JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

PARTIAL REPLACEMENT OF FILTER CAKE AS A FILLER IN HOT MIX ASPHALT

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

By: Buzunesh Gutu

July, 2021

Jimma, Ethiopia

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By: Buzunesh Gutu

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Co-advisor: Engr. Salem H/Kiristos (MSc)

July, 2021

Jimma, Ethiopia

DECLARATION

I, the undersigned, student declare that the thesis entitled: **“Partial replacement of filter cake as a filler in hot mix asphalt”** is my original work, and has not been presented by any other person for an award of a degree in this or any other University.

Buzunesh Gutu ______________ ______________

Name Signature Date

As Master’s Research Advisors, we have reviewed and approved for examination, the research entitled as **“Partial replacement of filter cake as a filler in hot mix asphalt.”** which is done by **Buzunesh Gutu** under our guidance.

Dr. Fekadu Fufa ______________ ______________

Main Advisor Signature Date

Engr. Salem H/Kiristos, (MSc) ______________ ______________

Co-advisor Signature Date

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ABSTRACT

The road pavement construction industry of consumes a large amount of virgin aggregate and Solid waste material has impacts on environmental problem. Therefore, this investigation aims to explore the suitability of filter cake powder as a filler in hot mix asphalt. FCP is taken from alum factory from awash melkasa town. The study used purposive method of sampling materials. Marshall mix design method was used for designing both conventional and filter cake powder mixtures. For conventional four percent of bitumen content (4.3,4.8,5.3 and 5.8%) and three crushed stone filler content 5.5,6.5 and 7.5% were used to determine optimum bitumen content and optimum filler content. Optimum bitumen content and optimum filler content was used to prepare Marshall Specimen with mixture of filter cake by replacement 0,10,20,30,40 and 50%. Marshall Immersion test method was used to determine tensile strength ratio of both fillers (conventional and filter cake) to evaluate Moisture susceptibility of the mix. The results show that adding filter cake by partially in hot mix asphalt improves its mechanical properties. The optimum filter cake ratio gives the maximum stability of HMA is at 30% FCP. The values of stability, flow, bulk specific gravity, voids filled with asphalt, air voids and voids filled in mineral aggregates at 30% optimum filter cake powder content were, 11.49 kN, 3.21 mm,2.253 g/cm3, 72.7%, 3.84%, and 14.06%, respectively. While the 0,10,20,40 and 50% FCP fulfill the requirements of Ethiopian Road Authority and Asphalt Institute standard specifications. Marshall Immersion test resulted, tensile strength ratio was 83.6 and 90.2% for mix with fully crushed stone dust and replaced filter cake at 30% respectively. Result showed that resistance of moisture induced damage of filter cake is higher than crushed stone dust filler in hot mix asphalt. This study concluded, all the mixes with partial replacement of filter cake has significant effect on performance of hot mix asphalt concrete production. Therefore, based on this study, filter cake powder can be considered as an alternative to conventional filler in hot mix asphalt. The amounts of waste filter cake can be removed from factory and significantly environmental damage can be reduced.

Key words: *Filter cake, Hot mix asphalt, Marshal properties, and Moisture susceptibility of asphalt.*

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ACRONYMS

AASHTO	American Association of State Highway and Transport Officials
AC	Asphalt Concrete
Alum	Aluminum Sulfate
AMASSAF	Awash Melkasa Aluminum Sulfate and Sulfuric Acid
ASTM	American Society for Testing and Materials
Bc	Bitumen Content
BS	British Standard
CSD	Crushed Stone Dust
ERA	Ethiopia Road Authority
FCP	Filter Cake Powder
HMA	Hot Mix asphalt
HMA	Hot mix Asphalt
ITS	Indirect Tensile Strength
JIT	Jimma Institute of Technology
NP	Non-Plastic
OBC	Optimum Bitumen Content
OFC	Optimum Filler Content
TSR	Tensile Strength Ratio
Wt	Weight
WFC	Waste Filter Cake

CHAPTER ONE

INTRODUCTION

1.1 Back ground

Flexible pavements are one the major part of global road network, which comprises of hot mix asphalt concrete mixes as their wearing course. Hot mix asphalt, concrete is composed of aggregate, air voids and asphalt binder. The mineral aggregate includes coarse, fine particles and filler in asphalt paving mixtures. The various sizes of mineral aggregate are used stability by forming skeleton to resist traffic load and act as a structural frame work. Hot mix asphalt contains aggregate 90-95% by weight and 75% up to 85% by volume of mineral aggregate. Whereas asphalt provides as a binding as well as provide durability to asphalt mixes. (Choudharya, 2020). The mixture of coarse aggregate, fine aggregate, filler and asphalt binder hot mixed in an asphalt plant machine and then hot lay to form the surface course of a flexible pavement according to specification guideline to withstand traffic load. The properties of asphalt concrete depend on; the quality of its components (asphalt binder and aggregates), mix proportions and construction process (Asphalt institute., 2014) .The qualities required of aggregates are described in terms of shape, hardness, durability, cleanliness and bitumen affinity. Asphalt is a dark brown to black cementitious material in which predominating constituents are bitumen, which occur in nature or is obtained in petroleum processing. (Abebu, 2019). which consist of finely divided mineral matter such as rock dust including limestone dust, hydrated lime, cement, or other suitable mineral matter.

Many researches have been studied on filler in HMA, filler is the finest portion of aggregate which passes through a particular sieve (0.075 mm united states standard). Mineral filler has two important roles in hot mix asphalt, the first important is to fill the voids between course and fine aggregates; hence, density and stability layers can be obtained from the mixture this facilitate improvements in the performance of the pavement (Saltan, et al., 2015). The second role of filler is to provide more contact points between aggregates, Bitumen cover large surface area, stiffer contact points can be generated with the aggregates. Mostly, crushed stone dust has been utilized in hot mix asphalt as mineral filler. Currently, there is not enough availability of natural resources due to increases in civil infrastructures, making it crucial to find an alternative to these. Recycling fillers from the industrial sector is preferable as it is environmentally friendly as well as economically preferable. Hence, Filler in HMA have a lot of benefits like filling the voids in the aggregate by reducing the voids in the mixture, decrease moisture sensitivity, improving the bond of aggregate and asphalt concrete, increase the stiffness, workability, durability and long-term characteristics of HMA (Dulaimi, et al.,2020).

In highway engineering works, various byproducts/wastes have been used for several purpose amongst which are as a replacement of filler and stabilization of soil. Currently due to an increase in environmental impact of waste from industry and inflation in cost of pavement materials, various researches were investigated in replacing conventional fillers (hydrated lime, stone dust and cement) with alternative environmentally friendly materials. Numerous researchers have studied the performance of asphalt mixes incorporated with wastes fillers like: bagasse ash (Zainudin,Z.,et al., 2016) ,biomass ashes (Tahami,et al., 2018), calcium carbide (Dulaimi et al.,2020), glass powder (Jony ,et al., 2011), ceramic dust, coal waste dust (Cai et al., 2019),Aluminum sludge (Tameem, 2019) and etc. They found out that at different percentage of bitumen and filler content, the stability, flow, voids in mixed aggregates, air void, bulk specific gravity and void filled by bitumen in the mix is evaluated with the standard specification. The results enhance that the byproduct replacement or mixes make the better in hot mix asphalt. In this study solid waste from Aluminum sulfate filter cake is considered as filler. Aluminum sulphate [$(Al_2SO_4)_3$]is an essential water treatment chemical that is used as coagulant in purification of water in Ethiopia. Filter cake is one of the major wastes generated from aluminum sulfate factory during concentration stage of aluminum sulfate extraction process. It is the sludge remaining after extraction has been processed. After wasted from factory it is dried on the field after few days it becomes as a form of powder. Awash melkasa Aluminum sulfate and sulfuric acid share company (AMASSASC) produces aluminum sulfate 13,600 tons per annual (Awash melkasa alluminum sulphate and sulphuric acid share company, 2000).Generally, filer cake contains useful chemical compounds such as silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3), Iron oxide (Fe_2O_3) which are the main components of cement.

Therefore, in this study the partial replacement of filter cake as filler in asphalt concrete mix was investigated. The performance properties of mixes containing filter cake were evaluated by preparing laboratory samples with different percentages of the primary conventionally used crushed stone dust filler were replaced with the filter cake waste and Marshal Stability, flow, and volumetric properties evaluated by the method of Marshall mix design and filter cake on indirect tensile strength was determined.

1.2 Statement of the problem

Flexible pavement is the preferred type pavement structure around the world. 95% of the world's roads are made of this type of pavement (flexible pavement), this flexible pavement uses bituminous mixes which is cheaper as compared to rigid pavement. (Shanbara, et al., 2018) . Flexible pavement mixes comprise asphalt binder, mineral aggregates and filler. Looking to the material constituents of asphalt pavement. i.e. Portland cement (hydrated lime), bitumen and aggregate, they are very much expensive due to increases in civil infrastructures, especially for developing country like Ethiopia. Among the ingredient of asphalt concrete, cement is the second costly construction material next to bitumen. (Alemu, 2019). Thus, it is mandatory to find an alternative filler material for replacing conventional filler in asphalt concrete. Industrial wastes materials are often less expensive than the virgin materials they replace and use, this waste makes good economic sense for project owner and contractors. Re using wasted solid from industry will contribute in minimizing the area of landfills, disposing of waste material and saving the natural resources by reducing the demand of raw materials. (Karacasu, et al., 2014).

Generally, the main advantages of the re-use of industrial waste (by-products) are used to reduce manufacturing cost of conventional filler used in HMA, minimizing the landfill, the protection of the environment and the positive economic effects. Therefore, Application of filter cake powder from aluminum sulfate as a partial replacement in hot mix asphalt concrete production is the alternative one that reduces economic and environmental impacts. Thus, this study was considered by this intension.

1.3 Research Question

1.What are the effect of partial replacement of filter cake on marshal properties of HMA?
2.What is the optimum content of filter cake in HMA?
3.What is the effect of filter cake powder on moisture susceptibility of asphalt?

1.4 Objectives

1.4.1 General objective

The Purpose of the study is to evaluate the partial replacement of filter cake powder as a filler in hot mix asphalt.

1.4.2 Specific objectives

The Specific objectives of the study are;

1. To investigate the effect of partial replacement of filter cake on marshal properties of HMA.
2. To determine the optimum content of filter cake in HMA.
3. To evaluate the effect of filter cake powder on moisture susceptibility of asphalt.

1.5 Significance of the study

This study is proposed to evaluate the suitability of solid waste powder from alum (filter cake) as filler in HMA. The significance is,

- Reduce environmental risks (impacts) of filter cake waste around factory and minimize consumption of natural material (conventional filler) used in road construction industry.
- Reducing the amount of waste materials and the area of land used for landfill.
- The road construction industry (ERA) will be beneficial from the study finding as a basis for selection of alternative asphalt pavement construction materials.
- Both clients and contractors will be enforced to reuse of wasted material from factory. Since the shortage of standard material would face and delayed construction project.

- The findings of the study will help for researcher as a reference for further investigation regarding the suitability of FCP from allum factory as filler in HMA mixture.

Therefore, using Filter cake powder for improving engineering properties of the asphalt concrete is an environmental risk resolution in Ethiopia.

1.6 Scope of the study

The scope of the study was filter cake powder on hot mix asphalt (HMA) to determine Marshall properties and moisture susceptibility. Marshal properties such as; voids in mineral aggregate (VMA), Air voids (Va), void filled with asphalt (VFA), bulk specific gravity, flow and stability. asphalt concrete was produced from FCP and CSD, Bitumen and mineral aggregate. The mixtures were prepared using filter cake powder with different amount. The results produced in this research were based on the Marshal Mix design procedures. Generally, the mixture was designed and evaluated based on Marshall Mix design procedures.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Asphalt concrete is basically a mixture of natural raw materials: Aggregate (coarse, intermediate and fine aggregates) and bitumen binder hot mixed in an asphalt plant and then hot lay to form the surface course of flexible pavement. In addition to these standard materials from natural sources, some additives in the mixture was incorporated to influence the performance of the product (Asphalt Institute, 1994). Component of Flexible asphalt pavement layers blended at pre specified weight proportions determined from the mix design method. The blend of mineral filler and asphalt binder forms the asphalt mastic destined to play a major role in controlling the mechanical behavior of its mixture (Roman, 2017).

Hot mix asphalt concrete is the most popular pavement material utilized for binder and wearing course on the world. mineral filler is one of the components of HMA. Mineral fillers are added to asphalt paving mixes to modify asphalt concrete mix. The filler form filler-asphalt mastic which has binder consistency characteristics that improve the bond between asphalt cement and aggregate the other function of aggregate in the mixture is fill the voids between course aggregate and fine aggregate and also fills the void between bitumen and aggregate as well as increasing the density, stability, and toughness of the compacted mix. (AL-Saffar, 2013). In construction of asphalt concrete pavement fine sand, cement, hydrated lime, crushed stone dust and marble dust are using as a conventional filler material. However, these materials are not sufficiently obtained and also requires high cost to allocate as filler in asphalt concrete production and leads consume of raw materials.

Thus, this study was concentrated on the Marshal properties of hot mix asphalt mixtures prepared using partial replacement of filter cake on hot mix asphalt concrete. In this chapter, previous study conducted on components of HMA, effect of mineral filler on HMA and moisture susceptibility was reviewed. This chapter discuses about the literature reviewed that has been found much more related with the title of this thesis.

2.1.1 Types of pavement

Rigid pavements: Those which are surfaced with Portland cement concrete (PCC). These types of pavements are called "rigid" because they are substantially stiffer than flexible pavements due to PCC's high stiffness (Chandra and Delhi, 2020).

Flexible pavements: Flexible asphalt pavement layers consist of mineral filler, coarse and fine aggregates all cemented by the asphalt binder and blended at pre specified weight proportions determined from the mix design method (Roman, 2017).Those which are surfaced with bituminous (asphalt binder) materials. These types of pavements are called "flexible" since the total pavement structure "bends" or "deflects" due to traffic load and the weather. A flexible pavement structure is generally composed of several layers of materials. They comprise several layers of carefully selected materials designed to gradually distribute loads from the pavement surface to the layer's sub grade. The design ensures that the load transmitted to each successive layer does not exceed the layer's load bearing capacity (Bradshaw, et al, 2019).

Typical flexible pavement layer: Typical flexible pavement consists, surface course, binder course, Base course, sub base course, and sub grade (ERA, 2002).

Surface course: - This is the top layer and the layer that comes in contact with traffic that's which contains superior quality materials. It may be composed of one or several different HMA sub layers. HMA is a mixture aggregates and asphalt binder. Generally, this surface prevents the penetration of surface water to the base course; provides a smooth, well-bonded surface free from loose particles resists the stresses caused by aircraft loads.

Asphalt binder course: Binder course is an HMA course between the wearing course and stabilized base course on existing pavement. Its purpose is to distribute traffic loads to the others (base course, sub base, sub grade); so that stresses transmitted to the pavement foundation will not result in permanent deformation of that layer. Additionally, it facilitates the construction of the surface layer.

Base course layer: The base coarse serves as the principal structural component of the flexible pavement and it distributes the imposed wheel load to the pavement foundation, the sub-base and the subgrade. The quality of the Base course is a function of its composition, physical properties, and compaction of the material. It may be composed of crushed stone, and other untreated or stabilized materials.

Sub-base course layer: The sub-base course is the layer of material exists between the subgrade and the base course. It provides structural support and improves drainage from the subgrade in the pavement structure. Moreover, if the base course is opening graded the sub-base course with more fines can serve as filler between subgrade and the base course (Blades, *et a.l,* 2004). Its functions like the base course i.e. it provides additional help to the base and the upper layers in distributing the load, but the material requirements for the sub-base are not as strict as those for the base course since the sub-base is subjected to lower load stresses.

Subgrade: The natural soil surface is the boundary between the base soil (subgrade) and the upper layers of pavement. The in-place soils, called the subgrade, serve as the foundation that supports the road. After removal of topsoil and other organic materials, the subgrade may be stabilized by compaction alone, or by compaction after mixing in asphalt emulsion, foamed asphalt, Portland cement, lime, or other proprietary stabilizing materials. The properties and characteristics of the subgrade soil determine the pavement thickness needed to carry the expected traffic loads.

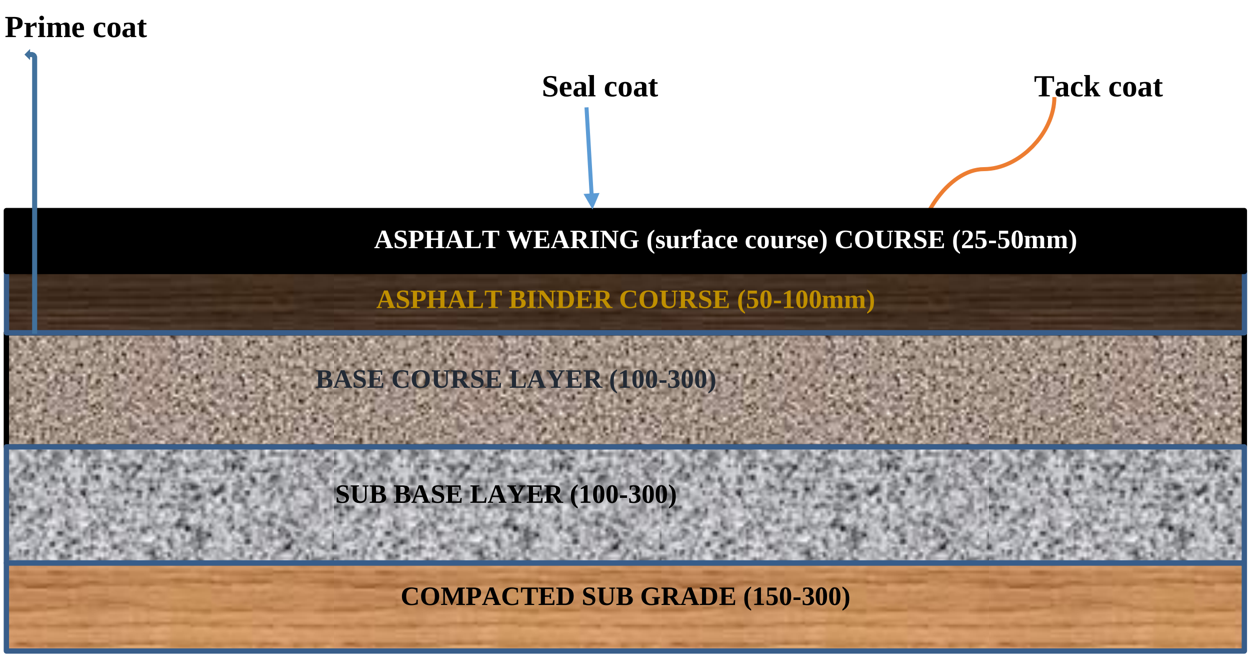


Figure 2-1: Typical Cross section of Flexible Pavement. (Chandra,2020)

2. 2 Asphalt concrete (bituminous mixtures)

Asphalt concrete is a composite material commonly used to surface roads, parking lots, airports, and the core of embankment dams. Asphalt mixtures have been used in pavement construction since the beginning of the twentieth century. It consists of mineral aggregate bound together with asphalt, laid in layers, and compacted. The terms asphalt (or asphaltic) concrete, bituminous asphalt concrete, and bituminous mixture are typically used only in engineering and construction documents, which define concrete as any composite material composed of mineral aggregate adhered with a binder.

According to (Daniel and Stacks , 2019..),Hot Mix Asphalt is the mixture of aggregate (gravel and sand) and asphalt cement (binder) that require heating before installation. HMA is heated production facility to temperature 300ºF to 350ºF before being shipped and laid at the job site**.** Produced by heat the asphalt binder to decrease its viscosity and drying the aggregate to remove moisture from its prior to mixing. Mixing is generally performed with the aggregate at about 300 °F (roughly 150 °C to 110°C) and for bitumen 325 °F (155°C to 160 °C).

Warm Mix Asphalt is manufactured at temperatures between 200 and 250 ºF. It is the generic name of technologies that allow the producers of hot-mix asphalt pavement material to lower the temperatures at which the material is mixed and placed on the road. Because of less energy is needed to heat the asphalt mix, less fuel is needed to produce WMA. Fuel consumption during WMA manufacturing is typically reduced by 20percent. Additionally, WMA saves time in production as well as in surfacing roads. Because WMA makes compaction easier, cost savings are achieved by reducing time and labor spent compacting the mix (Woszuk,et al., 2019). Cold mix asphalt is the most affordable option on the market, because it doesn’t need heat during the process. It is typically used to repair cracks over an inch wide and potholes when the outside temperature is too cold for hot mix asphalt. This is produced by emulsifying the asphalt in water with an emulsifying agent prior to mixing with the aggregate. While in its emulsified state, the asphalt is less viscous and the mixture is easy to work and compact. The emulsion will break after enough water evaporates and the cold mix will, ideally, take on the properties of an HMA pavement. Cold mix is commonly used as a patching material and on lesser trafficked service roads.

2.3 Hot Mix Asphalt

Hot mix asphalt is a mixture of asphalt binder and graded mineral aggregate, mixed at an elevated temperature 160 C^0 ±5 °C, it is the highest quality among the different types and compacted to form a relatively dense pavement layer of binder and aggregates. After plant mixing is complete, the hot - mix is transported to the paving site and spread with a paving machine is a partially - compacted layer to uniform, smooth surface It has many different names: Asphaltic concrete, plant mix, bituminous mix, bituminous concrete, bitumen aggregate and many others**.**

2.3.1 Performance Concerns of hot mix asphalt

(Daniel and Stacks , 2019..) Researchers Utilized the performance of asphalt concrete mix, where some of fractional fine aggregate is substituted with different percentages the mixed gives the following characteristics,

- ✓ ***Resistance to Permanent Deformation*****:** is defined as the resistance of the paving mix to deformation under traffic load. The true test will come during high summer temperatures under slow or standing truck traffic that soften the binder and, as a result, the loads will be predominantly carried by the aggregate structure, so resistance to permanent deformation is controlled through improved aggregate properties (crushed faces), proper gradation, and proper asphalt grade and content.
- ✓ **Durability:** The mix must contain sufficient asphalt cement to ensure an adequate film thickness around the aggregate particles. This helps to minimize the hardening and aging of the asphalt binder during both production and while in service. Sufficient asphalt binder content will also help ensure adequate compaction in the field, keeping air voids within a range that minimizes *permeability* and *aging.*
- ✓ ***Resistance to Moisture Damage (Stripping)*****.** Loss (inadequacy) of adhesion between the aggregate surface and the asphalt binder is often related to properties of the aggregates. The assumption on the part of the mix designer should be that moisture will eventually find its way into the pavement structure; therefore, mixtures used at any level within the

pavement structure should be designed to resist stripping by using anti-stripping agents (filler).

