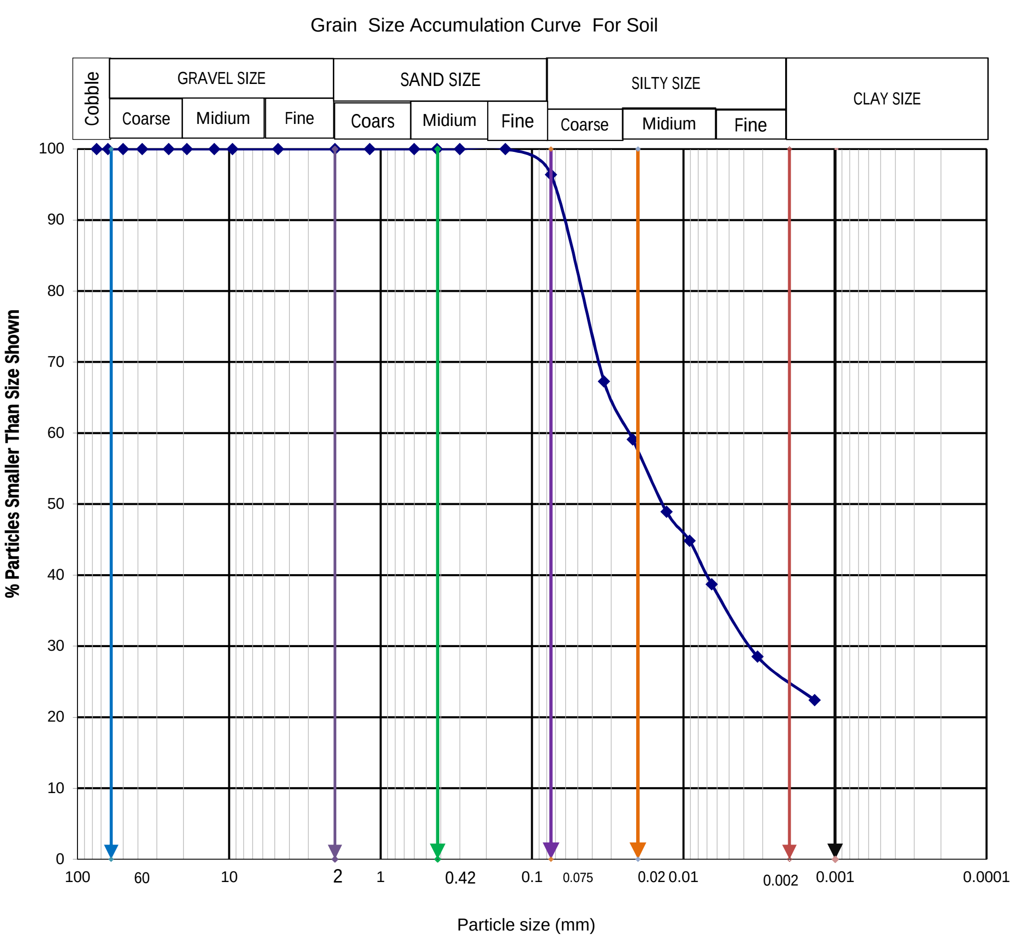
Sieve Size (mm)	**Wt. of Sample Retained**	**% Retained**	**% Passing**
9.5			**100.0**
4.75	9	0.8	**99.2**
2.36	19	1.9	**97.3**
1.18	30	2.9	**94.3**
0.600	27	2.7	**91.6**
0.300	22	2.2	**89.4**
0.150	23	2.3	**87.1**
0.075	20	2.0	**85.2**
Passing 0.075	851.5	85.1	

Remark :

Particle Size Analysis of Soil AASHTO T 88

Project :	**Thesis**	Lab No.:	
Client :		Date :	
Station/Location		Reported to :	
Sample of :	**Marble Chips**	Reported by :	
Submitted by :		Depth :	
Test pit/ B.H N°:			

Grain Size Analysis Test Result



SIEVESIZE IN (mm)	% Passing
75	100
63	100
50	100
37.5	100
25	100
19	100
12.5	100
9.5	100
4.75	100
2.00	100
1.18	100.00
0.600	100.00
0.425	100.00
0.300	100.00
0.150	100.00
0.075	96.40
0.033	67.28
0.022	59.12
0.013	48.92
0.009	44.84
0.007	38.72
0.003	28.52
0.001	22.40

	Percent (%)
1.1.1. particles larger than 2-mm percent ;	**0.0%**
1.1.2. Coarse sand 2.0 to 0.42mm percent ;	**0.0%**
1.1.3. Fine sand, 0.42 to 0.074-mm percent ;	**3.6%**
1.1.4. Silt, 0.074 to 0.002-mm percent	**70.9%**
1.1.5. Clay smaller than 0.002-mm percent;and	**25.5%**

Remark :

Bitumen Quality Test Results

SUMMARY OF BITUMEN TEST RESULTS

Project : **Thesis**

Client :

Sample of : **Bitumen (60/70)**

Submitted by :

Lab. No. :

Date Reported

Reported to :

Reported by :

Sample No.	AASHTO T 44 Solubility in Trichloro ethylene, (%)	AASHTO T 47 Loss on Heating, (%)	AASHTO T 48 Flash Point, ^{O}F	AASHTO T 49 Penetration at $25^{o}C$, 100g, 5sec	AASHTO T 51 Ductility at $25^{o}C$ (cm)	Penetration of residue percent of original, at $25^{o}c$,100g, 5sec	Ductility of residue, cm	AASHTO T 53 Softening Point (^{0}C)	AASHTO T 228-06 Specific gravity at $25^{o}C$ (kg/m^3)
1	99.8	0.02	310	65	100^{+}	91	100^{+}	52.0	1022

Remark:

Marshall Test Results

0% Mix

%AC by weight of aggregate	%AC by weight of total mix	Max SG of Paving Mix	Weight grams			Bulk Volume CC	Bulk S.G. Comp. Mix	Air Void (%)	% V.M.A.	% V.F.A.	Stability (KN)		Flow (mm)
			In Air	In water	In Air SSD						Read	Adjusted	
4.17	4.0A		1228.7	682.2	1245.1	562.9	2.183				10.40	9.22	2.49
	B		1228.1	681.9	1243.6	561.7	2.186				10.16	9.10	2.51
	C		1229.5	683.1	1244.2	561.1	2.191				10.18	9.20	2.52
Average		2.471					2.187	11.50	17.75	35.22		9.2	2.51
4.71	4.5 A		1233.9	697.5	1245.3	547.8	2.252				12.61	11.2	2.61
	B		1235.1	698.1	1245.0	546.9	2.258				12.60	11.2	2.63
	C		1227.1	695.1	1241.9	546.8	2.244				12.21	10.9	2.62
Average		2.449					2.252	8.06	15.79	48.98		11.1	2.62
5.26	5.0 A		1237.6	704.0	1245.9	541.9	2.284				11.51	10.7	2.71
	B		1241.1	706.1	1246.3	540.2	2.297				11.54	10.7	2.75
	C		1234.2	702.5	1244.1	541.6	2.279				11.49	10.7	2.73
Average		2.428					2.287	5.82	14.98	61.14		10.71	2.73
5.82	5.5 A		1237.8	704.1	1239.2	535.1	2.313				10.70	10.2	2.8
	B		1237.5	705.9	1240.7	534.8	2.314				10.60	10.2	2.9
	C		1242.2	706.1	1244.9	538.8	2.305				10.70	10.0	2.8
Average		2.408					2.311	4.03	14.58	72.35		10.1	2.8
6.38	6.0 A		1255.8	715.2	1257.8	542.6	2.314				9.70	9.0	2.8
	B		1249.4	714.1	1251.5	537.4	2.325				10.10	9.2	3.0
	C		1257.1	717.1	1258.9	541.8	2.320				9.90	9.1	2.9
Average		2.372					2.320	2.20	14.76	85.11		9.1	2.9
6.75	6.5 A		1259.6	710.4	1269.8	559.4	2.252				9.20	8.8	3.3
	B		1258.2	709.7	1268.9	559.2	2.250				9.00	8.7	3.1
	C		1256.9	707.2	1266.1	558.9	2.249				9.00	8.7	3.2
Average		2.347					2.250	1.55	14.95	87.65		8.8	3.2