- ✓ **Workability:** Workability Mixes that can be adequately compacted under laboratory conditions may not be easily compacted in the field. Adjustments may need to be made to the mix design to ensure the mix can be properly placed in the field without sacrificing performance.
- ✓ ***Resistance to Low Temperature (Thermal) Cracking****:* Cooler regions of Texas are particularly confronted with thermal cracking concerns. Thermal cracking is mitigated by the selection of an asphalt binder with the proper low temperature properties.
- ✓ ***Skid Resistance.*** This is a concern for surface mixtures that must have sufficient resistance to skidding, particularly under wet weather conditions. Aggregate properties such as texture, shape, size, and resistance to polish are all factors related to skid resistance.

2.4 Components of Hot mix asphalt

(ERA, 2013), HMA is normally composed of aggregate (course, fine and filler) and bitumen. The types of HMA most frequently used in tropical countries are manufactured in an asphalt plant by hot-mixing appropriate proportions of the following materials:

(i) Coarse aggregate, defined as material having particles larger than 2.36mm;

(ii) Fine aggregate, defined as material having particles less than 2.36mm and larger than 0.075mm;

(iii) Filler, defined as material having particle sizes less than 0.075mm, which may originate from fines in the aggregate or be added in the form of cement, lime or ground rock; and

(iv) A paving grade bitumen with viscosity characteristics appropriate for the type of HMA, the climate and loading conditions.

(Benert,2005), Hot mix asphalt is the mixture of Asphalt Binder, Mineral Aggregate, Air, and Optional Modifiers/Additives, so hot mix asphalt is described by volume.

- Binder Modifiers/Additives (e.g., polymers, elastomers, fibers, rubber)

- Aggregate Modifiers/Additives (e.g., lime, granulated rubber, anti-strip agents)

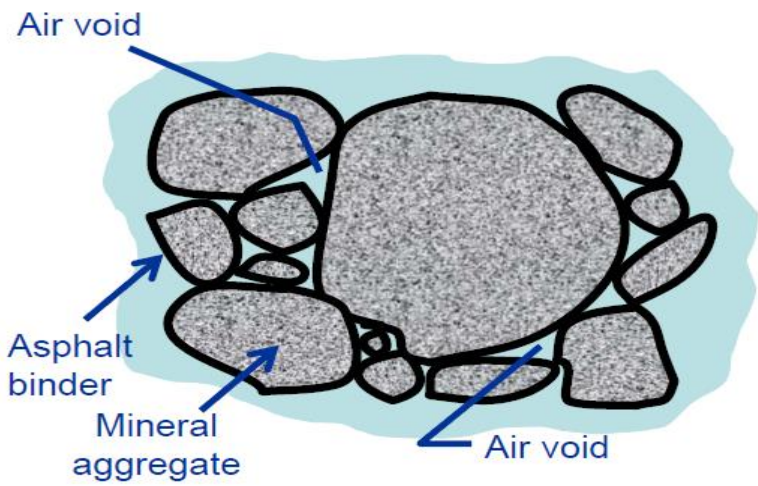


Fig 2.2 Component of hot mix asphalt (Sources; https://www.state.nj.us/transportation/eng/pavement/pdf/HotMix0709.pdf)

Thus, hot mix asphalt is a composite of aggregate (course, fine and filler) and bitumen binder to provide durability and resistance of cracking of fatigue and rutting.

2.4.1 Bitumen

Bitumen is the liquid binder that holds asphalt together. Bitumen is defined as dark brown material, at room temperature is slightly solid. If it heated to a certain temperature, it becomes fluid or soft and hardened and bond in place (thermoplastic character) when the temperatures start to decrease. So that it can wrap the aggregate particles at the time of making HMA or can penetrate the pores of aggregate when it sprays or mixed on hot mix asphalt process (ERA 2013), Only,4%-10% of total weight or 10%-15% of total volume, but bitumen is an expensive material. (Tahmoorian and Samali , 2018)

Bitumen Characteristics

Generally, asphalt binder has the following five 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: When one takes a thread of an asphalt binder from a sample and stretches or elongates it, it has the ability to return to a length close to its original length eventually. This property is referred to as the elastic character of bitumen

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. At higher temperatures and slow loading condition there is more flow or plastic behavior, while at a lower temperature, bitumen tends to be stiff and elastic. At intermediate temperatures it tends to be a combination of the two. (Anderson, 1995).

2.4.2 Mineral aggregate

Mineral aggregate is defined as a porous and thus can absorb water and asphalt to a variable degree. Normally the aggregates used for wearing courses should be produced from crushed sound rock, the un weathered rock of natural gravels. Gravels could be crushed to provide at least two fractured surfaces on individual particles, be angular, as well as not too much flaky. the ratio of water to asphalt absorption varies with different aggregate. By taking this variation into account, there are three various methods of measuring aggregate specific gravity, namely ASTM bulk, ASTM apparent, and effective specific gravities. However, for any mix design, the accuracy of specific gravity measurement is very important and recommended to be determined to four significant figures in order to avoid an error in the air void value (Asphalt institute, 1993).graded aggregates are mixed with the asphalt binder to form HMA pavements. Aggregates are the principal load-supporting components of HMA pavement. The shear strength is mainly dependent on the internal friction provided by the aggregate. Here, the shape and texture of the aggregate play important role in providing the required interlock. Cubical, rough textured aggregate provide more shear resistance than rounded, smooth-textured aggregate. The internal friction provides the ability of aggregate to interlock and create a strong mass that is able to resist the applied traffic load. Aggregates are the dominant ingredient of HMA, by making up 80% to 85 % of the mixture by volume and roughly 95 percent of the mixture by weight (Tayh, 2011). Coarse aggregate is type of aggregate which is retained on 2.36mm sieve diameter according to asphalt institute. It will crush according manually and will bring to the size 25.0 mm or less. Fine aggregate is Aggregate passing through 2.36 mm sieve and retained on 0.075 mm sieve is selected as fine aggregate it should be free from impurity. Generally, aggregates that are larger than 4.75 mm are categorized as coarse aggregate, whereas those smaller than 4.75 mm are fine aggregates. Conventional filler is dust finer than 0.075 mm size sieve will use as filler in the bituminous mixture for comparison and economical point of view. The stability of asphalt mixture is affected by several features such as gradation of aggregate, type and amount of filler material (Sutradhar, 2015).

2.4.2.1 Aggregate gradation for HMA

Gradation helps to determine almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, and resistance to moisture damage in the mixture. This indicates that aggregate gradation plays a key role in the asphalt mixture's properties and further significantly influences the performance of HMA. Gradation is usually measured by a sieve analysis starting from 25mm to 0. 075.According to researcher (Brown & Basset, 1990) .Increasing the size of maximum aggregate in asphalt mixture will produce a quality mix with respect to creep performance of HMA, resilient modulus, and tensile strength but however, it will not have a significant effect on the Marshall stability. But a higher flow value observed for the mixes having larger size aggregate gradation.

An aggregate's particle size distribution is one of the most influential characteristics in hot-mix asphalt the particle size distribution of aggregate was chosen, a blend of aggregate particles suitable for dense asphalt concrete surfacing must produce a mix which, have sufficient VMA to accommodate enough bitumen to make it workable during construction (ERA ,2013). Be durable in service and Retain a minimum of 3 percent VIM after secondary compaction by traffic. The choice of particle size distribution of aggregate based on local experience or the recommendations of the Asphalt Institute. Particle size distributions recommended by the Asphalt Institute for binder course layers are shown in table 2.2 whereas Table 2.1 indicates international gradation limits for the asphalt binder course (ASTM D3515).

Table 2.1 Particle Size Distributions for AC Wearing Courses (ASTM 3515)

Sieve No	Sieve size(mm)	Percentage by weight passing	
		Min	Max
1”	25	100	100
¾	19	90	100
½	12.5	71	88
¾	9.5	56	80
No.4	4.75	35	65
No.8	2.36	23	49
No.16	1.18	15	37
No.30	0.6	10	28
No.50	0.3	5	19
No.100	0.15	4	13
No.200	0.0075	2	8
Bitumen content (%)		4	10

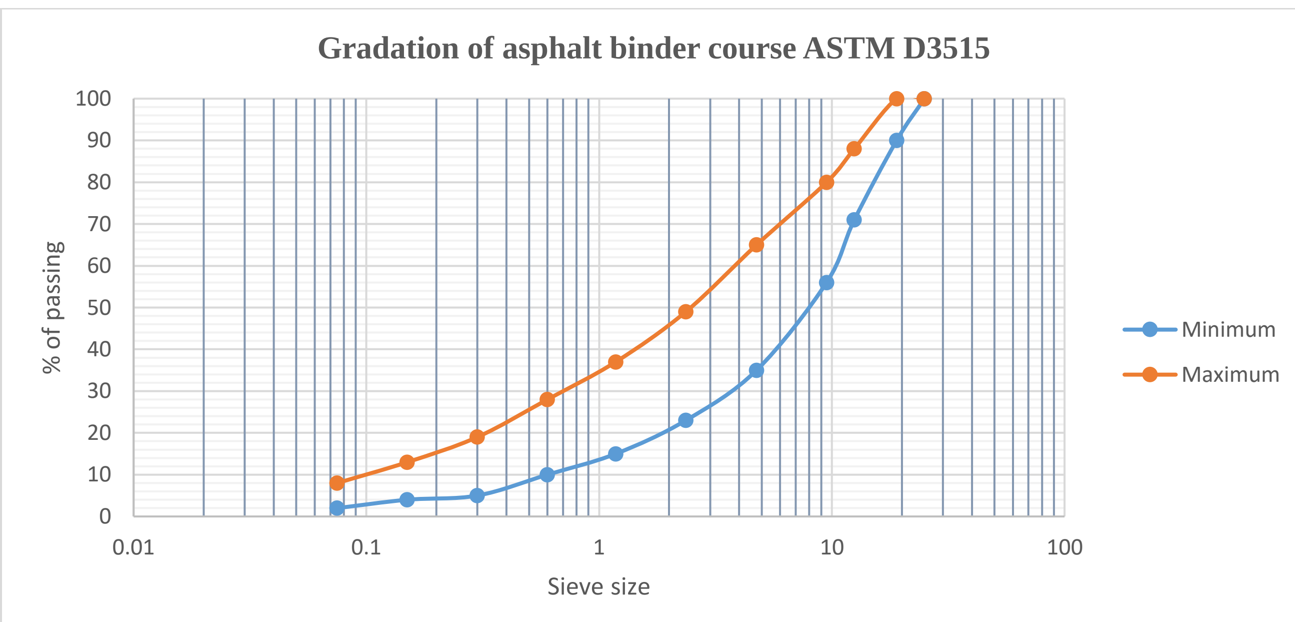


Figure 2.3 Gradation of asphalt binder course (ASTM 3515)

Particle size distribution of aggregate for 19,12.5 and 9.5 nominal maximum stone recommended by Asphalt Institute is present in the following table.

Table.2.2 Particle Size Distributions for AC Wearing Courses (Asphalt institution of Hot Mix Asphalt Pavement Manual, series No.22, 2nd edition)

Mix Designation and Nominal Maximum Size of Aggregate						
Sieve Size		1 1/2in (37.5mm)	1in (25.0 mm)	3/4 in (19.0mm)	1/2 in (12.5mm)	3/8in (9.5 mm)
2"	50 mm	100	......	......	......	......
1 1/2"	37.5 mm	90 to100	100	......	......	......
1"	25.0 mm	......	90 to100	100	......	......
3/4"	19.0 mm	56 to 80	......	90 to100	100	......
1/2"	12.5 mm	......	56 to 80	......	90 to 100	100
3/8'	9.5 mm	......	......	56 to 80	......	90 to100
No.4	4.75 mm	23 to 53	29 to 59	35 to 65	44 to 74	55 to 85
No.8	2.36 mm	15 to 41	19 to 45	23 to 49	28 to 58	32 to 67
No. 16	1.18 mm	......	......	......	......	......
No.30	0.6 mm	......	......	......	......	......
No.50	0.3 mm	4 to 16	5 to 17	5 to 19	5 to 21	7 to 23
No. 100	0.15 mm	......	......	......	......	......
No. 200	0.075 mm	0 to 5	1 to 7	2 to 8	2 to 10	2 to 10
Bitumen, Weight % of Total Mixture		3 to 8	3 to 9	4 to 10	4 to 11	5 to 12

2.4.3 Filler

Mineral fillers can be crushed rock fines, Portland cemen0t and hydrated lime to assist the adhesion between bitumen and aggregate, course and fine aggregate and fill up the void in the mixture. It should be the inert material which passes 75micron sieve or 0.075mm. The presence of filler in the asphalt-concrete mixture is even more important because of its possible interaction with asphalt. As well as, it also affects several on HMA properties such as workability, decreasing moisture sensitivity, increasing stiffness, durability, fatigue behavior and long-term characteristics of HMA (Dalloul, 2013).

2.4.3.1 Effects of Mineral Filler on Marshall Properties

Several studies demonstrated that the properties of the asphalt concrete are strongly influenced by the material passing the 0.075 mm sieve (filler). Addition of mineral fillers has dual purpose when added to asphalt mixtures Mineral fillers are added to asphalt paving mixtures to fill voids in the aggregate and reduce the voids in the mixture. Mineral filler that is finer than the asphalt film thickness mixed with asphalt binder forms a mortar or mastic and contributes to improved stiffening of mix. This modification to the binder that may take place due to addition of mineral fillers could affect asphalt mixture properties such as rutting and cracking. The other portion of fillers larger than the asphalt film thickness behave as a mineral aggregate and serves to fill the voids between aggregate particles, thereby increasing the density and strength of the compacted mixture. In general, filler have various purposes among which, they fill voids and hence reduce optimum asphalt content and increase stability, meet specifications for aggregate gradation, and improve bond between asphalt cement and aggregate, Thus the filler in hot mix asphalt has many roles. (Bouchard, 1992)

Performance of hot mix asphalt can be affected by many factors such as material property, traffic load, environmental condition, paving aging process, design and way of construction. (Feyissa, 2001) According to (Choudhary,et al., 2016) , effect of fillers in the asphalt mix are satisfying the aggregate gradation specification and influencing the strength and volumetric requirements of the mix and reducing optimum bitumen content and material cost of the mix. Effect of filler is not only the ability of mixes, resist permanent deformation at high temperatures but also cracking resistance at low temperatures and fatigue life at intermediate temperatures.

(Nathem, 2013) ,studied the effect of different filler types on performance properties of asphalt paving , filler is used to evaluate the resistance to plastic flow using Marshall Stiffness test and low temperature cracking and temperature susceptibly using indirect tensile strength test in addition to study retained strength test and resistance to permanent deformation by using indirect tensile creep test .The results indicate that filler type has a great effect on the cohesion of the mix where such types shows high indirect tensile strength values with respect to other types of filler at different test temperature.

Thus, the effect of filler on hot mix asphalt has dual roles, by filling the void in the mix and mineral aggregates, it increases the stability, toughness, and density of asphalt mixes by minimizing percentage of bitumen content which is absorbed by void in mineral aggregate. increases the density and strength of the compacted mixes. improves bond between asphalt cement and aggregates. fillers reduce the voids asphalt mixes. As filler content increases, the brittleness and tendency to crack in service also increase.

2.4.3.2 Effects of waste material on Marshall Properties

Due to increased highway construction amount of natural resources is consumed, especially mineral aggregates derived from quarry extraction. recycling of industrial waste materials in pavement preservation, maintenance and reconstruction has been a very popular way to achieve sustainable solutions. Billions of tons of waste materials have been produced annually around the world. pavement applications are the best ways to consume these wastes by reducing the landfills, saving raw materials extracted from the environment and consuming lower amounts of energy (Choudhary, et al., 2018). Recycling the waste materials as fillers by using them in place of conventional fillers looks very effective for sustainability practices in pavement construction. different wastes contain high content of SiO_2 in mineral filler does not disqualify the material and has not negative influence on the quality of asphalt mixture (Kaya and Yıldırım , 2020). For this reason, it will always be desirable to find affordable and environmentally friendly alternative materials in asphalt mixtures. The current literature shows that the use of waste materials in pavement designs has been studied for many years. Especially, the waste materials used as fillers include tire-derived fuel, fly ash, calcium carbide, rice husk ash recycled waste lime, ceramic powder, construction and demolition waste, brick, sewage sludge powder, cement kiln dust, kaolin residue, waste glass powder and etc. the studies on the use of waste materials in asphalt mixes indicates that they are very valuable to meet the required standard specification. Thus, the use of industrial and by products wastes as replacement of mineral fillers in asphalt mixtures to enhance the properties and performance of asphalt concrete pavements.

solid waste from aluminum sulphate factory (filter cake) is one of the solid wasted material used as a filler in HMA. Filter cake recycling used in researches as concrete arenas against Sitophilus zeamais (Tadesse and Subramanyam, 2018), Simultaneous removal of nitrate and phosphate (Berkessa,et al., 2019) and as cement replacement in concrete. Alum One of the main chemicals used in water treatment process used as coagulant thus forming clean water. Aluminum sulfate

[$Al_2(SO_4)_3$] or alum is one of the chemicals that are required both in industry and water treatment companies.

Aluminum sulphate is produced from row material such as kaolin, bauxite and aluminum hydroxide, but awash melkasa aluminum sulfate chemical is produced from kaolin material. Which available in Oromia region at guji zone in shakiso. Kaolin is a rock mass composed of clay material with a low iron content. Classified as non-metallic mineral, kaolin and primer clay soil types that has a coarse-grained soil, fragile, is plastic when moist, harden when dry and heated. In general, the color is grayish white, but sometime can be found as yellow, orange and reddish gray color. Kaolin chemically formulated $Al_2O_3.2SiO_2.2H_2O$ as minerals. (Saisa, et al., 2020).kaolin is mixed with sulfuric acid to extract alum, Kaolin and sulfuric acid was poured into beaker glass while simultaneously stirred to reach perfect mixing and the solution temperature. While constant sulfuric acid concentration. Aluminum sulfate extracted during the reaction and filter cake is removed as waste material

According to the literature, there is no clear statistical information on the amount of filter cake powder. Chemical composition of filter cake Powder demonstrated by the below table. Chemical composition of filter cake powder has no significant effect on mixture adhesion.

Table 2.3: Chemical composition of filter cake powder (AMASSASC, 2020).

Property	%, wt.
Kaolin	8.883
SiO_2	39.391
Fe_2O_3	0.059
$Al(OH)_3$	0.872
$CaSO_4$	0.194
$Al_2(SO_4)_3$	1.778
$Fe_2(SO_4)_3$	0.023
$MgSO_4$	0.008
Na_2SO_4	0.007
K_2SO_4	0.005
H_2SO_4	0.001
H_2O	48.178

2.5 Marshall Mix Design Method

The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method.is the resistance to plastic deformation of a compacted cylindrical specimen of the asphalt mixes is measured when the specimen is loaded diametrically at a deformation rate of 50 mm per minute. The Marshall stability of the mix is defined as the maximum load carried by the test specimen at a standard test temperature of 60°C. The temperature 60°C represents the weakest condition for a bituminous pavement. The flow value was the deformation that the test specimen undergoes during loading up to the maximum load. Flow was measured in (0.25) mm units with rate of loading 0.05 in /min. Marshall Test, Stability, flow, bulk density, void ratio can have determined. (Naglaa K. and Rashwan, 2016) There are two major features of the Marshall method of designing mixes namely, density–voids analysis and stability-flow test. Strength is measured in terms of the 'Marshall's Stability' of the mix following the specification. ASTM D 1559 (2004), which is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60°C. The flexibility is measured in terms of the 'flow value' which is measured by the change in diameter of the sample in the direction of load application between the start of loading and at the time of maximum load. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading. The associated plastic flow of specimen at material failure is called flow value. The density- voids analysis is done using the volumetric properties of the mix (Kennedy,a nd Roberts, 2000).

2.5.1 Mechanical properties specifications for asphalt binder course

Specifications for the mechanical properties of asphalt binder course are reviewed. Specification of asphalt binder course is established on different manuals such as ASTM, AASHTO, and etc. Also, in our country on manuals of Ethiopian Road Authority (ERA) and Addis Ababa City Road Authority (AACRA). Two specifications for the mechanical properties of asphalt binder course are reviewed. First is the Ethiopian Road Authority (ERA) local projects specification. Second is the Asphalt Institute specification (AIS). Below Table summarizes these specifications.

Table 2.4 Mechanical properties local specifications for asphalt binder course (ERA, Pavement Design Manual, 2002).

Total traffic (10^6 ESA)	Light traffic wearing and binder course HMA		Medium traffic wearing and binder course HMA		Heavy Traffic wearing &binder coarse HMA	
Traffic class	T1, T2, T3		T4, T5, T6		T7 $T8	
	Min	Max	Min	Max	Min	Max
No. of blows of marshal compaction	2*35		2*50		2*75	
Stability (KN)	3.5	_	6.0	_	7.0	_
Flow(mm)	2		2		2	4
Percent air voids	3	5	3	5	3	5
Percent VFA	70	80	65	78	65	75
%VMA (for 4% VTM & Nom. Max, Particle size of 19mm)	13	-	13	-	13	-

Table 2.5 Mechanical properties international specifications for asphalt binder course *(Asphalt Institute, 1996)*

Marshal method mix criteria	Light Traffic		Medium Traffic		Traffic Heavy	
	Surface- Base		Surface-Base		Surface-Base	
	Min	Max	Min	Max	Min	Max
Compaction number of blows each end of specimen	35		50		75	
Stability (N at 60ºC)	3336	-	5338	-	8006	-
Flow(mm)	2	4.5	2	4	2	3.5
Percent air voids	3	5	3	5	3	5
Percent VFA	70	80	65	78	65	75
Percent VMA	13	-	13	-	13	-

.