4% Mix

%AC by weight of aggregate	%AC by weight of total mix	Max SG of Paving Mix	Weight grams			Bulk Volume CC	Bulk S.G. Comp. Mix	Air Void (%)	% V.M.A.	% V.F.A.	Stability (KN)		Flow (mm)
			In Air	In water	In Air SSD						Read	Adjusted	
4.26	3.5A		1239.9	695.0	1259.9	564.9	2.195				8.97	8.61	2.60
	B		1241.9	687.3	1253.3	566.0	2.194				8.99	8.63	2.60
	C		1240.9	691.2	1256.6	565.4	2.195				9.02	8.66	2.60
Average		2.481					2.195	11.54	17.51	34.06		8.6	2.60
4.17	4.0A		1233.9	697.0	1252.8	555.8	2.220				10.30	9.2	2.71
	B		1221.1	689.9	1239.9	550.0	2.220				10.60	9.4	2.69
	C		1227.5	693.5	1246.4	552.9	2.220				10.45	9.3	2.70
Average		2.456					2.220	9.60	16.47	41.68		9.3	2.70
4.71	4.5 A		1240.2	708.6	1261.0	552.4	2.245				9.50	8.5	3.00
	B		1215.2	690.1	1231.6	541.5	2.244				9.70	9.0	3.20
	C		1227.7	699.4	1246.3	546.9	2.245				9.60	8.5	3.10
Average		2.431					2.245	7.66	16.02	52.16		8.7	3.10
5.26	5.0 A		1231.4	701.4	1243.9	542.5	2.270				8.60	8.0	3.20
	B		1234.2	704.5	1248.2	543.7	2.270				8.90	8.3	3.10
	C		1232.8	703.1	1246.1	543.0	2.270				8.14	8.1	3.15
Average		2.406					2.270	5.65	15.56	63.69		8.1	3.15
5.82	5.5 A		1227.4	703.2	1238.0	534.8	2.295				8.00	7.4	3.6
	B		1238.1	707.0	1246.5	539.5	2.295				8.90	8.3	3.4
	C		1232.8	705.1	1242.3	537.2	2.295				8.45	7.9	3.5
Average		2.381					2.295	3.61	15.14	76.13		7.9	3.5
6.38	6.0 A		1240.2	706.1	1254.1	548.0	2.263				8.10	7.4	3.7
	B		1238.6	705.5	1251.5	546.0	2.268				7.80	7.1	3.7
	C		1239.2	704.7	1251.9	547.2	2.265				7.90	7.2	3.9
Average		2.356					2.265	2.10	15.85	78.65		7.2	3.8

5.5% Mix

%AC by weight of aggregate	%AC by weight of total mix	Max SG of Paving Mix	Weight grams			Bulk Volume CC	Bulk S.G. Comp. Mix	Air Void (%)	% V.M.A.	% V.F.A.	Stability (KN)		Flow (mm)
			In Air	In water	In Air SSD						Read	Adjusted	
4.26	3.5A		1224.6	683.2	1235.6	552.4	2.217				12.00	10.68	2.30
	B		1224.2	682.6	1234.2	551.6	2.219				11.90	10.59	2.20
	C		1224.4	682.1	1234.1	552.0	2.218				12.00	10.68	2.25
Average		2.477					2.218	10.45	16.69	37.37		10.7	2.25
4.17	4.0A		1218.5	688.2	1225.6	537.4	2.267				10.10	9.4	2.60
	B		1224.9	689.1	1226.1	537.0	2.281				10.30	9.6	2.70
	C		1221.7	687.5	1225.9	538.4	2.269				10.20	9.5	2.65
Average		2.463					2.273	7.73	14.56	46.90		9.5	2.65
4.71	4.5 A		1227.9	694.1	1229.5	535.4	2.293				9.00	8.6	2.90
	B		1227.1	693.5	1228.9	535.4	2.292				10.50	10.1	2.90
	C		1227.5	693.8	1229.2	535.4	2.293				9.80	9.4	2.90
Average		2.421					2.293	5.30	14.29	62.91		9.4	2.90
5.26	5.0 A		1229.1	702.3	1230.2	527.9	2.328				9.30	8.9	3.50
	B		1237.2	701.9	1239.6	537.7	2.301				9.40	9.0	3.10
	C		1233.2	700.9	1236.1	535.2	2.304				9.40	9.0	3.30
Average		2.417					2.311	4.38	14.10	68.94		9.0	3.30
5.82	5.5 A		1230.7	707.1	1231.9	524.8	2.345				8.30	8.0	3.5
	B		1245.8	706.0	1247.7	541.7	2.300				8.60	8.3	3.7
	C		1238.3	706.9	1239.8	532.9	2.324				8.50	7.9	3.6
Average		2.403					2.323	3.33	14.18	76.47		8.0	3.6
6.38	6.0 A		1238.2	704.9	1246.1	541.2	2.288				8.20	7.6	4.0
	B		1241.6	706.9	1248.9	542.0	2.291				7.80	7.3	4.0
	C		1244.5	708.5	1253.2	544.7	2.285				8.20	7.6	3.9
Average		2.384					2.288	2.22	14.55	78.56		7.5	3.95

7.5% Mix

%AC by weight of aggregate	%AC by weight of total mix	Max SG of Paving Mix	Weight grams			Bulk Volume CC	Bulk S.G. Comp. Mix	Air Void (%)	% V.M.A.	% V.F.A.	Stability (KN)		Flow (mm)
			In Air	In water	In Air SSD						Read	Adjusted	
4.26	3.5A		1227.9	682.9	1251.5	568.6	2.160				8.80	8.15	1.84
	B		1222.3	680.5	1245.9	565.4	2.162				8.74	8.05	1.86
	C		1230.2	683.2	1254.2	571.0	2.154				8.81	8.22	1.85
Average		2.498					2.159	10.10	18.92	28.20		8.1	1.85
4.17	4.0A		1232.5	686.8	1250.5	563.7	2.186				9.90	9.3	2.00
	B		1235.9	688.1	1253.8	565.7	2.185				10.00	9.3	2.10
	C		1234.9	689.9	1252.3	562.4	2.196				9.80	9.5	2.00
Average		2.468					2.189	8.10	17.70	36.15		9.4	2.05
4.71	4.5 A		1243.9	696.5	1257.1	560.6	2.219				10.20	9.2	2.28
	B		1243.9	696.3	1258.2	561.9	2.214				10.50	9.4	2.20
	C		1244.6	698.2	1258.3	560.1	2.222				10.10	8.8	2.28
Average		2.438					2.218	6.20	17.07	47.21		9.1	2.25
5.26	5.0 A		1249.2	706.1	1261.6	555.5	2.249				8.30	8.0	2.51
	B		1231.6	698.9	1244.8	545.9	2.256				8.60	8.2	2.50
	C		1245.4	702.8	1258.1	555.3	2.243				8.50	7.9	2.50
Average		2.408					2.249	4.10	16.40	59.76		8.0	2.50
5.82	5.5 A		1247.3	708.6	1255.8	547.2	2.279				8.00	7.6	2.7
	B		1249.3	710.1	1258.6	548.5	2.278				7.80	7.3	2.8
	C		1249.8	709.8	1257.9	548.1	2.280				8.00	7.5	2.7
Average		2.378					2.279	2.60	15.79	73.67		7.5	2.75
6.38	6.0 A		1262.7	710.9	1271.9	561.0	2.251				7.70	7.1	3.0
	B		1259.9	709.2	1268.4	559.2	2.253				7.65	7.1	3.0
	C		1258.2	707.1	1266.2	559.1	2.250				7.66	7.1	3.0
Average		2.348					2.251	1.40	17.20	77.50		7.1	3.02

Moisture Sensitivity Test Results

Mix Type	%AC by weight of aggregate	Weight grams			Bulk Volume CC	Bulk S.G. Comp. Mix	Compressive Strength	
		In Air	In water	In Air SSD			Load (kN)	Strength (MPa)
0% Mix (Control)	5.81	1237.8	704.1	1239.2	535.1	2.313	26.95	3.32
		1237.5	705.9	1240.7	534.8	2.314	26.82	3.30
		1242.2	706.1	1244.9	538.8	2.305	26.40	3.25
		Average				2.311	26.72	3.29
0% Mix (Test)	5.81	1255.8	715.2	1257.8	542.6	2.314	23.24	2.86
		1249.4	714.1	1251.5	537.4	2.325	23.70	2.92
		1257.1	717.1	1258.9	541.8	2.320	23.90	2.94
		Average				2.320	23.61	2.91
Index of Retained strength =			88.4					

Mix Type	%AC by weight of aggregate	Weight grams			Bulk Volume CC	Bulk S.G. Comp. Mix	Compressive Strength	
		In Air	In water	In Air SSD			Load (kN)	Strength (MPa)
4% Mix (Control)	5.82	1227.4	703.2	1238.0	534.8	2.295	24.52	3.02
		1238.1	707.2	1246.5	539.3	2.296	24.73	3.04
		1232.6	705.1	1242.8	537.7	2.292	24.20	2.98
		Average				2.294	24.48	3.01
4% Mix (Test)	5.82	1231.4	701.4	1243.9	542.5	2.270	20.01	2.46
		1234.2	704.5	1248.2	543.7	2.270	20.56	2.53
		1232.8	703.0	1245.2	542.3	2.273	20.29	2.50
		Average				2.271	20.28	2.50
Index of Retained strength =			82.8					

Mix Type	%AC by weight of aggregate	Weight grams			Bulk Volume CC	Bulk S.G. Comp. Mix	Compressive Strength	
		In Air	In water	In Air SSD			Load (kN)	Strength (MPa)
5.5% Mix (Control)	5.82	1235.2	697.1	1253.0	555.9	2.222	25.84	3.18
		1237.2	706.5	1258.9	552.4	2.240	26.12	3.22
		1233.3	703.1	1257.2	554.1	2.226	26.07	3.21
		Average				2.229	26.01	3.20
5.5% Mix (Test)	5.82	1229.1	698.2	1252.3	554.1	2.218	22.58	2.78
		1237.2	707.0	1264.8	557.8	2.218	22.51	2.77
		1233.15	702.6	1258.6	556.0	2.218	22.23	2.74
		Average				2.218	22.44	2.76