2.6 Indirect tensile strength

This test method covers measurement of the loss of compressive strength resulting from the action of water on compacted bituminous mixtures containing asphalt cement. Premature failure may result due to stripping when critical environmental conditions act together with poor and/or incompatible materials and traffic. Moisture susceptibility is a problem that typically leads to the stripping of the asphalt binder from the aggregate, and this stripping makes an asphalt concrete mixture ravel and disintegrate. Moisture damage can occur due to three main mechanisms: loss of cohesion of the asphalt film, failure of the adhesion between the aggregate particles and the asphalt film, and degradation of aggregate particles due to freezing (Brown and Kandhal, 2001). Moisture damage in asphalt mixtures refers to loss in strength and durability due to the presence of water. Many variables affect the amount of moisture damage which occurs in an asphalt concrete mixture. Some of these are related to the materials forming hot mix asphalt such as aggregate and asphalt binder. Others are related to mixture design and construction (air void level, film thickness, permeability and drainage), environmental factors, traffic conditions and type, and properties of the additives. The presence of moisture, combined with the repeated action of traffic, accelerates damage to the asphalt pavement (Tahami,et al., 2018).

The retained stability value for asphalt mixes prepared with Rice husk ash and Slag fillers satisfy the minimum retained stability requirement of AASHTO standard specification (75%). It indicates that mixes containing Stone dust, Slag, and Rice husk ash as filler had good resistance to moisture-induced damages (Akter and Hossain,2017). 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 (Roberts, et al., 1996). Among the test methods mentioned: Boiling test (ASTM D 3625), Static-immersion test (AASHTO T 182), Lottman test (NCHRP 246), Modified Lottman Test (AASHTO T283) and Marshall Immersion test (ASTM D1075). All of these tests have weaknesses that result in an ongoing search for a better moisture susceptibility test. small variations in key HMA parameters such as air voids (Va), can substantially affect test results. for this study Marshall Immersion test (ASTM D1075) was selected. Marshall Immersion test (ASTM D1075): - Six Marshall specimen is prepared for this test. The specimens are grouped into two groups, each with three specimens. Group 1 is the control specimen maintained in air temperature of 25ºC while group 2 is immersed in water for 24 hrs at 60°c or at 49°c for four days. Group 2 specimen is then transferred to 25°c water bath for 2hrs and compressive strength of both groups is determined. Index of retained strength is determined just like TSR in Lottman test. A value of at least 70% is specified as a requirement in many agencies. Super pave design guideline requires a minimum of 80% retained strength.

Therefore, Moisture is a key factor in the deterioration of asphalt pavement. Factors that influence moisture damage include aggregate, asphalt binder, type of mix, weather and environmental effects, and pavement subsurface drainage. Moisture susceptibility of a mix can be determined by indirect tensile strength test. The indirect tensile strength (ITS) test involves loading a cylindrical specimen with a compressive load along two opposite sides in the diametrical plane. maximum load is recorded and is used to calculate the indirect tensile strength. Indirect tensile strength of a given specimen was determined using ASTM D 3967or ASTM 6931 (Getnet., 2018).The higher TSR value typically indicates that the mixture will perform well with a good resistance to moisture damage. The higher the TSR value, the lesser will be the strength reduction by the water soaking condition. Results from the moisture susceptibility test may be used to predict the potential for long-term stripping and to evaluate anti-stripping additives, which are added to the asphalt binder, aggregate, or HMA mixture to help prevent stripping.

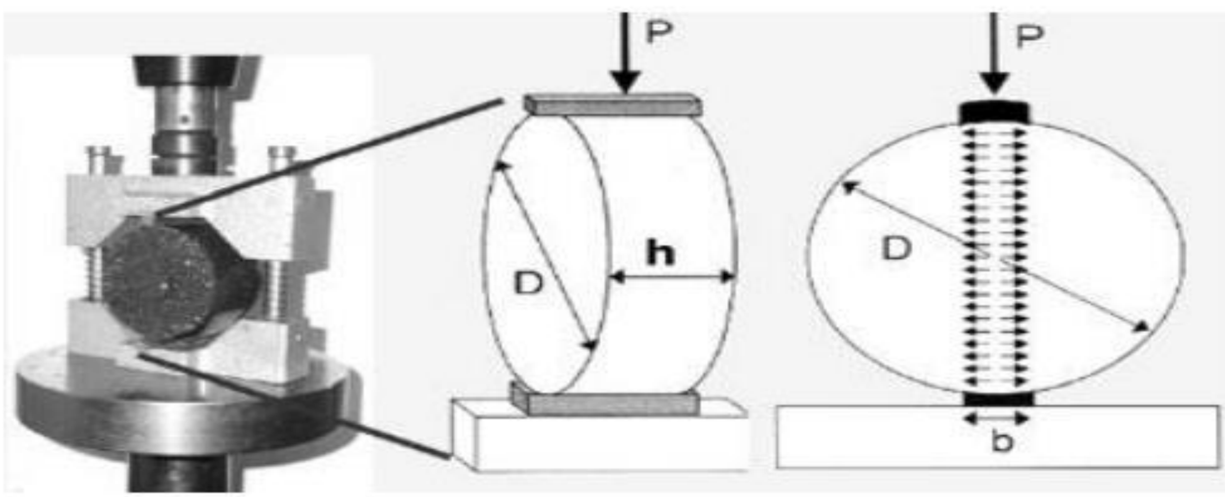


Figure 2.4 A typical ITS apparatus (Getnet,2018)

2.7 Aluminum Sulfate Factory in Ethiopia

Awash-Melkassa Aluminum Sulfate Factory (AMAlumF) is located at Awash-Melkassa, 18kms from Adama town, 105km from the capital city of AA, on the way to Assela, which is at absolute 1600m above sea level. Aluminum sulfate and Sulfuric acid factory is the only chemical industry in Ethiopian producing sulfuric acid and aluminum sulfate. Awash Melkassa Aluminum Sulfate and Sulfuric Acid Share Company (AMASSASC) is the biggest chemical factory in the country. The company first started since,1991 G.C by dirge government. Later on, one-year company was built by Poland government with the association of dirge government. know, the company is strictly public enterprise solely owned and operated by the federal democratic republic of Ethiopia.

The Alum Factor state-owned company currently produces around 13,600 tons of aluminum sulphate per annual of hydrate aluminum sulphate with the concentration of 17% aluminum oxide as a final packing product and 17,000 tons of sulfuric acid annually, which are used in the production of leather, car batteries, paper sizing, Dyeing, pharmaceutical, soap modification, tanning, cotton and for water treatment (Tamerat., 2007).

2.8 Summary of the literature review

Generally, this chapter describes the related literature review about what the research was focused on. The review of literature includes basic concepts of flexible pavement and component of hot mix asphalt which includes aggregates and asphalt binder, basic concepts of mineral fillers, the effect of mineral filler in hot mix asphalt and also the effect of waste material on hot mix asphalt. Generally, this chapter was mainly focused on the effects of using non-conventional fillers as an alternative to mostly used conventional filler materials, or the effect of replaced crushed stone dust by partial replacement of filter cake on hot mix asphalt.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Sampling Area

The sampling area for this thesis has been located in Oromia region, East shoa zone at AWASH MELKASA district. The factory Located eastern direction of the country (Ethiopia), 106km faraway from capital city of Addis Abeba, and 18 km from Adama town and on the way of asella. The Awash Melkassa Factory mainly produces Aluminum Sulfate and Sulfuric acid chemicals. The factory is located at latitude of 8°24'42.1"N and longitude 39°20'11.8"E with an elevation of 1539.5m.Source:https://www.google.com/search?q=map+of+awash+melkasa+factory&oq=map+of+awash+melkasa+factory&aqs=chrome.69i57j33i160.21581j0j4&sourceid=chrome&ie=UTF-8

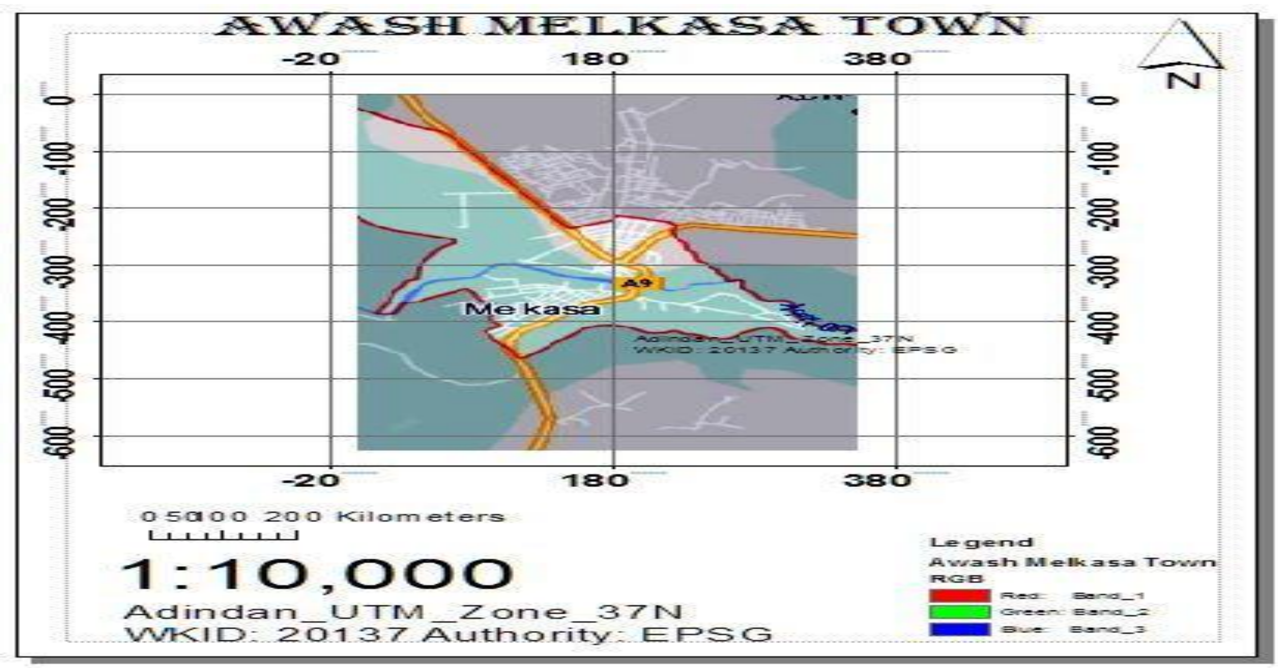


Figure 3.1 Sampling area of filter cake powder

3.2 study design and period

Research was designed to answer the research questions and to meet its objectives based on experimental study and This academicals research study was conducted starting from October 1, 2020 to May 25, 2021 G.C. The first step in this research work was material collection. At this stage, the samples of the hot mix asphalt component materials such as; crushed aggregate, bitumen, and filter cake were collected from different places. The quality of used materials was performed according to specification of AASHTO, ASTM and BS laboratory procedure. In this study; the Marshall mix design method was used to design the HMA mixes. Four different bitumen content between 4.3 - 5.8% by total weight of total mixes by 0.5% increments and three trial different aggregate gradation was used. Mixes was containing 5.5, 6.5 and 7.5% crushed stone dust (conventional) filler. After preparation of the HMA mixes, Marshall stability and flow value were determined. Then volumetric properties of the asphalt mixes were calculated and the Marshall design requirements criteria were checked by the design specification guideline. Waste filter cake from aluminum sulfate factory was used as replacement to replace conventionally used filler (CSD) at 0,10,20,30,40 and 50% by weight of optimum crushed stone dust. Tensile strength ration and moisture sensitivity was performed to determine the ratio between sensitivity of submerged sample in 24 hrs and unsubmerged sample.

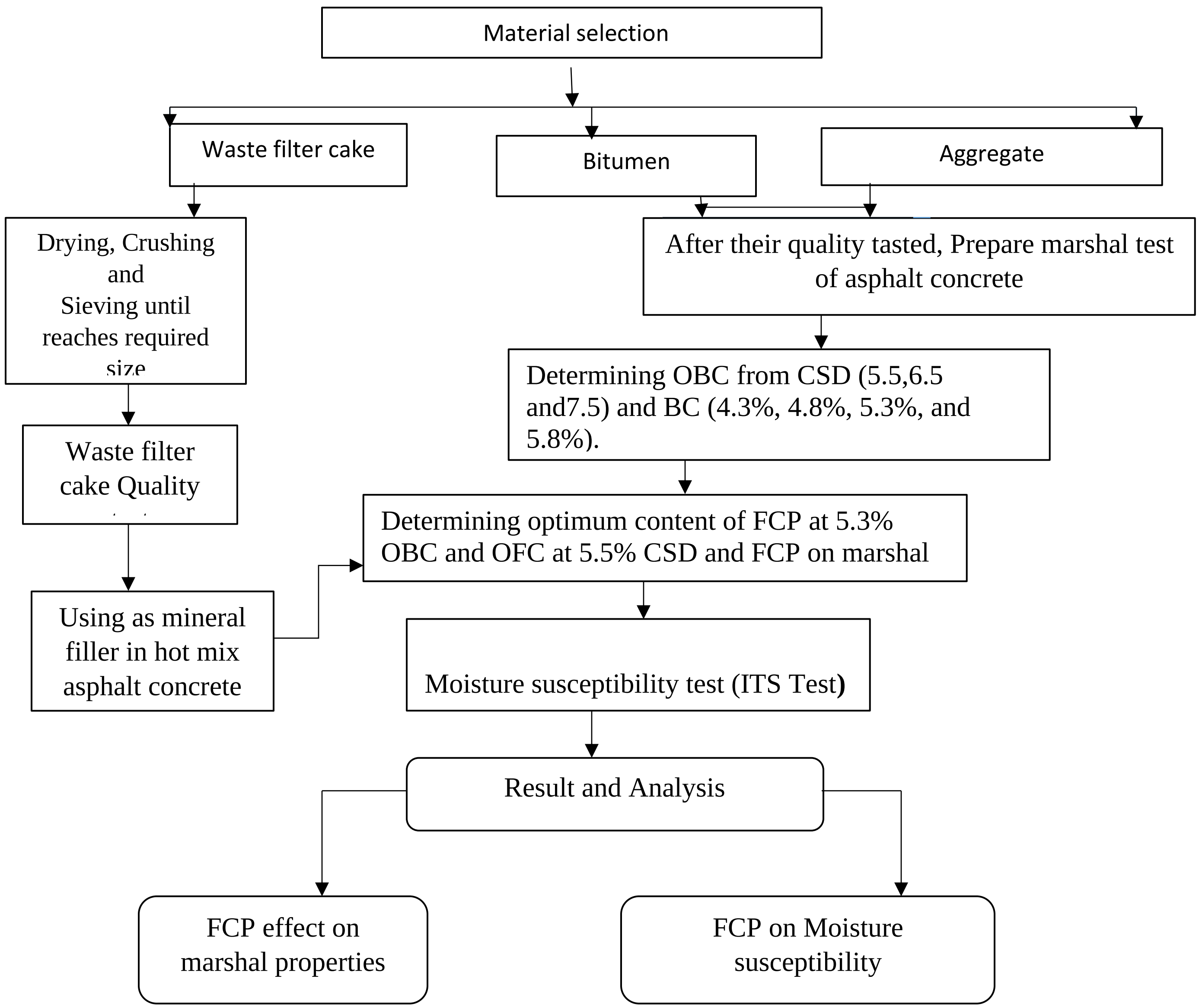


Fig 3.2 Flow chart of experimental work

3.3 Sampling Techniques and Preparation

The Sampling techniques for filter cake powder was Purposive sampling techniques it is a non-probability (purposive) sampling method that is the selection of a group from the population purposefully to get the objective of the study. Representative sample of aggregates was collected manually in accordance with AASHTO T2 methodology for sampling from stockpiles and AASHTO T40 for Sampling Bituminous Materials. The sample taken were prepared properly to ensure the applicable test results accurately by reflecting the true characteristics of the material. The samples obtained from the field in accordance with AASHTO T2 were reduced to the test size be reduced to an appropriate size for testing to determine physical characteristics, such as, sieve analysis, Aggregate crushing value, aggregate impact value and hardness, and etc. accordance to AASHTO T248. Samples were dried to the same size and entered in the oven at 110 ± 5°C according to AASHTO T87 Practice for dry preparation of soil samples. Finally, the sample collected were evaluated for physical test and mechanical analysis.

3.4 Method of data collection

From development of study topic various data were collected for accomplishment of this study (to achieve the objective of this study). Data was collected reviewing previous related literature and different international & local standard specification were assessed, according laboratory tests regarding the preparation of HMA mixtures. Generally, two type sources of data were obtained in this study. Those are primary and secondary data.

3.4.1 Primary Data

The primary source of data was collected through laboratory tests on used material, on marshal property test and from ITS test.

3.4.2 Secondary Data

The secondary source of data was obtained from the related previous studies, national and international pavement design manual and standard, and scientific researches.

3.5 Study variables

3.5.1 Dependent variable

The dependent variable in this study was the partial replacement of filter cake as a filler on HMA.

3.5.2 Independent variable

The independent variables of the study were, Properties of used material, the amount of filter cake added to the mix (OFC), Marshall Mix properties and moisture susceptibility.

3.6 Data Processing and Analysis

Data Processing and analysis was considered on this study it was shown and explained using tables and graphs. Analysis of data was based on the outstanding and presented specification suggested by ASTM, BS, AASHTO, asphalt institute and ERA manual.

3.7 Material collection

To attain the objective of this research, component of hot mix asphalt such as aggregate, bitumen and filler were collected. The origin of the aggregate used in this study was collected from Ethiopian Road Construction Corporation (ERCC) quarry, which located approximately 80 km from Jimma town, namely the Deneba site, as well as bitumen grade 60/70, also obtained from Deneba Quarry Site. Filter cake used as replacement in this study was taken from aluminum sulfate product factory located in Awash Melkasa 105 km far from Addis Abeba.

3.7.1 Filler

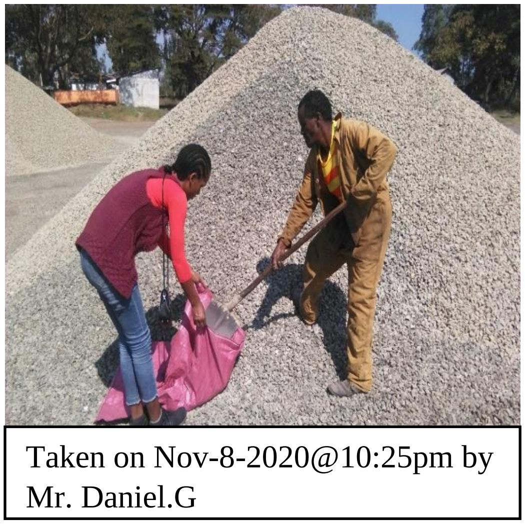
Filler was selected as the main reasons to conduct this research. The filler is one of the ingredients of asphalt mixture and material which passes 0.075mm sieve size so, filler passes 0.075 mm sieve size was taken. In this study CSD (as control) and FCP (as replacement) were used as mineral filler in the preparation of HMA. For CSD and FCP tests of, specific gravity, plastic index and gradation parameters were determined as specification limits. plasticity index was determined using cone penetrometer according to BS 1377: Part 2 1990, whereas an apparent specific gravity was performed according to ASTM D 854 and Gradation according to ASTM D242.Thus, before using waste filter cake powder as filler in hot mix asphalt that was crushed up to required size and gradation filler was determined. Particle size of filler which passes on 0.075 mm was taken and putted in the oven for drying.

3.7.2. Aggregates

Aggregates for HMA are usually classified by size; coarse aggregates, fine aggregates, or mineral fillers. Aggregate gradation, surface texture, shape, resistance to impact, and crushing loads have a vital role in the HMA performance. Aggregate should be clean and free from organic impurity. AASHTO, ASTM and BS standards are taken for the methods of tests of aggregate for road construction for dense graded asphalt. Generally, various quality tests were conducted on the physical properties of the aggregate used in this study in order to determine the suitability for wearing course material. Those are Sieve analysis, Aggregate gradation, Specific gravity and water absorption, Los Angles abrasion, Flakiness index, Aggregate crushing value, Aggregate impact Value tests were performed for aggregates quality test. All the test results are presented in Table 4.2.

3.7.3. Bitumen

Bitumen provides durability to the mix; it is the most commonly used material in pavement construction today. Because of its high engineering performance capabilities such as elasticity, adhesive and water resistance. Bitumen grade 60/70 was used in this research. 60/80 it is the common type of asphalt that widely utilized in most of the road projects in tropical areas. The physical properties of asphalt binder were determined according to the procedure specified by AASHTO and ASTM standards. A series of tests including penetration, specific gravity, softening point, ductility, and flash point were determined. The test requirement of ERA specifications and result are presented in table 4.3.



a) Taking Aggregate

(b) taking waste filter cake powder

Fig.3.3 Used Material collection

3.8 Laboratory test procedures

This study is based on laboratory testing to evaluate the suitability of filter cake in HMA. the main procedure to achieve study goals. All the testing is conducted using equipment and devices available in the laboratories of Jimma institute of technology. Laboratory tests are divided into several stages, which begin with the property's evaluation of the used materials: such as aggregates, bitumen, and mineral filer (filter cake and crushed stone dust). Sieve analysis is carried out for each aggregate type to obtain wearing course gradation curve used to prepare asphalt mix. After that, Asphalt mixes with different bitumen contents 4.3-5.8% by increment of 0.5% and different filler 5.5,6.5, and 7.5%. three samples were prepared for each bitumen contents. marshal test is performed to obtain optimum bitumen and These samples were tested under marshal stability test in order to determine the optimum filler content for asphalt mixes based on maximum Marshall stability. Step by step optimum bitumen contents were determined for each of the three filler contents. Then after, the value of the optimum bitumen content determined and the selected filler content is used to prepare the filler replacement in asphalt mixes by 0,10,20,30,40 and 50 % FCP. Then marshal test were utilized to evaluate the properties of these replaced mixes on marshal test and optimum content of FCP. The effect of filter cake on moisture sensitivity was evaluated. Finally, laboratory test results are obtained and analyzed compared with ERA, AASHTO, ASTM, and BS standards.