Index of Retained strength = 86.3

Mix Type	%AC by weight of aggregate	Weight grams			Bulk Volume CC	Bulk S.G. Comp. Mix	Compressive Strength	
		In Air	In water	In Air SSD			Load (kN)	Strength (MPa)
7.5% Mix (Control)	5.82	1220.3	708.2	1246.1	537.9	2.269	22.23	2.74
		1233.1	711.5	1242.1	530.6	2.324	22.51	2.77
		1227.4	709.2	1253.2	544.0	2.256	22.37	2.75
		Average				2.283	22.37	2.75
7.5% Mix (Test)	5.82	1220.1	710.8	1246.1	535.3	2.279	21.09	2.60
		1225.5	715.3	1254.9	539.6	2.271	20.95	2.58
		1224	718.4	1252.5	534.1	2.292	20.84	2.57
		Average				2.281	20.96	2.58

Index of Retained strength = 93.7

Appendix – II
Book of Rate Computations

Marble Chips Hauling Cost

Detailed Break down of Work Item

Unit Prices

Project : **Thesis**

Work Item : **Marble Chips Hauling** 1.35

Total quantity of work item :

Cap.	16 m^3
Av Dist.	50 km
Av. Spd	55 km/h
for L&UnL	8 min

Performance rate : 500 M^3/day

71.43 M^3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	**Unit**	**Qty**	**Rate**	**Cost/Unit**	**Title**	**Qty**	**UF**	**Indexed Hourly Cost**	**Total Hourly**	**Equipment Type**	**Qty**	**UF**	**Rental rate hrly**	**Rental rate Total**
					Equip. operator I	1	0.50	50.00	25.00	Dump Truck 6x4	1	1.00	520.00	520.00
					Equip. operator II	1	0.25	65.00	16.25	Loader	1	0.50	625.00	312.50
Total				0.00	**Total**				41.25	**Total**				832.50

A = Material Unit Cost Birr/m^3 B = Manpower Unit Cost 0.58 Birr/m^3 C = Equipment Unit Cost : 11.66 Birr/m^3

Direct cost of work item = A+B+C = 12.23 Birr/m^3

UF : Utilization Factor **including 35% of indirect cosr** **16.5139**

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

0% Mix

Detailed break down of work item
unit prices

Project : **Thesis** 1.35

Work Item : **Asphalt concrete production** 200.00

Total quantity of work item : **Performance rate : 33.333** M3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
Bitumen 60/70	Ton	0.1499	21000.0	3,146.85	St.Eq. operator II	1	1	64.25	64.25	Asphalt plant (150 Ton/hr)	1	1.00	12838.49	12838.49
19mm Aggregate for surfacing	m3	0.2040	160.00	32.6	Equip. operator II	1	1.5	75.14	112.72	Loader, Wheel	3	1.00	625.00	1875.00
10mm Aggregate for surfacing	m3	0.6950	200.00	139.0	Helper II	1	1.0	34.15	34.15	Welding machine	1	0.75	19.83	14.87
Filler for surfacing	m3	0.1010	300.00	30.3	Labourer I	4	1	34.15	136.61					
Marble	m3	0.0000	12.23	0.0	Mechanic I	1	1	43.56	43.56					
					Electrician I	1	1	43.56	43.56					
					welder	1.00	1.00	35	35.39					
Total				3348.79	**Total**				434.85	**Total**				14728.36

A = Material Unit Cost 3,348.79 Birr/m3 B = Manpower Unit Cost : 13.05 Birr/m3 C = Equipment Unit Cost : 442 Birr/m3

Direct cost of work item =A+B+C= 3,803.69 Birr/m3

Remark

*Each bareel(drum) contains 210 kg of bitumen.