3.9 Marshal mix design

Marshal Mix Design method was used to determine the optimum asphalt content and evaluate the stability and flow of the mixtures in the laboratory. The total mix designs to be carried out in the Marshall test were 3 (types of filler content) × 12(samples for four different bitumen * the three samples for each bitumen) = 36 specimens were prepared in order to determine OBC (prepare trial specimen for three different gradations with varying asphalt contents and fillers). These Marshall specimens were subjected to Marshall Stability and flow test as per ASTM D 1559 or ASTM D 6927 standards. Marshall Stability parameters such as stability, flow, air void, void filled with asphalt, and void in mineral aggregates were determined and evaluated following ERA (2013) standards After all the data was collected, plots were developed in order to indicate the relationship between the various volumetric properties and obtained optimum bitumen content. The OBC and optimum filler content were determined based on the maximum stability of the mixtures.by keeping OBC and constant designed aggregate gradation crushed obtained optimum crushed stone dust was replaced by filter cake from 0 to 50% at 10% increments. Thus, a total of 18 specimens were prepared to obtain optimum filter cake on marshal properties.

3.9.1 Gradation of aggregate

When selecting an aggregate for an HMA mixtures the initial focus is on the aggregate gradation. To produce an asphalt concrete Aggregate was combined in different percentages in order to get the proper size gradation within the allowable limits according to ASTM 3515 standard specifications by using mathematical trial method. This mathematical trial method was depending on suggested specification limits different aggregate passing on each sieve size for each trial was performed. The percentage of each aggregate size is to be computed and compared to limits of ASTM specifications.1200 gm weight of aggregate is taken from each size to produce compacted bituminous mix specimens. Gradation for mix designation for wearing course nominal maximum aggregate size was 19mm. If the calculated aggregate gradation is within the allowable limits, no further adjustments need to be made; if not, an adjustment in the proportions must be made and the calculations must be repeated.

3.9.2 preparation and testing of marshal specimen

In order to prepare hot mix asphalt specimen, the aggregate with proper gradation (Corse aggregate, fine and filler) are thoroughly dried (moisture loosed) to full fill the requirement of the standards. Aggregate are weighted at 1200g specimens (well blended aggregate and filler) put in the oven with 102 mm diameter and 63.5 mm height molds for 24 hrs, at temperature of 160C⁰ to 170 C⁰. As shown in figure below 3.4. A bitumen was heated at temperature of 140 ⁰C to 170 ⁰C for the mixture of each trial. Starting from the first trial, different bitumen was added in required quantity starting from 4.3%-5.8 % by 0.5% increment (4.3, 4.8, 5.3, and 5.8) by weight of total mix mixed with three different fillers (5.5%,6.5% and 7.5%) then the heated aggregates and bitumen are thoroughly mixed for two minutes until a homogenous mix is obtained. The mixture was then placed in the preheated mold as shown in figure 3.4 and compacted by a Marshall compactor. Hammer had having a weight of 4.5 kg and a free fall of 45.7 cm giving 75 blows on each side of the specimen for heavy traffic according to marshal test procedure standardized by ASTM D1559. The compacted specimens were leaved at room temperature for 24 hrs. The specimen was removed from molds by using extrusion jack as shown by the figure in appendix. Three samples were prepared for each bitumen contents and also, for each Trial gradation to get an average value of bulk specific gravity, flow, marshal stability and other volumetric properties. The specimens were then weighed dry in air, in water and saturated surface dry weight of each three-specimen result were obtained to calculate the bulk specific gravity of the specimen. The specimen was also tested for stability and flow, before that the specimens to be tested are immersed in controlled water bath at temperature of 60˚C for 30 minutes. After sample is immersed in required water temperature, they are tested for marshal stability and flow in accordance with ASTM D 1559. Theoretical Maximum Specific Gravity of the Mix (Gmm) were determined using ASTM D 2041-95 and compacted Bulk Specific Gravity using ASTM D1188-96 and ASTM D3203-94 was used to estimate Void in the Mix (VIM) or air voids. To determine the optimum bitumen content, the relationships between binder content and the properties of mixtures such as stability, flow, bulk specific gravity, voids filled with bitumen (VFB), void in mineral aggregate (VMA) and void in mix (VIM) or air void for control were established.

a) b)

Fig 3.4 Prepared Samples before mixing a**)** weighing sample for Marshall mix, and **b)** pre heated aggregate and mold. (Taken: on 08 Dec 2020 By Mr Jalela.W and Labeta.B)

3.9.3 Optimum Binder Content (OBC) Determination

OBC is the main intention of the Marshall Mix design, determined OBC should satisfy the required values of design parameters. If those parameters are outside standard, the mixture should be redesigned. Optimum bitumen content of the HMA mixture can be determined by two methods those are a) by asphalt institute method and b) NAPA (National Asphalt Pavement Association) Procedure method). NAPA (National Asphalt Pavement Association) Procedure method is commonly used. In this study, the optimum bitumen content was determined by NAPA procedure method.

NAPA (National Asphalt Pavement Association) Procedure method which they suggest preparing the plots contained in figure 4.2 to 4.4 Then the optimum bitumen content is determined by:

1. The bitumen content which corresponds to the specification's median air void content (4 percent typically) of the specification. At This the optimum bitumen content determined.
2. The optimum bitumen content is then used to determine the value for Marshall stability, VMA, flow, bulk specific gravity and VFA from each of the plots.
3. Compare each of these values against the specification values for that property and if all are within the specification range, the bitumen content at 4 percent air voids is optimum

bitumen content. If any of these properties is outside the specification range, the mixture should be redesigned.

3.10 Replacement of crushed stone by filter cake

After determining optimum bitumen content and optimum conventional filler proportion together with design aggregate. We constant Determined OBC, OFC and aggregate designed. The next step would be replacing the crushed stone dust by filter cake powder filler. In this study, the optimum bitumen content and optimum filler content of the control mix was 5.3% and 5.5% respectively. Filter cake powder should be dried to exclude its moisture content, passed sieve no. 200 mesh (0.075mm) and Blended by 0-50% with crushed stone dust filler and aggregate. Heated at 160C⁰ to 170 C⁰ temperature and mixed with bitumen. The specimen preparation procedures for replacement is the same as specimen preparation for control. Marshall Mix specimens were produced for each filler proportion, and the average values of bulk specific gravity, Marshall Stability, flow and volumetric properties (air void, void in mineral aggregate, void filled with asphalt) were determined and checked against specification range. (Jendia, 2000), A set of controls is recommended in order to obtain the optimum content that produce an asphalt mix with the best marshal properties. optimum filler content Asphalt mix is obtained as the basis of control mix. Optimum filler content should satisfy the Maximum stability, Maximum bulk density and % Air void within the allowed range of specifications.

Then Optimum content of filter cake were obtained the mixes having maximum stability, maximum bulk density and air void within the allowed range of specifications. Therefore, the effects of replacing the primary used filler with the filter cake partially on marshal stability, flow, and volumetric properties of a typical binder course asphalt concrete has been evaluated. A total of 18 Marshall specimen for partial replacement filter cake mixture was prepared, each one of them weighs 1200 gm details are given in *Appendix F4.*

(a) (b)

Figures 3.5 Marshal specimens with different content of filter cake powder a) Prepared sample with FCP before mixture and b) compacted specimen with constant bitumen content. (Taken on 08 Feb 2021 by Mr.Giza.A and Mokonon.B).

3.11 Volumetric Properties of HMA Mixes

The important volumetric properties of bituminous mixtures that are to be considered include the theoretical maximum specific gravity (Gmm), the bulk specific gravity (Gmb), percentage of voids in total mix (VTM), percentage volume of bitumen (Vb), percentage void in mineral aggregate (VMA) and percentage voids filled with asphalt (VFA). These properties indicate the performance of the mixes in the field. The volume of the mix is affected by; The proportions of the different aggregates and filler and the specific gravity of the different materials. if porous aggregate is present, the amount of asphalt binder is absorbed. (ERA, 2013)

Theoretical Maximum specific gravity (Gmm): Theoretical maximum specific gravity is the ratio of the weight in air of a unit volume of un-compacted bituminous paving mixture to the weight of an equal volume of gas free distilled water at stated temperature. The Gmm of HMA mixture is the specific gravity excluding air void (impermeable material). Thus, theoretically all the air voids eliminated from HMA sample, the combined specific gravity of the remaining aggregate and asphalt binder would be the theoretical maximum specific gravity. The maximum specific gravity (Gmm) at different bitumen contents was measured to calculate air voids. According to AASHTO

T 209 and ASTM D 2041.Gmm is critical in HMA characteristic because it is used to calculate percent air void in compacted hot mix asphalt. The theoretical maximum specific gravity of a mix is defined as:

$$Gmm=\frac{A}{A-(C-B)} \quad \text{......(1)}$$

Where, Gmm= Maximum Theoretical Specific Gravity is calculated as per ASTM D 2041

A = Mass of the dry sample in air, g, B = Mass of Jar Filled with Water, g, and C = Mass of Jar Filled with Water + Sample, g

Bulk specific gravity of compacted specimen (Gmb): is the ratio of mass of compacted specimen in air to volume of permeable material (including both permeable and impermeable voids). Bulk specific gravity is the specific gravity of a sample when the aggregate volume includes all pores in the sample. The bulk specific gravity is determined for the compacted specimens after extruded from the mold first measure the thickness of specimen then taking the weight in air, weight in water and saturated surface dry. Normally, this value is utilized to determine the mass per unit volume of the compacted mixture in water. In this study, the bulk specific gravity of compacted mixtures was determined by using saturated surface dry specimen as per AASHTO T 166.The standard bulk specific gravity test is expressed as:

$$Gmb=\frac{A}{B-C} \quad \text{......(2)}$$

Where, A= Mass of the dry specimen in air, g, B= Mass of the saturated surface-dry specimen in air, g, and C= Mass of the specimen in water, g

Percent Air Void in Total Mix (Av): 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. The voids in a compacted mixture are obtained in accordance with ASTM D3203- 94 standard test method. The percentage of air voids in compacted mix (VTM) is the ratio (expressed as a Percentage) between the maximum theoretical specific gravity of the loose asphalt mixes (Gmm) and the bulk density of each compacted specimen (Gmb), and given by:

$$Av=\left(\frac{Gmm-Gmb}{Gmm}\right)*100 \quad \text{......(3)}$$

Where, Av=Air void, Gmm= Theoretical Maximum specific gravity of un compacted and Gmb = Bulk specific gravity of compacted specimen

Void in mineral aggregates (VMA): This is the volume of 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 volume of a sample. The VMA are calculated based on the bulk specified gravity of the aggregates and is expressed as a percentage of the bulk volume of the compacted paving mixture. It is calculated as,

$$VMA=100-\left(\frac{100-Pb}{Gsb}\right)*Gmb \quad \ldots\ldots (4)$$

Where, Gmb= bulk specific gravity of the compacted mixture, Gsb = bulk specific gravity of total aggregate and Pb= bitumen content, percent by mass of total mixture

Void filled with asphalt (VFA): 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. VFA is the ratio (expressed as a percentage) between the volume of the air voids between the coated particles and the void in mineral aggregate, and given by:

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

Where, VFA = Voids filled with asphalt, VMA = Voids in mineral aggregates, and Va = Air voids in compacted mixture.

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

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

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

3.12 Moisture Susceptibility

Presence of water reduces the performance of pavement resistance to moisture damage and may cause sudden failure of flexible pavement. Moisture susceptibility of a mix can be determined by indirect tensile strength test, Marshall Immersion test (ASTM D1075) was used for this study to evaluate HMA against moisture susceptibility. ITS involves loading cylindrical specimen with compressive load along two opposite side in diametrical plane. A total of 12 Marshall Specimens were prepared which is 6 specimens for conventional filler and 6 specimens for filter cake replacement at optimum asphalt binder content 5.3%. specimen prepared with CSD and FCP was divided in to two group. The first group (three sample from CSD and three from FCP) was immersed in a water bath at 60°C, for a period of 24 hours for the conditioned sample. The samples were then removed from the water bath and kept at a temperature of 25°C for a period of 2 hours. The other unconditioned samples were kept at a temperature of 25°C for a period of 2 hours without soaking. These specimens are then attached between two opposite load stripes and are loaded radially half inch wide stainless-steel loading at a speed of 50mm/min and the load at failure is recorded at each case. Then the tensile strength of water conditioned as well as an unconditioned specimen for each mix was determined. Then the tensile strength ratios were calculated as given in ASTM D 6931 using the following equation.

$$TSR = \frac{St(cond)}{St(uncond)} * 100 \quad \text{.......} \quad (1)$$

Where, TSR, Tensile Strength Ratio (%), St (cond), Average tensile Strength of Conditioned Sample (kpa) and St (uncond), Average tensile Strength of Unconditioned Sample (kpa).

Tensile strength (KPa), is

$$St = \frac{2000P}{\pi DT} \quad \text{.......} \quad (2)$$

Where St = tensile strength (kPa), P = Maximum load (N), T = Specimen thickness (mm, and D = Specimen diameter (mm).

3.13 Data Quality management

The quality of the data was ensured during replication of measurement, instrument development and analysis with standard specification. Triplicate measurements were conducted and presented by mean ± standard deviation. To check the accuracy and validity of data verification was carried out. Instrument calibration was checked before any measurement according to standards.

CHAPTER FOUR

RESULT AND DESCUSSION

4.1 Properties of Materials

4.1.1 Physical Properties of Mineral Filler

Table 4.1 shows the gradation of fillers CSD and FCP passing sieve 0.6,0.3 and 0.075 mm according to ASTM D242. apparent specific gravity of CSD and FCP according to ASTM D-854 by using Water Pycnometer method is 2.61 and 2.13 respectively. The specific gravity of FC is lower than specific gravity of the CSD. Both filter cake powder and crushed stone dust are non-plastic, according to ASTM D 242 plastic index of miner filler is less than four. The details of the physical properties of mineral fillers are given in *Appendix A.*

Table 4.1 Physical properties of mineral filler.

Sieve size	Passing (%)		Specification	
	CSD	FCP	ASTM	ERA (2013)
No.30 (0.6 mm)	100	100	100	
No.50 (0.3 mm)	100	96	95 – 100	
No. 200 (0.075)	100	98.8	70 – 100	
PI (Plastic Index)	NP	NP	ASTM D242	<4
Gsa (Apparent specific gravity)	2.61	2.13	ASTM D854	

4.1.2 Mineral Aggregate Physical Property

Table 4.2 shows the Physical property of aggregate used in the asphalt concrete. Such as Los Angeles Abrasion test (LAA), Flakiness Index (FI), aggregate impact value (AIV) and aggregate crushing value (ACV). The obtained value was 11.5,21.6, 6.32 and 14.7 % respectively. Water absorption aggregates is less than 2% indicated that the aggregate has low water absorption with durable and economic mix. It was a useful data for computing the specific gravity of aggregate and voids in asphalt. Similarly, the aggregate crushing value is less than 25% which shows that the aggregate had resistance to crushing under a 400 kN gradually applied compressive load. Flakiness index of Aggregate is less than 35% indicates that used aggregate had good interlocking. Los Angeles Abrasion test was less than 35% which is sufficiently hard to resist the abrasion effect.

Also, the aggregate impact value indicates less than 25% which is aggregate resist sudden impact loading. All the test determined are in the range of Specification requirement of ERA 2013.Therefore Aggregate used for this study are suitable for HMA wearing course, the details of the aggregate physical properties are given in *Appendix C.*

Table 4.2 Aggregate physical properties

Test	Test method	Test result (mm)			Specification requirement as per ERA (2013)
		9.5 to 25	2.36 to 9.5	0.075-2.36	
Bulk dry S. G	AASHTO T84 -95	2.61	2.59	2.63	-
Bulk SSD S. G		2.64	2.63	2.68	-
Apparent S. G		2.71	2.7	2.76	-
Water absorption, (%)	BS 812, part 2	1.29	1.57	1.68	< 2
FI, (%)	BS812, part 105	21.6	-	-	< 35
LAA, (%)	AASHTO T96	11.5	-	-	< 35
AIV, (%)	BS 812, part 112	6.32	-	-	< 25
ACV, (%)	BS812, part 110	14.7	-	-	< 25

4.1.3 Bitumen Property Test

Table 4-3 illustrates asphalt binder property test. penetration, flash point, ductility, softening point, and specific gravity tests are carried out for this study. Penetration test was used to measures resistance to penetration (hardness) of semisolid bitumen at normal temperature (25 ^{o}C). the result is 64.6 mm. Softening point test was 47.2 ^{o}C that was temperature at which bitumen became elastic. Ductility value, flash point and specific gravity was 98.9,325 and 1.018 respectively. Therefore, bitumen used as a binder in HMA was satisfactory and the results are in the range of requirement of ERA 2013 specification. The details of the bitumen physical properties are given in *Appendix D.*

Table 4.3 Bitumen quality test results

Test	Test method	Test result	Specification per ERA (2013)
Penetration@25^{o}C (0.1mm)	AASHTO T 49	64.6	60-70
Ductility@25 ^{o}C (cm)	AASHTO T 51	98.9	Min 50
Softening point (^{o}C)	AASHTO T 53	47.2	46-56
Flash point (^{o}C)	ASTM D 92	325	Min 232

Specific gravity @25⁰C;(gm/cm³)	AASHTO D70-97	1.018	1.01 – 1.06

4.2 Marshal Mix Test Property

4.2.1 Marshal Mix Properties for Conventional Filler

Table 4.5,4.6 and 4.7 indicates the properties of marshal mix at their various bitumen content, (4.3-5.8%), different aggregate gradation and different crushed stone dust filler content (5.5,6.5 and 7.5%). Further details are presented in Appendix F.

4.2.1.1 Gradation of aggregate

Figure 4.1 shows percentage of passing of aggregate at each corresponding sieve size for three different aggregate gradations with 5.5%, 6.5%, and 7.5% filler contents for Asphalt concrete wearing courses. Aggregate gradation used was satisfying the specification guideline. Determined according to ASTM D3515 for 19mm nominal size. Further details are presented in Appendix B.

Table 4.4 Aggregate gradation and specification criteria based on ASTM D3515 for nominal size 19mm for three different fillers (5.5%,6.5% and 7.5%)

Sieve size(mm)	Gradation of three different filler Percentage of passing			Asphalt institute ASTM 3515 specification
	5.5%	6.5%	7.5%	
25	100	100	100	100
19	94	94.5	93.5	90-100
12.5	78.3	77.8	80.5	71-88
9.5	68	67.5	70	56-80
4.75	50	48.5	51	35-65
2.36	34.5	33	37	23-49
1.18	24	25	28	15-37
0.6	17.5	15.7	19	10-28
0.3	11	11.1	13	5-19
0.15	8.5	8.6	8.8	4-13
0.075	5.5	6.5	7.5	2-8

Table shows the final proportion of each aggregate material in asphalt concrete and aggregates gradation curve is found by satisfying ASTM specification for asphalt concrete course gradation. From them aggregate gradation for 5.5% CSD was selected regarding maximum marshal stability.

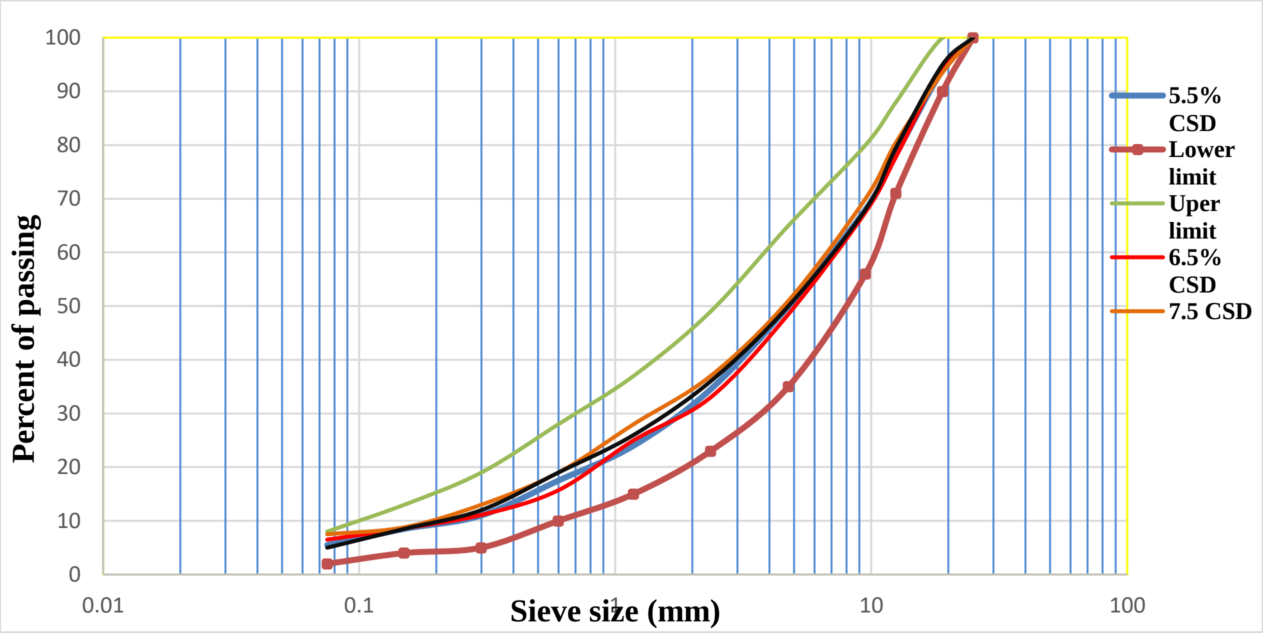


Figure 4.1 Aggregate Gradation Curve

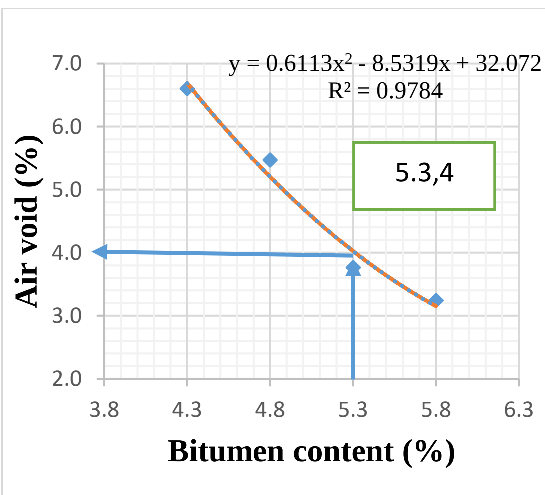
4.2.1.2 Marshal Mix properties for 5.5% CSD

Figure 4.2 shows the relationships between binder content and the marshal properties of mixtures with 5.5% CSD filler. The stability value increases with increasing asphalt content (bitumen) up to a maximum (10.4 kN) after which the stability gradually decreases. This indicates aggregate internal friction was good at the point of used bitumen content due to this their marshal stability become high. VMA in the mixes is decreases with increases of asphalt binder. This is due to increment of weight of bitumen in the mix. Whereas, VFA increases with the increases of asphalt binder and bulk specific gravity of the compacted specimen increases with increasing asphalt binder content. Also flow increases due to asphalt binder increases, it indicates mix became plastic and loss stability. The air void in the mix decreased as bitumen content increases as shown on Figure 4.2. This indicate that as bitumen content increases hot bitumen lubricates the aggregates allowing closer together in which air void decreases hence density increases. Therefore, the result of marshal stability, flow and volumetric properties obtained at OBC 5.3% fulfil ERA (2013) standard specification. The details of the analysis are given in *Appendix F1*.

Table 4.5 Marshal properties of asphalt mixture with 5.5 %Crushed stone dust with different bitumen content by mean and standard deviation form.

% BC	Gmb (g/cm³)	VA (%)	VMA (%)	VFA (%)	Stability (kN)	Flow (mm)
4.3	2.229±0.012	6.6±0.49	14.3±0.45	54.2±2.02	8.45±0.21	2.68±0.20
4.8	2.238±0.014	5.5±0.60	14±0.55	61±2.73	10.82±0.48	3.1±1.01
5.3	2.245±0.002	3.8±0.09	13.7±0.08	72.5±0.51	9.85±0.39	3.18±0.29
5.8	2.249±0.126	3.2±0.54	13.6±0.48	76.2±3.19	8.76±0.09	3.62±0.06

Where, Gmb =compacted bulk specific gravity, AV =air voids, VMA =voids in mineral aggregates, VFA = Voids filled with bitumen, BC= bitumen content.



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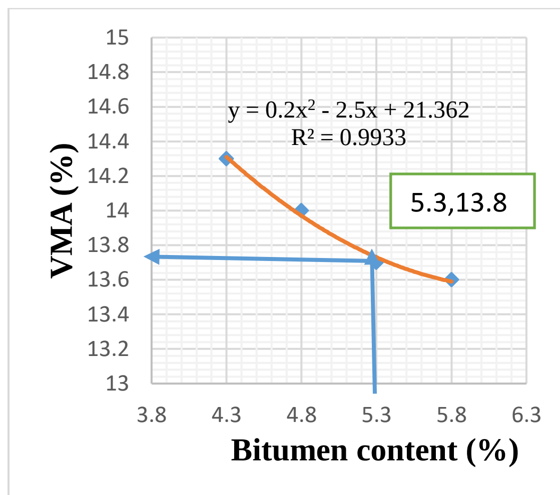

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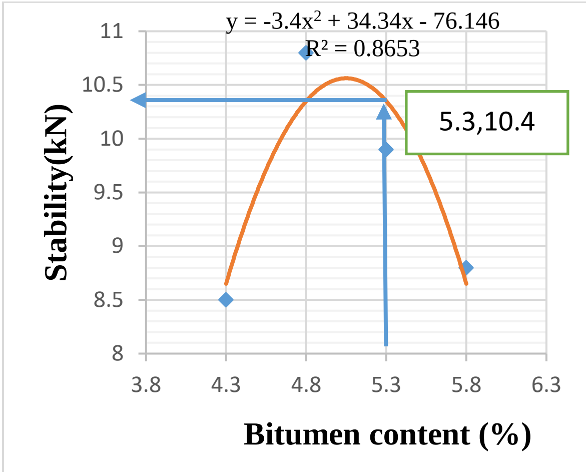

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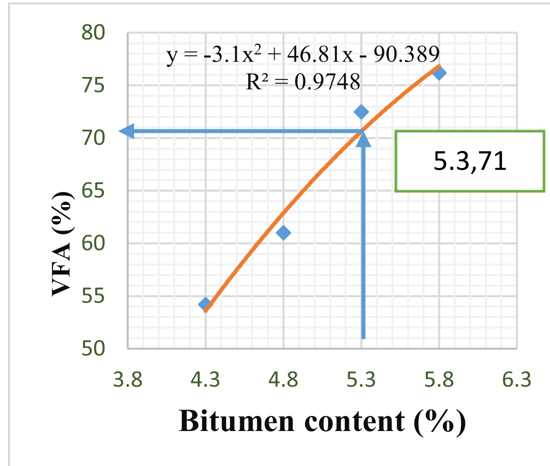

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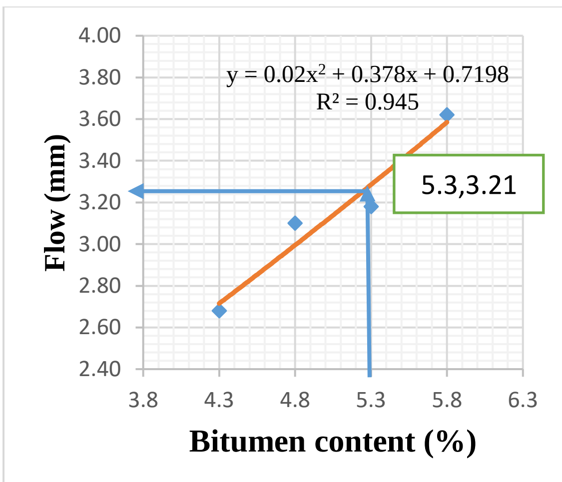

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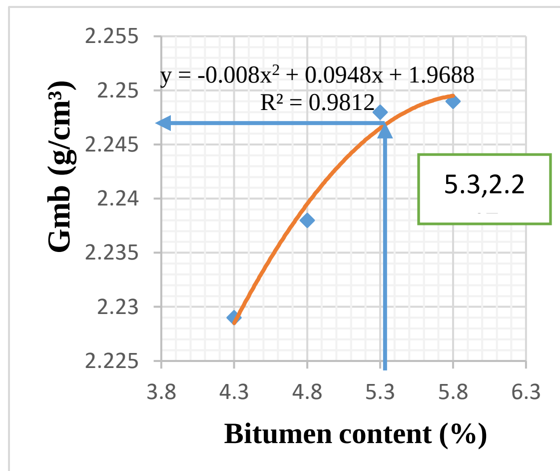
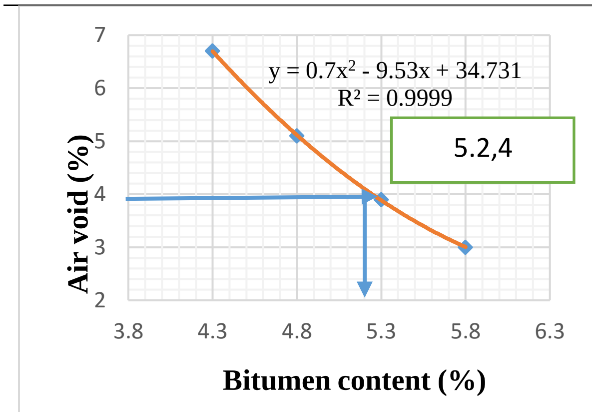


(f)

Figure 4.2 Relationship of OBC (5.3%) and marshal properties.

4.2.1.3 Marshal properties for 6.5% CSD

Figure 4.3 shows the relationships between binder content and the marshal properties of mixtures with 6.5% CSD filler. The stability value increase with increasing asphalt content (bitumen) up to a maximum (8.7 kN) after which the stability gradually decreased. The percent of AV decreases as increasing asphalt content. Very high air voids are not desirable to the mixture because it has the impact on the hardening of asphalt, due to this, brittle of pavement and short service life of asphalt can happen. The VMA gradually decreases to a minimum value due increasing percentage of asphalt binder content in the mixture. The VFA increases with increasing asphalt content. The flow value increased with increasing asphalt content at a progressed rate. Flow is an index of plasticity or the resistance to distortion. The amount of asphalt binder that fills the aggregate voids affects the flow. The curve is usually concave upwards. The specific gravity of the compacted specimen increased with increasing asphalt content. Therefore, the result of marshal stability, flow and volumetric properties obtained at OBC 5.2% fulfil ERA (2013) standard specification. The details of the analysis are given in *Appendix F2.*



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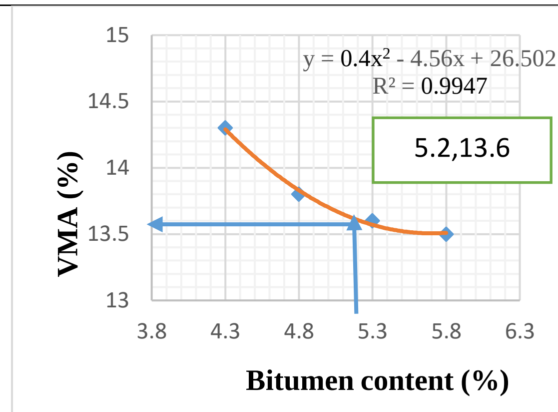

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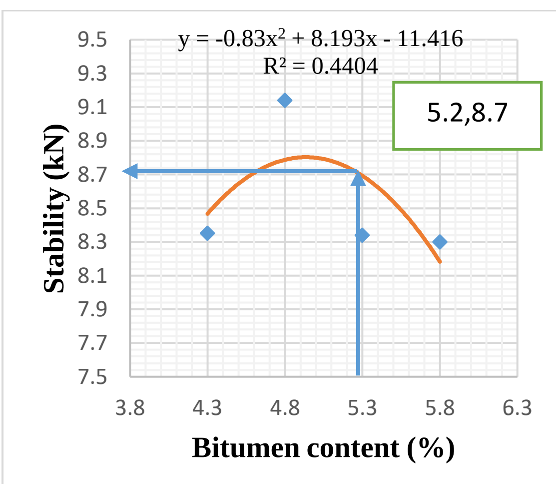

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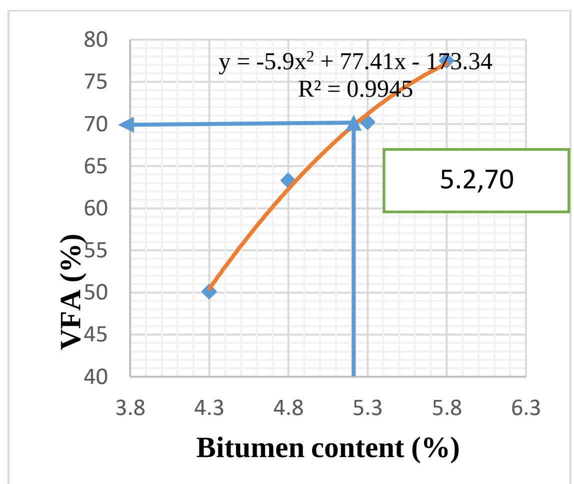

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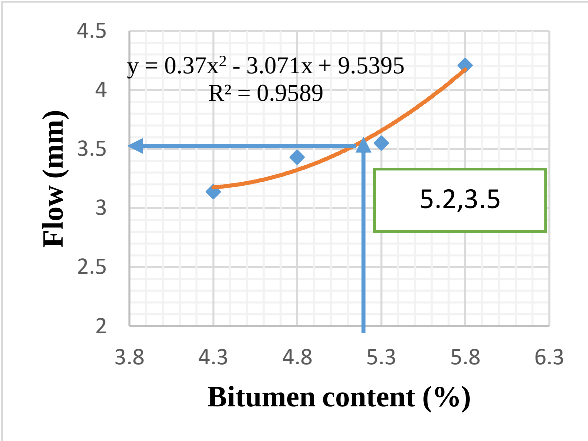

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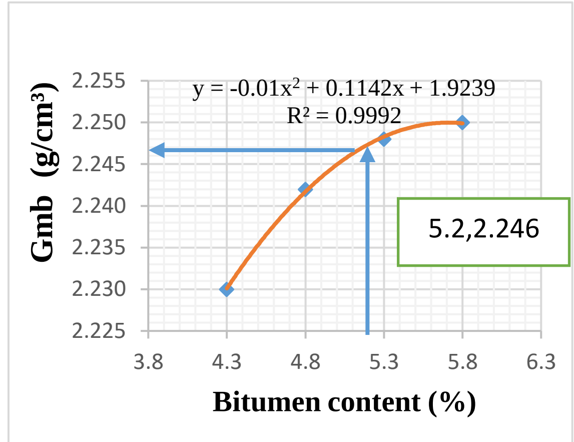
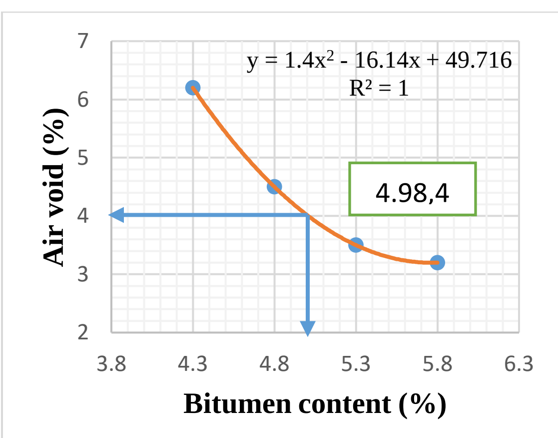


(f)

Figure 4.3 Relationship of OBC (5.2%) and marshal properties

4.2.1.4 Marshal properties for 7.5% CSD

Figure 4.4 shows the relationships between binder content and the marshal properties of mixtures with 7.5% CSD filler. From figure its show that the bulk specific gravity and Flow value increases with the increase the bitumen content. While, the Air void (AV) and VMA value decreases with the increasing of bitumen content. The stability value increases with increasing the bitumen content up to a maximum (9.5 kN) after which the stability gradually decreases. Therefore, the result of marshal stability, flow and volumetric properties obtained at OBC 4.98% fulfil ERA 2013 standard specification. The details of the analysis are given in *Appendix F3*



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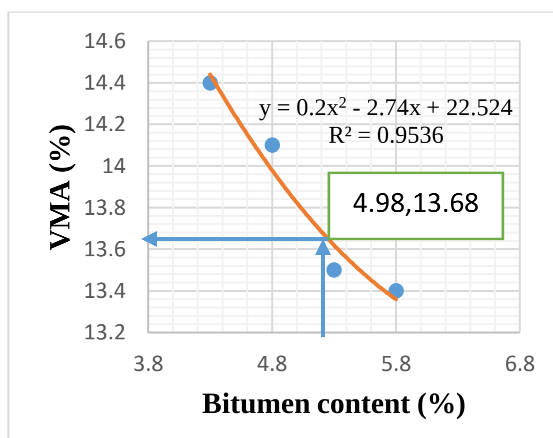

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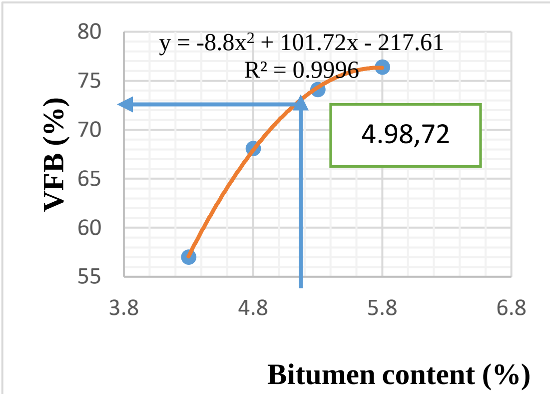

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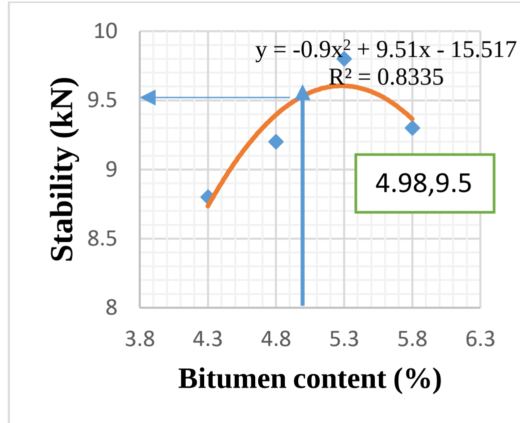

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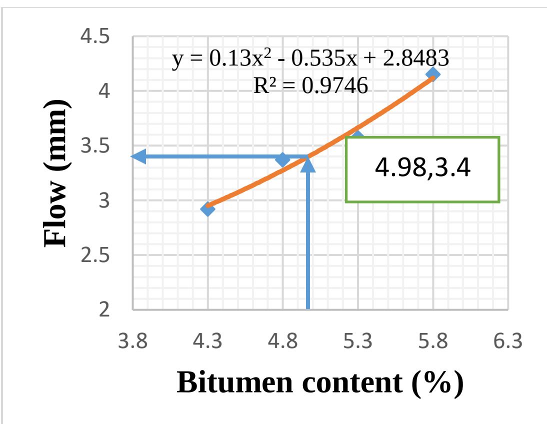

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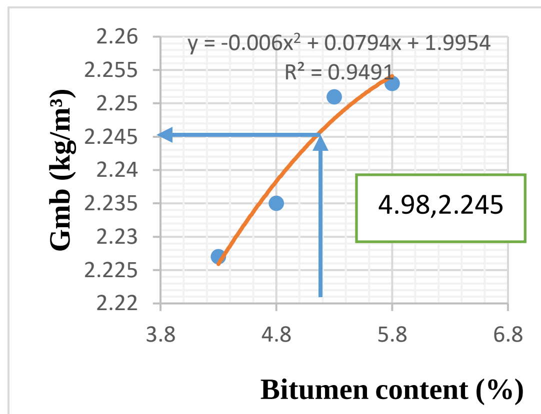

(f)

Figure 4.4 Relationship of OBC (4.98%) and marshal properties

4.2.1.4 Optimum Bitumen Content

Bitumen content along x-axis and Marshall Parameters along y-axis for different gradation are shown on Figure 4.2 to 4.4. The graph plotted indicates the OBC for different gradation according to NAPA procedure. The optimum bitumen content was 5.3,5.2 and 4.98% at 4 % air voids for 5.5, 6.5, and 7.5 % of crushed stone dust respectively. Marshal stability, flow, VMA, VFA, compacted bulk specific gravity, air void is also indicated according to determined OBC.

Table 4.6 Marshal properties of the asphalt mix with 5.3% OBC and 5.5% CSD filler.

Mix properties	Value obtained	ERA (2013)		Asphalt institute (1996)		Remark
		Lower	Upper	Lower	Upper	
OBC, %	5.3	4	10	4	10	OK
Air void, %	4.0	3.0	5.0	3.0	5.0	OK

VMA, %	13.8	Min 13	-	Min 13	-	OK
VFA, %	71	65	75	65	75	OK
Stability, kN	10.4	Min 7.0	-	Min 8.0	-	OK
Flow, mm	3.21	2	4	2	3.5	OK
Bulk density, gm/cm^3	2.247	-	-	-	-	

The table shows that the mix at 5.3% bitumen content has 4.0 percent air voids. The stability of the asphalt mix for 5.5% of CSD has 10.4 kN at 5.3 % OBC which is greater than the minimum value of 7.0kN specified by the ERA standard for heavy traffic. It was noticed that the VMA, VFA, flow and bulk specific gravity of the asphalt mix at 5.30% Optimum bitumen content was 13.8%, 71%, 3.21mm and 2.247 gm/cm3 respectively as indicated in figure 4.2. It indicates that the all marshal parameter at 5.5% of crushed stone dust at 5.3% OBC meets the criteria of national and international standard specification. hence, it is suitable for asphalt concrete mixture.

Table 4.7 Marshal properties of the asphalt mix with 5.2% OBC and 6.5% CSD filler

Mix properties	Value obtained	ERA (2013)		Asphalt institute (1996)		Status
		Lower	Upper	Lower	Upper	
OBC, %	5.2	4	10	4	10	OK
Air void, %	4.0	3.0	5.0	3.0	5.0	OK
VMA, %	13.6	Min 13	-	Min 13	-	OK
VFA, %	70	65	75	65	75	OK
Stability, kN	8.7	Min 7.0	-	Min 8.0	-	OK
Flow, mm	3.5	2	4	2	3.5	OK
Bulk density, gm/cm^3	2.246	-	-	-	-	

Table 4.7 Indicates that the obtained optimum bitumen content corresponding to the marshal properties meets the standard specifications. VMA, VFA, AV, bulk specific gravity and flow of the asphalt mix at 5.2% OBC is 13.6%, 70%,4%,2.246 g/cm^3 and 3.5 mm respectively in table 4.7. The stability of the mixed asphalt for 6.5 % of crushed stone dust filler is 8.7 kN at 5.2% OBC which is greater than the minimum value of 7.0 kN specified by the ERA 2013 and Asphalt institute 1996 standards as given for heavy traffic. Thus, the result indicates that the mix at 6.5% of CSD meets the criteria at 5.2% OB.