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Asphalt Plant is assumed to be located near to Crusher site

Detailed break down of work item

unit prices

Project : **Thesis** 1.35

Work Item : **AC Mix Hauling**

Total quantity of work item :

Cap.	12 m^3
Av Dist.	17 km
Av. Spd	35 km/h
for L&UnL	8 min

Performance rate : 300 M^3/day

50.00 M^3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Equip. operator I	3	1	66.98	200.93	Dump Truck 6x4	3	1	520.00	1560.00
Total				0.00	Total				200.93	Total				1560.00

A = Material Unit Cost 0.00 Birr/m^3 B = Manpower Unit Cost : 4.02 Birr/m3 C = Equipment Unit Cost : 31 Birr/m^3

Direct cost of work item =A+B+C= **35.22** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **47.55** Birr/m^3

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed break down of work item

unit prices

Project : **Thesis** 1.35

Work Item : **Item 64.01** **Asphalt concrete placing** 4000.00

Total quantity of work item : **Performance rate : 666.667 M2/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	**Unit**	**Qty**	**Rate**	**Cost/Unit**	**Title**	**Qty**	**UF**	**Indexed Hourly Cost**	**Total Hourly Cost**	**Equipment Type**	**Qty**	**UF**	**Rental rate hrly**	**Rental rate Total**
Asphalt hot mix	m3	0.05	3803.69	190.18	Construction Foreman I	1	1	84.95	84.95	Asphalt Paver (5-6 m)	1	1	830.22	830.22
AC Mix Haul	m3	1	35.22	35.22	Equip. operator II	3	1	75.14	225.43	Roller, 6t	2	1	277.42	554.84
					St.Eq. operator II	1	1	64.25	64.25	Roller, Pneumatic	2	1	651.93	1303.87
					Equip. operator I	2	1	66.98	133.95	Water Truck 6x4	1	1	480.00	480.00
					Helper II	2	1.0	34.15	68.30	Power broom	1	1.00	247.87	247.87
					Labourer I	6	1	34.15	204.91					
				0.00										
Total				225.40	**Total**				781.80	**Total**				3416.80

A = Material Unit Cost 225.40 Birr/m 2 B = Manpower Unit Cost : 1.17 Birr/m2 C = Equipment Unit Cost : 5 Birr/m2

Direct cost of work item =A+B+C= **231.70** Birr/m2

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **312.80** Birr/m2

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

4% Mix

Detailed break down of work item
unit prices

Project : **Thesis** 1.35

Work Item : **Asphalt concrete production** 200.00

Total quantity of work item : **Performance rate : 33.333** M3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
Bitumen 60/70	Ton	0.1325	21000.0	2,782.50	St.Eq. operator II	1	1	64.25	64.25	Asphalt plant (150 Ton/hr)	1	1.00	12838.49	12838.49
19mm Aggregate for surfacing	m3	0.1790	160.00	28.6	Equip. operator II	1	1.5	75.14	112.72	Loader, Wheel	2	1.00	625.00	1250.00
10mm Aggregate for surfacing	m3	0.7070	200.00	141.4	Helper II	1	1.0	34.15	34.15	Welding machine	1	0.75	19.83	14.87
Filler for surfacing	m3	0.0740	300.00	22.2	Labourer I	4	1	34.15	136.61					
Marble	m3	0.0400	12.23	0.5	Mechanic I	1	1	43.56	43.56					
					Electrician I	1	1	43.56	43.56					
					welder	1.00	1.00	35	35.39					
Total				2975.23	**Total**				434.85	**Total**				14103.36

A = Material Unit Cost 2,975.23 Birr/m3 B = Manpower Unit Cost : 13.05 Birr/m3 C = Equipment Unit Cost : 423 Birr/m3

Direct cost of work item =A+B+C= 3,411.38 Birr/m3

Remark

*Each bareel(drum) contains 210 kg of bitumen.

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Asphalt Plant is assumed to be located near to Crusher site

Detailed break down of work item

unit prices

Project : **Thesis** 1.35

Work Item : **AC Mix Hauling**

Total quantity of work item :

Cap.	12 m^3
Av Dist.	17 km
Av. Spd	35 km/h
for L&UnL	8 min

Performance rate : 300 M^3/day

50.00 M^3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Equip. operator I	3	1	66.98	200.93	Dump Truck 6x4	3	1	520.00	1560.00
Total				0.00	**Total**				200.93	**Total**				1560.00

A = Material Unit Cost 0.00 Birr/m ^{3} B = Manpower Unit Cost : 4.02 Birr/m3 C = Equipment Unit Cost : 31 Birr/m^3

Direct cost of work item =A+B+C= **35.22** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **47.55** Birr/m^3

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed break down of work item

unit prices

Project : **Thesis** 1.35

Work Item : **Item 64.01** **Asphalt concrete placing** 4000.00

Total quantity of work item : **Performance rate : 666.667 M2/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	**Unit**	**Qty**	**Rate**	**Cost/Unit**	**Title**	**Qty**	**UF**	**Indexed Hourly Cost**	**Total Hourly Cost**	**Equipment Type**	**Qty**	**UF**	**Rental rate hrly**	**Rental rate Total**
Asphalt hot mix	m3	0.05	3411.38	170.57	Construction Foreman I	1	1	84.95	84.95	Asphalt Paver (5-6 m)	1	1	830.22	830.22
AC Mix Haul	m3	1	35.22	35.22	Equip. operator II	3	1	75.14	225.43	Roller, 6t	2	1	277.42	554.84
					St.Eq. operator II	1	1	64.25	64.25	Roller, Pneumatic	2	1	651.93	1303.87
					Equip. operator I	2	1	66.98	133.95	Water Truck 6x4	1	1	480.00	480.00
					Helper II	2	1.0	34.15	68.30	Power broom	1	1.00	247.87	247.87
					Labourer I	6	1	34.15	204.91					
				0.00										
Total				205.79	**Total**				781.80	**Total**				3416.80

A = Material Unit Cost 205.79 Birr/m 2 B = Manpower Unit Cost : 1.17 Birr/m2 C = Equipment Unit Cost : 5 Birr/m2

Direct cost of work item =A+B+C= **212.09** Birr/m2

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **286.32** Birr/m2

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

5.5% Mix

Detailed break down of work item

unit prices

Project : **Thesis** 1.35

Work Item : **Asphalt concrete production** 200.00

Total quantity of work item : **Performance rate : 33.333** M3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	**Unit**	**Qty**	**Rate**	**Cost/Unit**	**Title**	**Qty**	**UF**	**Indexed Hourly Cost**	**Total Hourly Cost**	**Equipment Type**	**Qty**	**UF**	**Rental rate hrly**	**Rental rate Total**
Bitumen 60/70	Ton	0.1299	21000.0	2,726.85	St.Eq. operator II	1	1	64.25	64.25	Asphalt plant (150 Ton/hr)	1	1.00	12838.49	12838.49
19mm Aggregate for surfacing	m3	0.1790	160.00	28.6	Equip. operator II	1	1.5	75.14	112.72	Loader, Wheel	2	1.00	625.00	1250.00
10mm Aggregate for surfacing	m3	0.7250	200.00	145.0	Helper II	1	1.0	34.15	34.15	Welding machine	1	0.75	19.83	14.87
Filler for surfacing	m3	0.0410	300.00	12.3	Labourer I	4	1	34.15	136.61					
Marble	m3	0.0550	12.23	0.7	Mechanic I	1	1	43.56	43.56					
					Electrician I	1	1	43.56	43.56					
					welder	1.00	1.00	35	35.39					
Total				2913.46	**Total**				434.85	**Total**				14103.36

A = Material Unit Cost 2,913.46 Birr/m3 B = Manpower Unit Cost : 13.05 Birr/m3 C = Equipment Unit Cost : 423 Birr/m3

Direct cost of work item =A+B+C= 3,349.61 Birr/m3

Remark

*Each bareel(drum) contains 210 kg of bitumen.

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Asphalt Plant is assumed to be located near to Crusher site

Detailed break down of work item

unit prices

Project : **Thesis** 1.35

Work Item : **AC Mix Hauling**

Total quantity of work item :

Cap.	12 m^3
Av Dist.	17 km
Av. Spd	35 km/h
for L&UnL	8 min

Performance rate : 300 M^3/day

50.00 M^3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Equip. operator I	3	1	66.98	200.93	Dump Truck 6x4	3	1	520.00	1560.00
Total				0.00	Total				200.93	Total				1560.00

A = Material Unit Cost 0.00 Birr/m^3 B = Manpower Unit Cost : 4.02 Birr/m3 C = Equipment Unit Cost : 31 Birr/m^3

Direct cost of work item =A+B+C= **35.22** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **47.55** Birr/m^3

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed break down of work item

unit prices

Project : **Thesis** 1.35

Work Item : **Item 64.01** **Asphalt concrete placing** 4000.00

Total quantity of work item : **Performance rate : 666.667 M2/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	**Unit**	**Qty**	**Rate**	**Cost/Unit**	**Title**	**Qty**	**UF**	**Indexed Hourly Cost**	**Total Hourly Cost**	**Equipment Type**	**Qty**	**UF**	**Rental rate hrly**	**Rental rate Total**
Asphalt hot mix	m3	0.05	3349.61	167.48	Construction Foreman I	1	1	84.95	84.95	Asphalt Paver (5-6 m)	1	1	830.22	830.22
AC Mix Haul	m3	1	35.22	35.22	Equip. operator II	3	1	75.14	225.43	Roller, 6t	2	1	277.42	554.84
					St.Eq. operator II	1	1	64.25	64.25	Roller, Pneumatic	2	1	651.93	1303.87
					Equip. operator I	2	1	66.98	133.95	Water Truck 6x4	1	1	480.00	480.00
					Helper II	2	1.0	34.15	68.30	Power broom	1	1.00	247.87	247.87
					Labourer I	6	1	34.15	204.91					
				0.00										
Total				202.70	**Total**				781.80	**Total**				3416.80