Table 4.8 Marshal properties of the asphalt mix with 4.98% OBC and 7.5% CSD filler.

Mix properties	Value obtained	ERA (2013)		Asphalt institute (1996)		Status
		Lower	Upper	Lower	Upper	
Bitumen, %	4.98	4	10	4	10	OK
Air void, %	4.0	3.0	5.0	3.0	5.0	OK
VMA, %	13.68	Min 13	-	Min 13	-	OK
VFA, %	72	65	75	65	75	OK
Stability, kN	9.5	Min 7.0	-	Min 8.0	-	OK
Flow, mm	3.4	2	4	2	3.5	OK
Bulk density, gm/cm³	2.245	-	-	-	-	

4.2.1.5 Comparison of OBC at 5.5,6.5 and 7.5% CSD filler mix

Table 4.9 illustrate that marshal properties of the mixes corresponding to three varying filler content. The OBC of 5.5, 6.5 and 7.5% CSD filler was 5.3, 5.2 and 4.98% respectively. The bulk specific gravity of the mixtures with a varying filler content of 5.5, 6.5, and 7.5% was found to be 2.247 g/cm³, 2.246 g/cm³, and 2.245 g/cm³ respectively. The HMA mixture with 5.5% CSD filler content was relatively those provided highest values of bulk density that is 2.347 g/cm³. The marshal stability values of mixes containing 5.5, 6.5 and 7.5% CSD filler were 10.4 ,8.7 and 9.5kN respectively. Thus, the result of the experimental study, from gradation mixture 5.5% crushed stone dust samples gave higher stability than 6.5 and 7.5% mixtures. Thus, depending on high stability, high bulk density, 5.3 % OBC has been selected for replacement filler material for further study. Therefore, for the replacement of waste filter cake powder mix, depending on stability, optimum filler content and optimum bitumen content value is taken at 5.5% and 5.3% respectively, determined value used as a control point to replace filter cake. Thus, mixture with gradation of 5.5% optimum filler content was considered as design aggregate gradation with 5.3% OBC.

Table 4.9: Comparison of OBC and marshal properties at three percentage of mix proportion.

Mix properties	%, Crushed stone dust			(ERA,2013)	Asphalt institute (1996)
	5.5%	6.5%	7.5%		
Bitumen %	5.3	5.2	4.98	4-10%	4-10%
Air void, %	4	4	4	3-5%	3-5%

Stability, kN	10.4	8.7	9.5	Min,7 KN	8kN
VMA, %	13.8	13.6	13.5	Mi,13%	Min 13
VFA, %	71	70	72	65-75 %	65-75%
Flow, mm	3.21	3.5	3.4	2-4 mm	2-3.5mm
Compacted Bulk. Specific gravity(gm/cm³)	2.247	2.246	2.245	--	--

4.2.2 Effects of partially replacement of filter cake powder on Marshall properties of HMA

Table 4.10 indicates replacement of waste filter cake by the weight of OFC. It was replaced by partially at 0,10,20,30,40 and 50% on the basis of obtained OFC at 5.5% and with 5.3% optimum bitumen content. Table4.10 shows the partial replacement of filter cake by keeping unchanged design gradation, constant OFC and OBC. the average values of bulk specific gravity of mix, Marshall stability, flow, air void, void in mineral aggregate, void filled with asphalt were determined and compared with standard specification.

Table 4.10 Marshal properties of asphalt mix with partial replacement filter cake at constant 5.3% OBC by mean ± Standard Deviation form.

Replacement of FCP (%)	FCP (%) + CSD (%)	Gmb (g/cm³)	VA (%)	VMA (%)	VFA (%)	Stability (kN)	Flow (mm)
0	0.0 +5.5	2.244±0.008	4.62±0.35	14.39±0.31	67.9±1.71	10.83±0.45	3.34±0.34
10	0.55+4.95	2.249±0.009	4.50±0.41	14.20±0.36	68.39±2.08	11.16±0.11	3.22±0.48
20	1.1+4.4	2.252±0.003	4.09±0.12	14.09±0.11	70.97±0.62	11.37±0.15	3.26±0.28
30	1.65+3.85	2.253±0.009	3.84±0.37	14.06±0.33	72.70±1.99	11.49±0.49	3.21±0.13
40	2.2+3.3	2.248±0.004	4.00±0.18	14.23±0.16	71.91±0.93	11.23±0.31	3.45±0.09
50	2.75+2.75	2.238±0.001	4.36±0.04	14.63±0.04	70.17±0.20	11.18±0.39	3.54±0.19

Where, Gmb=Compacted bulk specific gravity, VA =Air voids, VMA =Voids mineral aggregates, VFA = voids filled with bitumen, FCP= filter cake powder, CSD= crushed stone dust.

4.2.2.1 Effect of filter cake on Marshal stability

Figure 4.5, show that the relationship between Marshall Stability and percentage filter cake powder. It is observed that all values of stability with partially replacement of FCP has meets the specification requirements, which is minimum of 7 kN according to ERA 2013 specification. The figure indicates that when the percentage of filter cake in asphalt mix increases, the marshal stability also increases until it reaches the maximum stability (maximum value) that is 11.49 kN at 30% FCP (eg.1.65% FCP and 3.85% CSD) and starts to decline. This indicates that filter cake has high internal friction(interlocking) up to point. Due to the fact that stability is a function of aggregate interlocking, then as filter cake content increases low internal friction between aggregate was gradually occurred. The result indicates that if the content of filter cake increases in mixture, stability is gradually decreased. Therefore, marshal stability of partial replacement of filter cake with increment of 10% in the mix met the standard specification which is greater than 7 kN. details are given in *Appendix F4*.

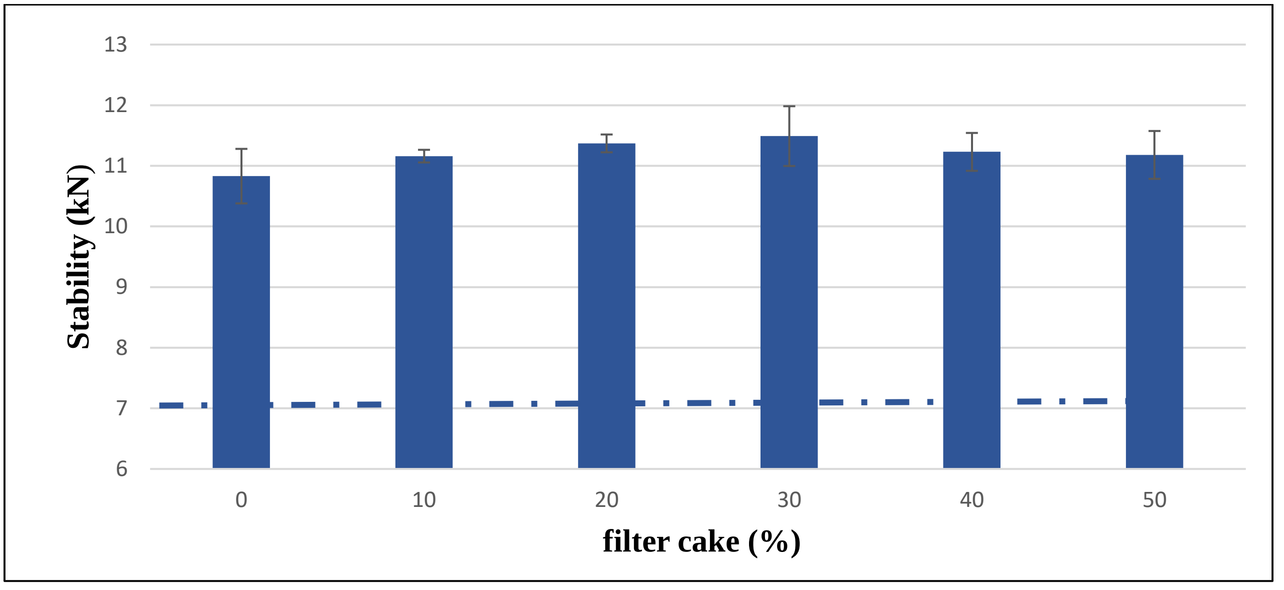

Figure 4.5 Relationship between Marshal Stability and partial replacement of WFCP as filler at constant bitumen content 5.3% OBC

4.2.2.2 Effect of filter cake on Marshal flow

Figure 4-6 indicates the relationship between marshal flow and filter cake content. The flow value was increased with increasing mineral filler content, which is resulted in increasing plastic deformation of the mix was caused by a load to collapse. The higher flow indicates the higher flow of plastic deformation Then; it becomes able to resist a vertical deformation corresponding to maximum load when replaced partially. FCP is finer than CSD. According to (ERA, 2013), the flow value limit must be minimum 2 mm and maximum 4 mm for heavy traffic. The flow of partial replacing mixes is still in the range of ERA Pavement Design Manual specifications at all partially replaced rates. Thus, the flow values of all partial replacement of filter cake are within the limits. details are given in *Appendix F4.*

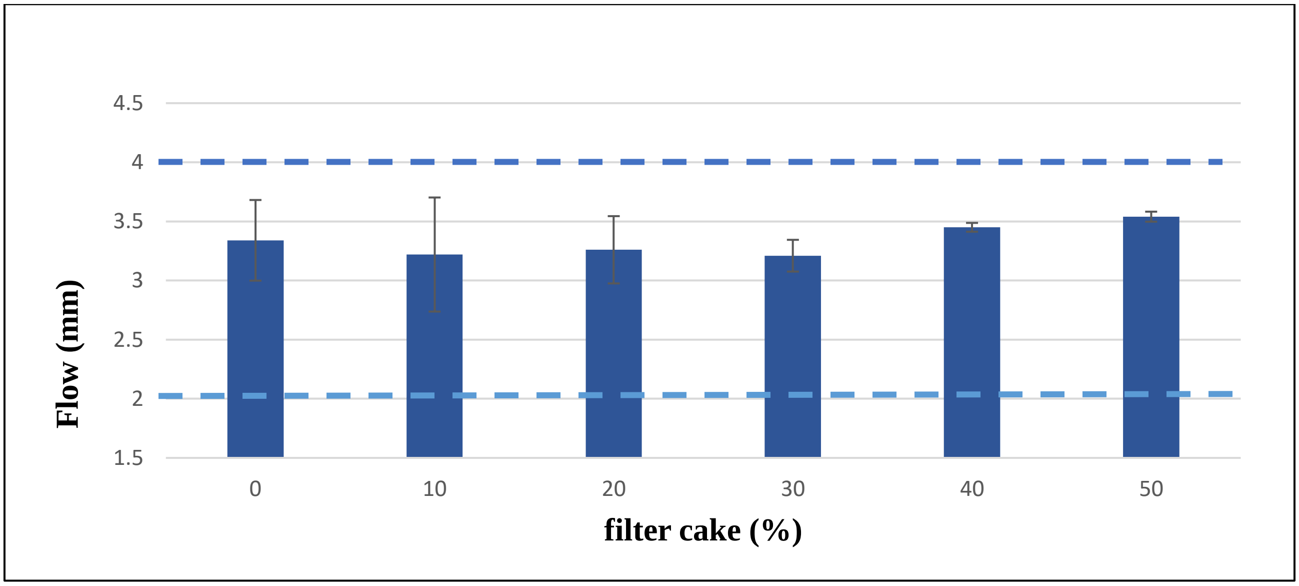

Figure 4.6 Relationship between Marshal flow and partial replacement of FCP as filler at constant bitumen content of 5.30%.

4.2.2.3 Effect of filter cake on air void

The durability of asphalt pavement is a function of the air void content in HMA pavement. The lower air voids (<3%) provide less permeable due to this asphalt concrete can expected to rut and shove, similarly if air void content is above 5% problems like brittleness and premature cracking can be occur (Asphalt Institute, 1996). Figure 4.7, show that at 30% FCP content (i.e. the sample prepared by 1.65% FC and 3.85% CSD) the air voids percentage was 3.84% which is within the range of local and international specification. The air void is slightly increased as FCP increased. Therefore, air void content obtained from replacement of FC from 0%- 50% mixes is within the range of standard which is 3%-5%. Details are given in *Appendix F4.*

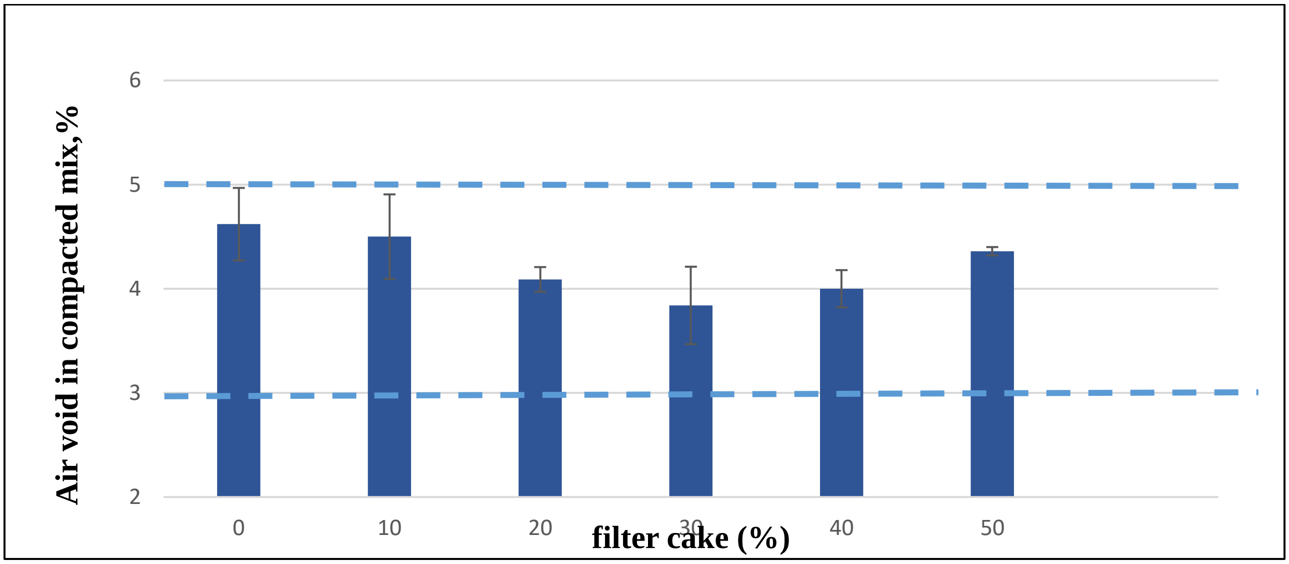

Figure 4.7 Relationship between air void and partial replacement of WFCP as filler at constant bitumen content of 5.30%.

4.2.2.4 Effect of filter cake on Void in mineral Aggregates

Figure 4-8 shows the relationship between percentage of voids in mineral aggregate and Percentage of filter cake. As can be seen from figure the percentage of voids in mineral aggregates decreases with an increase in percentage of filter cake up to the point of 30% FCP and then start to increases with an increasing of filter cake. Percentage of Void in mineral aggregate is the percentage of void space between the granular particle in compacted paving mixtures. A minimum percentage of VMA is required in mixes to allow adequate asphalt binder content to coat aggregate particles with sufficient asphalt binder. Thus, the All voids in mineral aggregate value obtained are within the permissible limits specified in the ERA Pavement Design Manual. Details are given in *Appendix F4*.

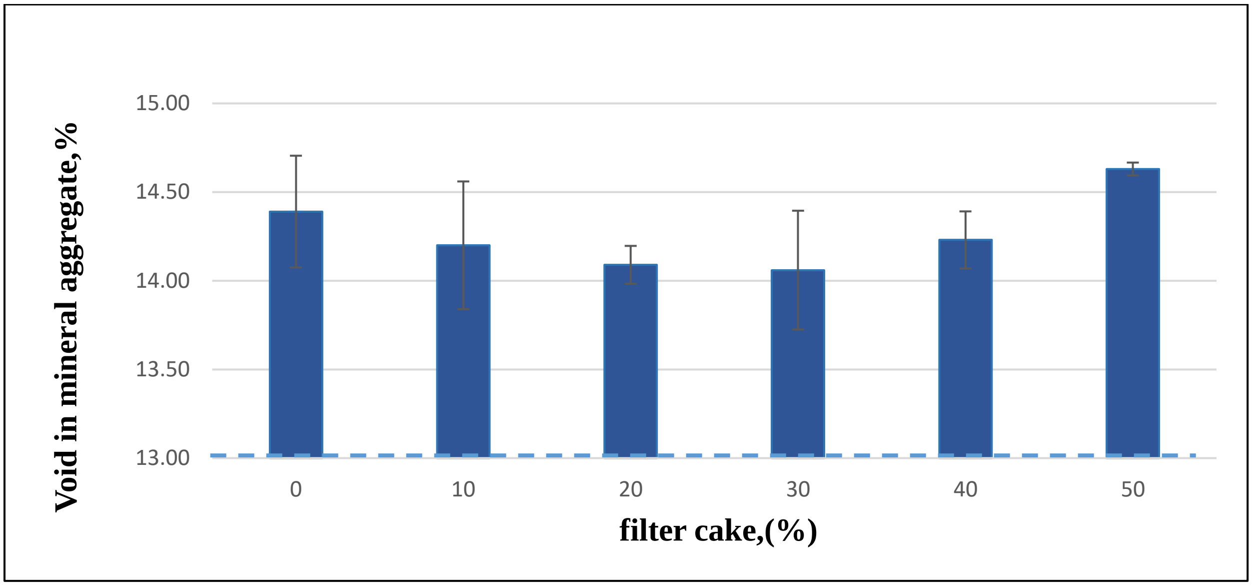

Figure 4.8 Relationship between Void in mineral aggregate (VMA) and partial replacement of WFCP as filler at constant bitumen content of 5.30%.

4.2.2.5 Effect of filter cake on Void Filled by Asphalt

The void filled with asphalt binder is the percentage of voids in the compacted aggregate mass that are filled with asphalt binder. If the percent VFA is too low, lower void may be obtained and there is not enough asphalt to provide durability so, pavement become brittle. Thus, VFA is a very important design property. Figure 4-9 indicates the relationship between percentage of voids filled with asphalt binder and percentage of filter cake. It shows that the percent VFA of compacted specimens increases with an increase of replacement of filter cake until it reaches the highest value at 30% WFC and gradually decreases. This was due to the fact that more effective bitumen content was present in the mix to fill available voids between the inter-granular spaces. Therefore, the VFA for partial replaced mixes with 0% - 50% filter cake powder was within the range of 65% - 75% specified by (ERA, 2002). Details are given in *Appendix F4.*

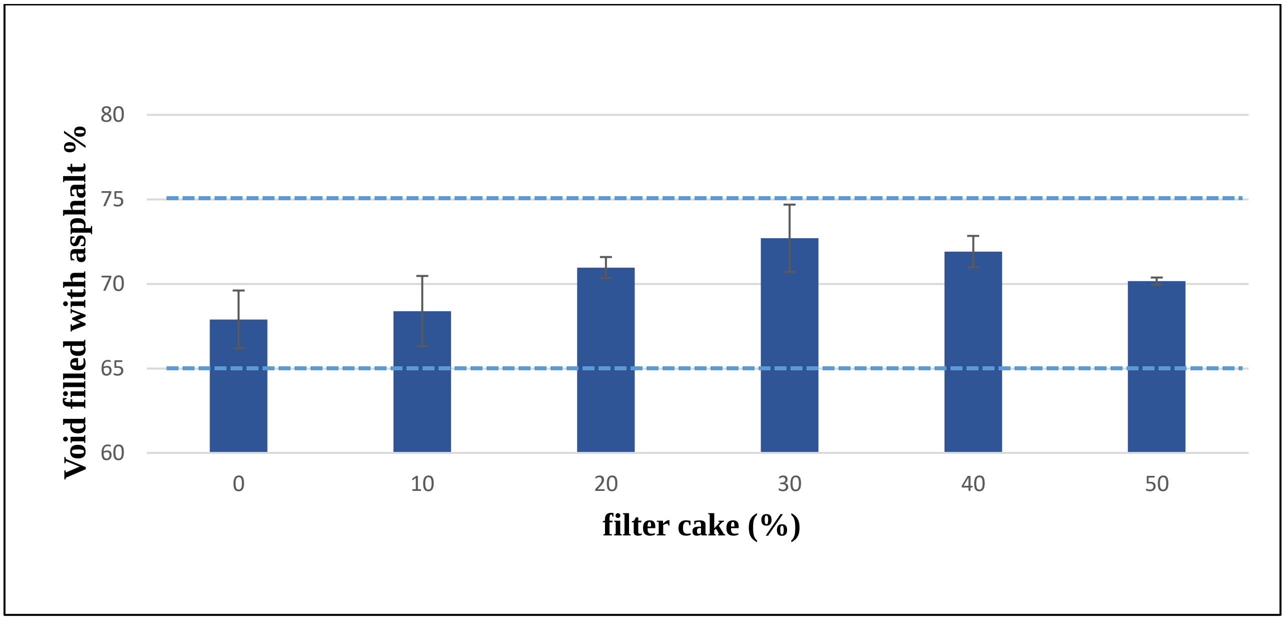

Figure 4.9 Relationship between Void Filled with asphalt (VFA) and partial replacement of WFCP as filler at constant bitumen content of 5.30%.