A = Material Unit Cost 202.70 Birr/m 2 B = Manpower Unit Cost : 1.17 Birr/m2 C = Equipment Unit Cost : 5 Birr/m2

Direct cost of work item =A+B+C= **209.00** Birr/m2

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **282.15** Birr/m2

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

7.5% Mix

Detailed break down of work item
unit prices

Project : **Thesis** 1.35

Work Item : **Asphalt concrete production** 200.00

Total quantity of work item : **Performance rate : 33.333** M3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
Bitumen 60/70	Ton	0.1272	21000.0	2,671.20	St.Eq. operator II	1	1	64.25	64.25	Asphalt plant (150 Ton/hr)	1	1.00	12838.49	12838.49
19mm Aggregate for surfacing	m3	0.1590	160.00	25.4	Equip. operator II	1	1.5	75.14	112.72	Loader, Wheel	2	1.00	625.00	1250.00
10mm Aggregate for surfacing	m3	0.7660	200.00	153.2	Helper II	1	1.0	34.15	34.15	Welding machine	1	0.75	19.83	14.87
Filler for surfacing	m3	0.0000	300.00	0.0	Labourer I	4	1	34.15	136.61					
Marble	m3	0.075	12.23	0.9	Mechanic I	1	1	43.56	43.56					
					Electrician I	1	1	43.56	43.56					
					welder	1.00	1.00	35	35.39					
Total				2850.76	**Total**				434.85	**Total**				14103.36

A = Material Unit Cost 2,850.76 Birr/m3   B = Manpower Unit Cost : 13.05 Birr/m3   C = Equipment Unit Cost : 423 Birr/m3

Direct cost of work item =A+B+C= 3,286.90 Birr/m3

Remark

*Each bareel(drum) contains 210 kg of bitumen.

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Asphalt Plant is assumed to be located near to Crusher site

Detailed break down of work item

unit prices

Project : **Thesis** 1.35

Work Item : **AC Mix Hauling**

Total quantity of work item :

Cap.	12 m^3
Av Dist.	17 km
Av. Spd	35 km/h
for L&UnL	8 min

Performance rate : 300 M^3/day

50.00 M^3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Equip. operator I	3	1	66.98	200.93	Dump Truck 6x4	3	1	520.00	1560.00
Total				0.00	Total				200.93	Total				1560.00

A = Material Unit Cost 0.00 Birr/m^3 B = Manpower Unit Cost : 4.02 Birr/m3 C = Equipment Unit Cost : 31 Birr/m^3

Direct cost of work item =A+B+C= **35.22** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **47.55** Birr/m^3

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed break down of work item

unit prices

Project :			**Thesis**												1.35
Work Item :	**Item 64.01**		**Asphalt concrete placing**									4000.00			
Total quantity of work item :										**Performance rate :**		**666.667 M2/hr**			
Material Cost					**Labor cost**					**Equipment cost**					
Material Type	**Unit**	**Qty**	**Rate**	**Cost/Unit**	**Title**	**Qty**	**UF**	**Indexed Hourly Cost**	**Total Hourly Cost**	**Equipment Type**	**Qty**	**UF**	**Rental rate**		
													hrly	**Total**	
Asphalt hot mix	m3	0.05	3286.90	164.35	Construction Foreman I	1	1	84.95	84.95	Asphalt Paver (5-6 m)	1	1	830.22	830.22	
AC Mix Haul	m3	1	35.22	35.22	Equip. operator II	3	1	75.14	225.43	Roller, 6t	2	1	277.42	554.84	
					St.Eq. operator II	1	1	64.25	64.25	Roller, Pneumatic	2	1	651.93	1303.87	
					Equip. operator I	2	1	66.98	133.95	Water Truck 6x4	1	1	480.00	480.00	
					Helper II	2	1.0	34.15	68.30	Power broom	1	1.00	247.87	247.87	
					Labourer I	6	1	34.15	204.91						
				0.00											
Total				199.56	**Total**				781.80	**Total**				3416.80	

A = Material Unit Cost 199.56 Birr/m 2 B = Manpower Unit Cost : 1.17 Birr/m2 C = Equipment Unit Cost : 5 Birr/m2

Direct cost of work item =A+B+C= **205.86** Birr/m2

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **277.91** Birr/m2

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item