4.2.2.6 Effects of Filler on Bulk specific gravity of HMA

The relationship between percentage of filter cake and the bulk density of compacted mixes is presented in figure 4.10. It is observed that the weight of compacted specimen (bulk density) increases with increase waste filter cake powder content until it reaches the maximum bulk density at 2.253 g/cm3 content consequently, and it starts to decreases. This indicates specific gravity of FCP (2.13 g/m³) is less than specific gravity of CSD (2.6 g/m³) as FCP content increase in the mix bulk specific gravity decreases. FCP is porous material which absorbs bitumen and decreases the density of the mixes when it became increases in the mix. Filler fills out air void which allows for denser compaction. The maximum compacted bulk density is (2.253 g/cm3) at 30% filter cake powder content (i.e, the sample prepared by 1.65% FCP and 3.85% CSD). Therefore, density is an important parameter since higher density will have lower air voids for durable mix and also, density can be influenced by increased filler content, increased bitumen content and increased compaction. Details are given in *Appendix F4.*

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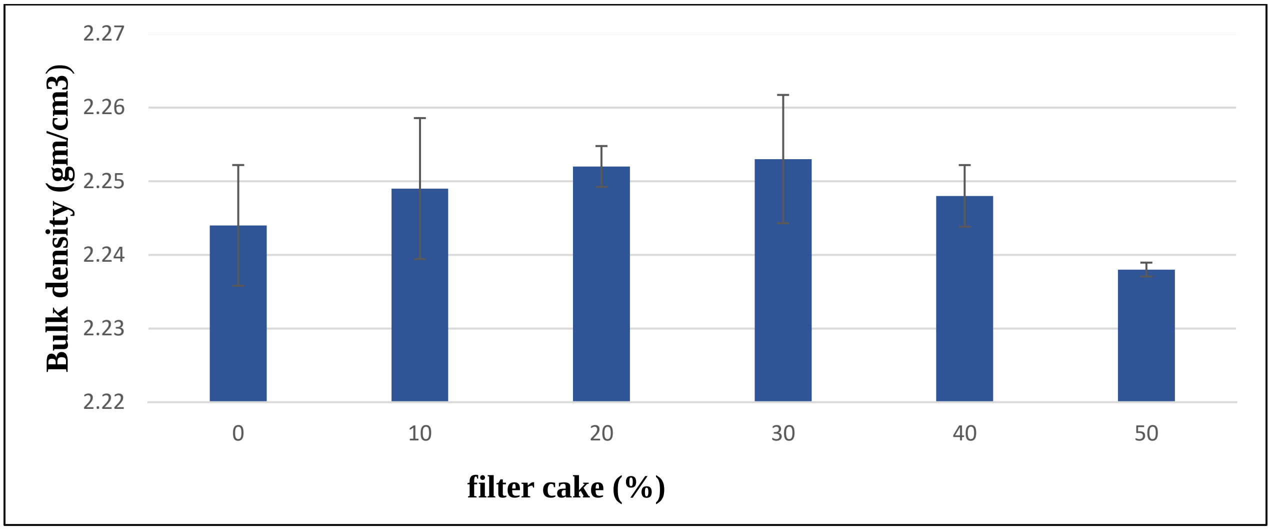

Figure 4.10 Relationship between Bulk specific gravity and partial replacement of WFCP as filler at constant bitumen content of 5.30%.

4.2.3 Optimum Filter cake content

From determined the optimum bitumen content value sample of concrete mix by using asphalt mixture by partial filter cake as filler was provided. The required Marshall parameters were same as for the parameter used for conventional filler. Table 4.11 indicates the summary of parameter needed to obtained the optimum filter cake content.

Then Optimum content of filter cake were obtained the mixes having maximum stability, maximum bulk specific gravity and air void within the allowed range of specifications. Figures (4.5, 4.7 and 4.10) was utilized to find optimum filter cake contents which satisfy these three requirements. Thus, the maximum stability value obtained was from the mixture corresponding to 30% FCP filler relative to others proportions which is 11.49 kN. Also corresponding to this proportion maximum bulk specific gravity values obtained was 2.253 gm/cm^3. The air void obtained at 30% FCP was 3.84%. Therefore, the result obtained at 30% FCP are satisfactory with standard specification. Details are given in *Appendix F4.*

The partial replacement of filter cake 0-50% applied in asphalt mixture is satisfactory. From figure 4.5 is noticed that all values of Marshal stability for 0-50% filter cake content satisfy the local and international specifications which are minimum 7.0 kN and 8.006 kN respectively.

Then, the mix obtained using 30% FCP and 70% CSD by weight of optimum crushed stone dust meets the standard specified in terms of Maximum stability, Maximum bulk density and Air void within the allowed range of specifications, at an optimum bitumen content of 5.30%. Thus,30% FCP was adopted as the optimum content of filter cake powder.

Table.4.11 Summary of properties of asphalt mix with different filter cake content.

Property	FCP (%)					
	0	10	20	30	40	50
Bitumen (%)	5.3	5.3	5.3	5.3	5.3	5.3
Stability (kN)	10.83	11.16	11.37	11.49	11.23	11.18
Flow (mm)	3.34	3.22	3.26	3.21	3.45	3.54
Bulk Density (g/cm^3)	2.244	2.249	2.252	2.253	2.248	2.238
Air void (%)	4.62	4.5	4.09	3.84	4.00	4.36
VMA (%)	14.39	14.20	14.09	14.06	14.23	14.63
VFA (%)	67.9	68.39	70.97	72.7	71.91	70.17

4.2.3.1 Comparison of properties of asphalt mix at optimum filter cake content with local and international specifications

Table 4.12 illustrates a comparison of the marshal properties of asphalt mix containing 30% Filter cake powder content with the local specifications (ERA,2013) and with the international specifications (Asphalt Institute, 1996) Also, All the rest results obtained at 0,10,20,40and 50% are satisfy the required specification ranges. Thus, the HMA mixture prepared with partial replacement of FCP filler at 30% (Sample prepared with 1.65% FCP + 3.85% CSD) weight of crushed stone dust satisfy the requirement of both local and international specification limits. for this study 30% FCP by content in the mix is selected as the best filler replacement proportion.

Table 4.12 Comparison of 30% FCP replacement in asphalt with ERA, pavement design manual and Asphalt institute.

Marshal mix criteria	Replacement of 30% FCP	(ERA,2013) Specification		International spec. (Asphalt Institute,1996)		Remark
		Heavy Traffic		Heavy Traffic		
		Min	Max	Min	Max	
Stability (kN)	11.49	7.0	_	8.0	_	OK
Flow(mm)	3.21	2	4	2	3.5	OK
air voids (%)	3.84	3	5	3	5	OK
VFA (%)	72.7	65	75	65	75	OK
VMA (%)	14.06	13	-	13	-	OK

4.2.4 Effects of Filter cake powder on Moisture Susceptibility of HMA

Table 4.13 presents the test results of the tensile strength ratio (TSR) for mixes prepared for crushed stone dust and optimum filter cake powder at 100% and 30% respectively at 5.3% OBC by OFC of CSD. from the table 4.13 result indicates moisture susceptibility of CSD and FCP for conditional and unconditional. From table observed that the ITS values of the conditioned mixes are lower in comparison with the ones for dry mixes. It was expected because the presence of water causes a strength reduction and reduction in asphalt–aggregate adhesion, and thus the strength of HMA samples decrease under loading. Thus, Presence of water affects the performance of the pavement Moisture susceptibility of a bituminous mix was determined by tensile strength ratio (TSR) by using the indirect tensile strength test. Tensile strength ratio (TSR) is the relation of the strength values obtained before and after soaking. Thus, result shows, asphalt mixes prepared with filter cake and crushed stone dust gives tensile strength ratio of 90.2% and 83.6% respectively. The result indicates the Mixes prepared with filter cake fillers provide higher tensile strength ratio value relative to conventional crushed stone filler. The TSR value of FCP and CSD mixture were above 75%. Thus, mixes prepared with filter cake filler provide better resistance to asphalt aggregate adhesion (good resistant to moisture damage). Details of the analysis are given in *Appendix G.*

Table 4.13 Tensile strength ratio test result

Filler type	Sample type	Bulk density(g/cm³)	Maximum load (KN)	Average ITS (kpa)	TSR (%)	Specification (ASTM D 1075)
CSD	Un conditioned	2.289	10.2	1.10	83.6	≥75
	Conditioned	2.277	8.6	0.92		
FCP	Un conditioned	2.260	9.6	1.02	90.2	
	Conditioned	2.270	8.6	0.92		

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

The main goal of this research study was to replace partially filter cake by crushed stone dust in order to have better performing asphalt concrete. A detail laboratory investigation was conducted to determine Marshall parameters. The following conclusions are drawn based on the results obtained, and finally, recommendations and suggestions for future studies are presented.

5.1 CONCLUSIONS

Based on the findings of the research the following conclusions are drawn.

- The laboratory test result for FCP of gradation parameters, plastic index and specific gravity satisfy the specification. FCP is non plastic and specific gravity of filter cake is 2.13% and specific gravity of CSD was 2.6%.
- Marshall Stability, flow values and volumetric properties for all three CSD filler content (5.5, 6.5 and 7.5%) with different aggregate gradation satisfy the ERA Pavement Design Manual specification limits.
- Accordingly, this study, the percentage of optimum bitumen contents was determined for each different conventional filler 5.5,6.5 and 7.5% was 5.3, 5.2, and 4.98% respectively.
- Optimum bitumen content used for replacement was 5.3% and Optimum filler content of CSD were determined on the basis of maximum Marshall stability and bulk specific gravity. It was observed that 5.5% OFC filler content of CSD has been shown at maximum Marshall stability.
- On the basis of determined OFC and OBC the mix was prepared by partially replaced filter cake has significant effect on performance of volumetric properties of hot mix asphalt.it is replaced by 0-50% by increment of 10%.
- Test results indicated that each of Marshall stability, bulk density, and VFA increase as the filter cake powder increases up to 30% then start to decreases. air voids and void in mineral

aggregates decreases as the filter cake powder content increases up to 30% FCP then, starts to increase.

- 30% FCP content have had best marshal stability and bulk specific gravity so,30% filler is recommended as optimum content filter cake for heavy traffic. But FCP can be replaced partially in hot mix asphalt, it has an effect on the volumetric properties and meets the standard specification.
- The mix with 30% filter cake powder resulted higher moisture resistance compared to the mix produced with fully crushed stone dust at optimum bitumen content.
- Thus, it was concluded that FCP waste can be used partially in hot mix asphalt concrete as mineral filler.

5.2 RECOMMENDATIONS

Based on the findings of the study, the researcher forwarded the following recommendations

- FCP can be replaced partially as a filler (at 30% FCP and 70% CSD) in hot mix asphalt.
- It is recommended for local authorities (ERA) to permit using filter cake powder in asphalt concrete pavements depending on the results of this research, consumption of natural resource can be reduced.
- Finally, after awareness of the importance of FCP in HMA, aluminum sulphate factory will be benefitted. As well as land fill can be reduced.

In order to further validate the findings of this research, the following further study are required.

- Performance of filter cake in hot mix asphalt with different grade of bitumen, content of bitumen and different aggregate gradation.
- The effect of filter cake on rutting of hot mix asphalt.
- Economic analysis of partially replaced filter cake in hot mix asphalt.

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APPENDICES

APPENDIX A: Mineral Filler Test Result

Test Method: ASTM D-854

Table A 1: Specific gravity of filter cake powder filler

Material Type	**Filter cake powder Filler**	
Pycnometer No.	8.00	3.00
Mass of Oven dry sample in air, gm (A)	25.00	25.00
Mass of Pycnometer + Water, gm (B)	127.71	125.60
Mass of Pycnometer + Water+ sample, gm (C)	140.99	138.77
Specific Gravity @25 ⁰C	2.13	2.11
Average	**2.13**	

Table A 2: Specific gravity of crushed stone dust filler (AASHTO T84-95)

Material Type	**Crushed stone dust (CSD)**	
Pycnometer No.	A3	A2
Mass of Oven dry sample in air, gm (A)	25.00	25.00
Mass of Pycnometer + Water, gm (B)	127.36	127.73
Mass of Pycnometer + Water+ sample, gm (C)	142.76	143.20
Specific Gravity @ 25 ⁰C	2.60	2.62
Average	**2.61**	

Appendix B: Particle Size Distribution of Aggregate

Appendix B1: Particle Size Distribution Of course Aggregate

Test method AASHTO T 27

Table B1: Particle size distribution for coarse aggregate (9.5-25 mm)

Material type: -Crushed coarse aggregate (9.5-25 mm)								
Dry sample weight, (gm)			5021.4		Dry sample weight, (gm)		5013.4	
Washed dry sample, (gm)			5011.2		Washed dry sample, (gm)		5004.9	
Sieve size, mm	**Mass of retained (g)**	**% retained**	**Cum. retained (g)**	**% passing**	**Mass of retained (g)**	**% retained**	**Cum. retained (g)**	**% passing**
25	0	0	0.0	100.0	0.0	0	0	100.0
19	1140.4	22.7	1140.4	77.3	1136.4	22.7	1136.4	77.3
12.5	2500	49.8	3640.4	27.5	2498.0	49.8	3634.4	27.5
9.5	1195	23.8	4835.4	3.7	1190.0	23.7	4824.4	3.8
4.75	141	2.8	4976.4	0.9	141	2.8	4965.4	0.9
2.36	25	0.5	5001.4	0.4	24.0	0.5	4989.4	0.5
1.18	11	0.2	5012.4	0.2	13.0	0.3	5002.4	0.2
0.6	6	0.1	5018.4	0.1	8.0	0.2	5010.4	0.1
0.3	3	0.1	5021.4	0.0	3.0	0.1	5013.4	0.0
0.15	0	0.0	0.0	0.0	0.0	0.0		
0.075	0	0.0	0.0	0.0	0.0	0.0		
pan								
Wash Loose	10.2				8.5			
Total	5021.4	100			5013.4	100		

Appendix B2: Particle Size Distribution Intermediate aggregate

Table: B2 Particle size distribution for intermediate aggregate (2.36-9.5 mm)

Dry sample weight, (gm)			4909.6		Dry sample weight, (gm)			4776.4
Washed dry sample, (gm)			4892.6		Washed dry sample, (gm)			4762.4
Sieve size, mm	**Mass of retained (g)**	**% retained**	**Cum. retained (g)**	**% passing**	**Mass of retained (g)**	**% retained**	**Cum. retained (g)**	**% passing**
25	0.0	0.0	0.0	100.0	0.0	0	0	100.0
19	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
12.5	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
9.5	720.3	14.7	720.3	85.3	700.8	14.7	700.8	85.3
4.75	2399.3	48.9	3119.6	36.5	2338	49.1	3038.8	36.2
2.36	1480.2	30.1	4599.8	6.3	1440.0	30.2	4478.8	6.0
1.18	137.2	2.8	4737.0	3.5	134.4	2.8	4613.2	3.2
0.6	128.5	2.6	4865.5	0.9	120.0	2.5	4733.2	0.7
0.3	34.3	0.7	4899.8	0.2	33.6	0.7	4766.8	0.0
0.15	9.8	0.2	4909.6	0.0	9.6	0.2	4776.4	0.0
0.075	0.0	0.0	4909.6	0.0	0.0	0.0	4776.4	0.0
pan								
Wash loose	17.0				14			
Total	4909.6	100			4776.4	100		

Appendix B3: Particle Size Distribution Fine aggregate

Table: B3 Particle Size Distribution for Fine aggregate (0.075-2.36)

Material type: -Crushed fine aggregate (0.075-2.36 mm)								
Dry sample weight, (gm)		5033.3			Dry sample weight, gm		4929.4	
Washed dry sample, (gm)		4411.4			Washed dry sample, (gm)		4333.7	
Sieve size, mm	**Mass of retained (g)**	**% retained**	**Cum. retained (g)**	**% passing**	**Mass of retained (g)**	**% retained**	**Cum. retained (g)**	**% passing**
25	0.0	0.0	0.0	100.0	0.0	0	0	100.0
19	0.0	0.0	0.0	100.0	0.0	0	0.0	100.0
12.5	0.0	0.0	0.0	100.0	0.0	0	0.0	100.0
9.5	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
4.75	52.2	1.0	52.2	99.0	48.2	1.0	48.2	99.0
2.36	2251.0	44.7	2303.2	54.2	2228.1	45.2	2276.3	53.8
1.18	1010.0	20.1	3313.2	34.2	998.7	20.3	3275.0	33.6
0.6	784.0	15.6	4097.2	18.6	797.1	16.2	4072.1	17.4
0.3	300.0	6.0	4397.2	12.6	278.5	5.6	4350.6	11.7
0.15	275.0	5.5	4672.2	7.2	278.2	5.6	4628.8	6.1
0.075	242.5	4.8	4914.7	2.4	200.6	4.1	4829.4	2.0
pan	118.6	2.4	5033.3		100.0	2.0	4929.4	0.0
Wash loose	621.9				595.7			
Total	5033.3	100			4929.4	100		

B4. Gradation of aggregates and their blends for hot mix asphalt mixture

Table B4.1: Aggregate gradation for 5.5% CSD filler.

Aggregate type	9.5-25mm		2.36-9.5mm		0-2.36mm		Total blend	Middle value	Specification limit
Blending, %	32		33.5		34.5				
Sieve size	% pass	% blend	% pass	% blend	% pass	% blend	X+Y+Z		
		X		Y		Z			
25	100.0	32.0	100.0	33.5	100.0	34.5	100.0	100	100
19	81.1	26.0	100.0	33.5	100.0	34.5	94.0	95	90-100
12.5	32.3	10.3	100.0	33.5	100.0	34.5	78.3	79.5	……
9.5	7.9	2.5	92.4	31.0	100.0	34.5	68.0	68	56-80
4.75	1.0	0.3	46.3	15.5	99.0	34.2	50.0	50	35-65
2.36	0.6	0.2	6.5	2.2	93.1	32.1	34.5	36	23-49
1.18	0.4	0.1	3.1	1.0	66.3	22.9	24.0	26	……
0.6	0.2	0.1	1.4	0.5	49.3	17.0	17.5	19	……
0.3	0.0	0.0	0.5	0.2	31.5	10.9	11.0	12	5..19
0.15	0.0	0.0	0.3	0.1	24.4	8.4	8.5	8.5	……
0.075	0.0	0.0	0.2	0.1	15.8	5.5	5.5	5	2..8

Table B4.2: Aggregate gradation for 6.5% CSD filler

Aggregate type	9.5-25mm		2.36-9.5mm		0-2.36mm		Total blend	Middle value	Specification limit
Blending, %	32.5		34.5		33				
Sieve size	% pass	% blend	% pass	% blend	% pass	% blend	X+Y+Z		
		X		Y		Z			
25	100.0	32.5	100.0	34.5	100.0	33.0	100.0	100	100
19	81.5	26.5	100.0	33.5	100.0	34.5	94.5	95	90-100
12.5	30.3	9.8	100.0	33.5	100.0	34.5	77.8	79.5	……
9.5	5.1	1.7	90.9	31.4	100.0	34.5	67.5	68	56-80
4.75	1.1	0.4	44.9	15.5	99.0	32.7	48.5	50	35-65
2.36	0.6	0.2	6.1	2.1	93.1	30.7	33.0	36	23-49
1.18	0.4	0.1	3.9	1.3	71.2	23.5	25.0	26	……
0.6	0.3	0.1	1.4	0.5	45.7	15.1	15.7	19	……
0.3	0.2	0.1	0.7	0.2	32.7	10.8	11.1	12	5..19
0.15	0.0	0.0	0.3	0.1	25.7	8.5	8.6	8.5	……

0.075	0.0	0.0	0.2	0.1	19.6	6.5	6.5	5	2..8

Table B4.3: Aggregate gradation for 7.5% CSD filler

Aggregate type	9.5-25mm		2.36-9.5mm		0-2.36mm		Total blend	Middle value	Specification limit
Blending, %	30		34		36				
Sieve size	% pass	% blend	% pass	% blend	% pass	% blend	A+B+C		
		A		B		C			
25	100.0	30.0	100.0	34.0	100.0	36.0	100.0	100	100
19	84.9	25.5	100.0	33.5	100.0	34.5	93.5	95	90-100
12.5	41.6	12.5	100.0	33.5	100.0	34.5	80.5	79.5	……
9.5	5.7	1.7	99.4	33.8	100.0	34.5	70.0	68	56-80
4.75	1.6	0.5	43.9	14.9	99.0	35.6	51.0	50	35-65
2.36	0.9	0.3	8.7	3.0	93.9	33.8	37.0	36	23-49
1.18	0.4	0.1	3.9	1.3	73.8	26.6	28.0	26	……
0.6	0.2	0.1	1.0	0.3	51.7	18.6	19.0	19	……
0.3	0.0	0.0	0.1	0.0	36.0	13.0	13.0	12	5..19
0.15	0.0	0.0	0.5	0.2	23.9	8.6	8.8	8.5	……
0.075	0.0	0.0	0.0	0.0	20.8	7.5	7.5	5	2..8

Appendix B5: Particle Size Distribution of mineral filler

Table B5: Particle size distribution of CSD filler (Test method: AASHTO T 11)

Material	Particle size distribution of Crushed stone dust, <0.075 mm							
Dry wt,g	350				370			
Washed g	0				0			
Sieve size, mm	Weight Retained, (g)	%retained	cum.retained wt(g)	% pass	Weight ret.(g)	% retained	cum.retaind wt,g	% pass
1.18	0	0	0	100	0	0	0	100
0.6	0	0	0	100	0	0	0	100
0.3	0	0	0	100	0	0	0	100
0.15	0	0	0	100	0	0	0	100
0.075	0	0	0	100	0	0	0	100
Pan	350				370			
wash loose	350				370			

Total	350				370			

Table B6: Particle size distribution of Filter cake powder (FCP)

Material	Particle size distribution of Filter cake powder, <0.075 mm AASHTO T 11							
Dry wt,g	1541				1213.5			
Washed	0				0			
Sieve size,mm	Weight Retained,g	% retained	Cum.retained wt(g)	% pass	Weight ret.(g)	% retained	cum.retained wt(g)	% pass
2.36	0	0.0	0	100.0	0	0.0	0	100.0
1.18	120	7.8	120	92.2	114	9.4	114	90.6
0.6	347.8	22.6	467.8	69.6	238.4	19.6	352.4	71.0
0.3	698.2	45.3	1166	24.3	588.3	48.5	940.7	22.5
0.15	189	12.3	1355	12.1	114	9.4	1054.7	13.1
0.075	88	5.7	1443	6.4	56.4	4.6	1111.1	8.4
pan	98	6.4	1541	0.0	102.4	8.4	1213.5	0.0
wash loose	1541				1213.5			
Total	1541	100			1213.5	100		

Appendix C: Aggregate Quality Test Results

C1: Specific gravity and Water Absorption of aggregate

Test Method: AASHTO T 85-91

Table C1: Specific gravity and Water Absorption of Coarse aggregate (9.5-25mm)

Trial no	1.0	2.0	Average
A: Mass of oven dry sample in air, gm(gm)	2500.0	2400.0	
B: Mass of SSD sample in air,gm	2532.8	2430.4	
C.Mass of saturated sample in water,gm(gm)	1558.5	1526.1	
Bulk sp, gravity (oven dry) =Gsb=(A/B-C)	2.57	2.65	2.61
Bulk sp, gravity (SSD)=Gss=(B/B-C)	2.60	2.69	2.64
Apparent specific gravity=Gsa=A/(A-C)	2.66	2.75	2.70
Water absorbition %=(B-A)/A*100	1.31	1.27	1.29

Table C2: Specific gravity and Water Absorption of intermediate aggregate (2.36-9.5mm)

Trial no	1.0	2.0	Average
A: Mass of oven dry sample in air, gm(gm)	1968.2	1965.1	
B: Mass of SSD sample in air,gm	2000.0	1995.0	
C.Mass of saturated sample in water,gm(gm)	1238.2	1239.1	
Bulk sp, gravity (oven dry) =Gsb=(A/B-C)	2.584	2.600	2.59
Bulk sp, gravity (SSD)=Gss=(B/B-C)	2.625	2.639	2.63
Apparent specific gravity=Gsa=A/(A-C)	2.696	2.707	2.70
Water absorbition %=(B-A)/A*100	1.616	1.522	1.57

Specific gravity of fine aggregate, Test Method: AASHTO T 84-95

Table C3: Specific gravity and Water Absorption of fine aggregate (0.075-2.36mm)

Trial no	1.0	2.0	Average
A: Mass of oven dry sample in air, gm(gm)	249.9	243.9	
B: Mass of pycnometr +water,gm	701.0	695.0	
C.Mass of pycnometr +water+sample,gm	859.8	850.8	
S=mass of SSD sample,gm	253.7	248.4	
Bulk sp, gravity (oven dry) =Gsb=(A/S-(C-B)	2.63	2.63	2.63
Bulk sp, gravity (SSD)=Gss=S/(S-(C-B)	2.67	2.68	2.68
Apparent specific gravity=Gsa=A/(A-(C-B)	2.74	2.77	2.76
Water absorbition %=(S-A)/A*100	1.52	1.85	1.68

C.4 Aggregate impact value (A.I.V) test result for crushed aggregate:
Test Method B.S Parts 112
Table.C.4 Aggregate impact value test result for crushed aggregate

Trial test	1	2
Total weight of aggregate sample filling the cylindrical measure=w1	506.7	500.7
Weight of aggregate passing 2.36mm sieve after the test=w2	31.8	29.7
Weight of aggregate retained on 2.36mm sieve after the test=w3	478.9	466.7
W2=W1-W3	27.8	34.0
Aggregate impact value=w2/w1*100	5.5	6.8
Average	**6.32%**	

C.5 Aggregate crushing value (A.C.V %): Test method B.S 812 parts 110

Table C5 Aggregate crushing value result

Trial test	1	2
Mass of sample (A)	2566.6	2566.6
Mass of proportioning passing 2.36mm sieve after crushing:(B)	382.4	372.3
A.C.V(%) Individual(B/A*100)	14.9	14.5
Average	**14.7**	

C.6 Loss angles abrasion test value of used aggregate: Test method T-96

Table: C.1 Los angles abrasion value test result

Grading of test sample	Trials	Fraction and mass		No of spheres	Mass of sample retained on 1.70 mm sieve after washing and oven dried(B)	Loss through 1.70mm Sieve(g) A-B=C	Loss angles abrasion (%)
		Fraction	Mass (g) A				
B	1	19-12.5	2500	11	4420	5000-4420=580	(580/5000) *100=11.6%
		12.5-9.5	2500				
	2	19-12.5	2500	11	4430	5000-4430=570	(570/5000) *100=11.4%
		12.5-9.5	2500				
Average=11.5%							

Appendix D: Bitumen Quality Test Result
D.1: Penetration test

Table D1: penetration Quality Test result

Test no	Temp test(C⁰)	Time of test(second)	Test load(g)	Reading(0.1mm)			Average(0.1mm)
				1st time	2nd time	3rd time	
1	25	5	100	64.2	61.1	63.5	62.9
2	25	5	100	67.3	63.8	62.7	64.6
3	25	5	100	65.1	67.3	66.2	66.2
Average							**64.6**

D:2 Ductility test

Table D2: Ductility Quality Test result

Test No	Test temp.(C⁰)	Speed cm/min	Ductility(cm)	Average (cm)

1	25	4	97.2	
2	25	5	101	
3	25	5	98.4	**98.86**

D.3 Softening point test

Table D3: softening point Quality Test result

Test No	Temp. when starting heating(C⁰)	Record of liquid temp.in beaker			Softening point(C⁰)
		4 min	5 min	6min	
1	25	34	39	46	46.15
2	24	34	42	48	48.25
Average					**47.2**

D.4 Specific gravity test

Table D4: Specific gravity Quality Test result

Trial no	1	2
Weight of picnometer (g)= (1)	31.89	30
Weight of picnometer + bitumen (g)= (2)	108.06	138.23
Weight of picnometer +bitumen+water (g)= (3)	132.49	137.2
Weight of picnometer +water (g)= (4)	130.43	132.3
Specific gravity=2-1/ (4-1) -(3-2)	1.03	1.05
Relative density=0.997 at 25 ⁰C	0.997	0.997
Specific gravity=density of water(0.997gm/cm3) *specific gravity	1.02	1.04
Average	**1.03**	

Appendix E: Maximum Theoretical Density:

Test Method: ASTM Designation: D 2041 -90

Table E 1: Theoretical maximum specific gravity of un compacted mixture with 5.5 % CSD

Bitumen content	4.30%		4.80%		5.30%		5.80%	
No of trials	1	2	1	2	1	2	1	2
(Ws)g.**A**	1252.9	1251.9	1259.5	1258.3	1266.8	1265.6	1272.9	1271.7
(Wp+w)g.**B**	2396.2	2396.2	2341	2341	2379.7	2379.7	2396.2	2396.2
(Wp+w+s)g.**C**	3124.5	3122.4	3070.1	3066.1	3101.4	3104.8	3121.8	3119.8
Temp. (Wp+w+s) g	25c⁰	24c⁰	25c⁰	25c⁰	25c⁰	25c⁰	24c⁰	24c⁰

Gmm(g/cm3) =A/(A+B-C)	2.388	2.381	2.375	2.360	2.324	2.342	2.326	2.320
Gmm(g/cm3) =K*A/(A+B-C)	2.388	2.382	2.375	2.360	2.324	2.342	2.326	2.321
Average	**2.385**		**2.367**		**2.333**		**2.324**	

Table E 2: Theoretical maximum specific gravity of un compacted mixture with 6.5 % CSD

Bitumen content	4.30%		4.80%		5.30%		5.80%	
No of trials	1	2	1	2	1	2	1	2
(Ws)g.**A**	1251.23	1253.7	1258.8	1259.1	1266.6	1266.2	1273.8	1273.7
(Wp+w)g.B	2379.7	2379.7	2341	2341	2379.7	2379.7	2396.2	2396.7
(Wp+w+s)g.**C**	3107.8	3108.9	3065.6	3067.9	3107.3	3101.8	3122.1	3120.2
Temp. (Wp+w+s) g	24c⁰	25c⁰	23c⁰	23c⁰	23c⁰	23c⁰	22c⁰	23c⁰
Gmm(g/cm3) =A/A+B-C	2.392	2.390	2.356	2.366	2.350	2.327	2.325	2.315
Gmm(g/cm3) =K*A/A+B-C	2.393	2.390	2.358	2.367	2.351	2.328	2.327	2.316
Average	**2.391**		**2.362**		**2.340**		**2.321**	

Table E 3: Theoretical maximum specific gravity of un compacted mixture with 7.5 % CSD

Bitumen content	4.30%		4.80%		5.30%		5.80%	
No of trials	1	2	1	2	1	2	1	2
(Ws)g.**A**	1250.52	1252.8	1259.1	1259.4	1263.5	1265.4	1271.1	1272.8
(Wp+w)g.**B**	2379.7	2377.7	2396.2	2396.2	2379.7	2379.7	2341	2341
(Wp+w+s)g.**C**	3105.7	3100.5	3113.5	3120.8	3098.8	3104.5	3062.8	3068.9
Temp. (Wp+w+s) g	25c⁰	25c⁰	22c⁰	22c⁰	21c⁰	21c⁰	22c⁰	22c⁰
Gmm(g/cm3) =A/A+B-C	2.384	2.364	2.324	2.362	2.329	2.344	2.314	2.336
Gmm(g/cm3) =K*A/A+B-C	2.384	2.364	2.326	2.363	2.332	2.346	2.316	2.337
Average	**2.374**		**2.341**		**2.333**		**2.327**	

Table E.4: K value for Water temperature

C°	18	19	20	21	22	23	24	25	26	27	28	29
K value (Water temp correction)	1.0016	1.0014	1.0012	1.001	1.0007	1.0005	1.0003	1	0.9997	0.9995	0.9992	0.9989

Table E 5: Theoretical Maximum Specific Gravity un compacted mixture at 5.3% OBC

Theoretical Maximum Specific Gravity of HMA Mixtures for 5.5% filler content at 5.3% OBC												
Filler proportion	100%CSD $ 0% FC		90%CSD$10%FC		80%CSD$20%FC		70CSD%$30%FC		60%CSD$40%FC		50%CSD $50%FC	
No of trials	A	B	A	B	A	B	A	B	A	B	A	B
(Ws)g.**A**	1266.7	1265.9	1260.5	1262.3	1261.5	1264.6	1261.5	1261.7	1262.5	1263	1261.5	1262
(Wp+w)g.**B**	2342.5	2342.5	2380.5	2379.5	2392.5	2392.7	2392.5	2392.5	2380.5	2380.5	2392.5	2392.5
(Wp+w+s)g.**C**	3070.5	3072.4	3104.1	3107.4	3115.6	3119.8	3115.1	3116.1	3103.1	3105.2	3114	3116
Temp. (Wp+w+s) g	26c°	26c°	25c°	25c°	25c°	25c°	25c°	25c°	25c°	25c°	25c°	25c°
Gmm(g/cm3) =A/A+B-C	2.351	2.362	2.348	2.362	2.343	2.353	2.341	2.345	2.338	2.346	2.336	2.344
Gmm(g/cm3) =K*A/A+B-C	2.351	2.361	2.348	2.362	2.343	2.353	2.342	2.345	2.338396	2.3456	2.336111	2.343547
Average	**2.353**		**2.355**		**2.348**		**2.343**		**2.342**		**2.340**	

CSD= Crushed Stone Dust,

FCP= Filter cake Powder

Ws= Sample weight in Air

Wp+w=Weight of picnometer with Water

Wp+w+s= Weight of picnometer +Water + sample and Gmm (Maximum Theoretical Specific Gravity) = K*A/(A+B-C)

APPENDIX F: Marshal Mix Design Test Results

APPENDIX F 1: Asphalt mix with Crushed Stone Dust Filler Content = 5.5%

Table F1: Marshal properties of asphalt mixture with 5.5 Crushed stone dust (CSD) with different bitumen contents

Tested by: Buzunesh Gutu	**Test name : ______________**	**Bulk specific gravity of aggregate: 2.61**
Location: Jimma University,JIT	**Test number:_____________**	**Filler material: Crushed stone dust**
Sample: Asphalt concrete mix	**Date tasted: ______________**	**Test method: AASTM D 1559/AASHTO T245**
Project: MSc Thesis	**Bitumen grade: 60/70 penetration grade**	
Checked by: _____________	**Spe. gravity of bitumen: 1.03**	

% of BC	Sp.ht	Gmm	Mass of specimen(g) Dry Wt(g)	Submerged wt(g)	SSD wt.(g)	Volume of specimen(cc)	Gmb	VA (%)	VMA (%)	VFA (%)	Stability (kN) Measured Stability	Peak load	Flow(mm)
						H	I	J	K	L			
A	B	D	E	F	G	G-F	E/H	(D-I)*100/D	(100-((100-Pb)/Gsb*Gmb)	(K-J)/K*100			
4.3	67.5		1232.9	690.3	1244.9	554.6	2.223	6.8	14.5	53.3	8.25	9.50	2.48
	68.5		1234.9	691.2	1242	550.8	2.242	6.0	13.8	56.6	8.67	10.04	2.67
	67		1235.8	691.3	1247.8	556.5	2.221	6.9	14.6	52.9	8.44	9.70	2.88
Mean±St.dv	**67.7**	**2.385**	**1234.5**	**690.9**	**1244.9**	**554.0**	**2.229±0.011**	**6.6±0.49**	**14.3±0.45**	**54.2±2.02**	**8.45±0.21**	**9.75±0.27**	**2.68±0.20**
4.8	68		1240.9	690.7	1249.4	558.7	2.221	6.2	14.6	57.8	10.36	11.58	4.23
	69		1248.8	700.5	1256.5	556	2.246	5.1	13.7	62.6	11.31	12.90	2.77
	68		1241.6	695.6	1248.5	552.9	2.246	5.1	13.7	62.5	10.80	12.40	2.30
Mean±St.dv	**68.3**	**2.367**	**1243.8**	**695.6**	**1251.5**	**555.9**	**2.238±0.143**	**5.5±0.60**	**14.0±0.55**	**61.0±2.73**	**10.82±0.48**	**12.29±0.67**	**3.10±1.01**
5.3	67		1251.5	697.6	1254.6	557	2.247	3.7	13.6	72.9	10.26	11.17	3.48
	69.5		1245.2	693	1248.2	555.2	2.243	3.9	13.8	72.0	9.47	10.94	2.89
	69.5		1248.4	695.6	1251.4	555.8	2.246	3.7	13.7	72.7	9.82	11.60	3.18
Mean±St.dv	**68.7**	**2.333**	**1248.4**	**695.4**	**1251.4**	**556.0**	**2.245±0.002**	**3.8±0.09**	**13.7±0.08**	**72.5±0.51**	**9.85±0.39**	**11.24±0.34**	**3.18±0.29**
5.8	70		1262.3	703.3	1265.7	562.4	2.244	3.4	13.7	75.1	8.67	10.15	3.63
	69		1255.5	698.9	1259.7	560.8	2.239	3.7	13.9	73.7	8.85	10.10	3.55
	69		1256.1	702.1	1257.2	555.1	2.263	2.6	13.0	79.8	8.77	10.40	3.67
Mean±St.dv	**69.3**	**2.324**	**1258.0**	**701.43333**	**1260.9**	**559.4**	**2.249±0.013**	**3.2±0.54**	**13.6±0.48**	**76.2±3.19**	**8.76±0.09**	**10.22±0.16**	**3.62±0.06**

APPENDIX F 2: Asphalt mix with Crushed Stone Dust Filler Content = 6.5 %

Table F2: Marshal properties of asphalt mixture with 6.5 Crushed stone dust (CSD) with different bitumen contents

Tested by:Buzunesh Gutu **Test name :** ______________ **Bulk specific gravity of aggregate: 2.61**

Location: Jimma University,JIT **Test number:**_____________ **Filler material: Crushed stone dust**

Sample: Asphalt concrete mix **Date tasted:** ______________ **Test method: AASTM D 1559/AASHTO T245**

Project: MSc Thesis **Bitumen grade: 60/70 penetration grade**

Checked by: _____________ **Spe. gravity of bitumen: 1.03**

% of BC	Sp.ht	Gmm	Mass of specimen(g) Dry Wt.(g)	Subm..wt(g)	SSD Wt.(g)	Volume of specimen(cc)	Gmb	AV (%)	VMA (%)	VFA (%)	Stability (kN)		
						H	I	J	K	L			
A	B	D	E	F	G	G-F	E/H	(D-I) *100/D	(100-((100-Pb)/Gsb*Gmb)	(K-J)/K*100	Measured Stability	Peak load	Flow(mm)
4.3	67.5		1237.9	692.3	1248.9	556.6	2.224	7.0	14.5	51.8	8.43	9.70	2.88
	67		1238.9	695.1	1250	554.9	2.233	6.6	14.2	53.2	8.10	9.38	3.41
	68.5		1242.8	694.3	1250.8	556.5	2.233	6.6	14.1	53.3	8.51	9.76	3.12
Mean±St.dv	**67.7**	**2.391**	**1239.9**	**693.9**	**1249.9**	**556.0**	**2.230±0.005**	**6.7±0.22**	**14.3±0.19**	**52.8±0.85**	**8.35±0.22**	**9.61±0.19**	**3.14±0.27**
4.8	69		1243.6	698.1	1252.7	554.6	2.242	5.1	13.8	63.3	9.09	10.37	3.65
	69.5		1239.3	692.8	1244.9	552.1	2.245	5.0	13.7	63.8	9.21	10.64	3.29
	69		1240.6	695.6	1249.5	553.9	2.240	5.2	13.9	62.8	9.11	10.74	3.35
Mean±St.dv	**69.2**	**2.362**	**1241.2**	**695.5**	**1249.0**	**553.5**	**2.242±0.002**	**5.1±0.10**	**13.8±0.09**	**63.3±0.51**	**9.14±0. 06**	**10.58±0.19**	**3.43±0.19**
5.3	69		1244.5	693.2	1248.5	555.3	2.241	4.2	13.8	69.5	8.04	9.28	3.83
	69		1240.2	690.5	1243.6	553.1	2.242	4.2	13.8	69.7	8.66	10.00	3.35
	69.5		1243.9	695.6	1245.8	550.2	2.261	3.4	13.1	74.2	8.32	9.7	3.48
Mean±St.dv	**69.2**	**2.34**	**1242.9**	**693.1**	**1246.0**	**552.9**	**2.248±0.011**	**3.9±0.47**	**13.6±0.42**	**71.1±2.62**	**8.34±0.31**	**9.66±0.36**	**3.55±0.25**
5.8	70		1257.3	699.3	1259.5	560.2	2.244	3.3	13.7	76.0	8.38	10.51	4.08
	69		1250.9	696	1252.5	556.5	2.248	3.2	13.6	76.8	8.22	10.61	3.69
	69		1256.1	701.1	1257.2	556.1	2.259	2.7	13.2	79.6	8.29	9.75	3.92
Mean±St.dv	**69.3**	**2.321**	**1254.8**	**698.8**	**1256.4**	**557.6**	**2.250±0.008**	**3.0±0.32**	**13.5±0.29**	**77.5±1.93**	**8.30±0.08**	**10.29±0.47**	**3.90±0.19**

APPENDIX F 3: Asphalt mix with Crushed Stone Dust Filler Content =7.5 %

Table F3: Marshal properties of asphalt mixture with 7.5 Crushed stone dust (CSD) with different bitumen contents

Tested by:Buzunesh Gutu **Test name : _______________** **Bulk specific gravity of aggregate: 2.61**

Location: Jimma University,JIT **Test number:______________** **Filler material: Crushed stone dust**

Sample: Asphalt concrete mix **Date tasted: _______________** **Test method: AASTM D 1559/AASHTO T245**

Project: MSc Thesis **Bitumen grade: 60/70 penetration grade**

% of BC	Sp ht	Gmm	Mass of specimen(g) Dry Wt.(g)	Subm.wt(g)	SSD Wt.(g)	Volume of specimen(cc)	Gmb	VA (%)	VMA (%)	VFA (%)	Stability (kN) Measured Stability (KN)	Peak load (KN)	Flow (mm)
						H	I	J	K	L			
A	B	D	E	F	G	G-F	E/H	(D- I) *100/D	(100-((100-Pb)/Gsb*Gmb)	(K-J)/K*100			
4.3	67.5		1237.9	695.3	1248.9	553.6	2.236	5.8	14.0	58.6	8.90	10.2	3.21
	68		1236.9	694	1250	556	2.225	6.3	14.5	56.5	8.61	9.94	2.65
	67		1242.8	691.3	1250.8	559.5	2.221	6.4	14.6	55.9	8.82	10.30	2.89
Average	**67.5**	**2.374**	**1239.2**	**693.5**	**1249.9**	**556.4**	**2.227±0.008**	**6.2±0.33**	**14.4±0.29**	**57.0±1.39**	**8.78±0.15**	**10.15±0.18**	**2.92±0.28**
4.8	68		1250.33	691.31	1256.5	565.19	2.212	5.5	15.0	63.2	8.06	9.43	3.22
	67		1243.6	696.2	1247.8	551.6	2.255	3.7	13.3	72.3	10.12	11.81	3.81
	69		1246.6	693.2	1249.9	556.7	2.239	4.3	13.9	68.8	9.31	10.9	3.08
Average	**68.0**	**2.341**	**1246.8**	**693.6**	**1251.4**	**557.8**	**2.235±0.021**	**4.5±0.92**	**14.1±0.82**	**68.1±4.57**	**9.16±1.04**	**10.71±1.20**	**3.37±0.39**
5.3	69		1249.5	696.1	1252.2	556.1	2.247	3.7	13.6	72.9	9.69	11.05	3.33
	68.5		1250.6	701.1	1252.5	551.4	2.268	2.8	12.8	78.3	9.88	11.13	4.08
	69		1249.4	693.1	1251.1	558	2.239	4.0	13.9	71.1	9.82	11.56	3.30
Average	**68.8**	**2.333**	**1249.8**	**696.8**	**1251.9**	**555.2**	**2.251±0.015**	**3.5±0.64**	**13.5±0.58**	**74.1±3.73**	**9.80±0.09**	**11.25±0.27**	**3.57±0.44**
5.8	68		1251	697.8	1252	554.2	2.257	3.0	13.2	77.4	9.52	11.70	4.35
	69		1247.6	696.2	1248.4	552.2	2.259	2.9	13.2	77.9	9.10	10.74	4.38
	70		1251.9	694.1	1252.2	558.1	2.243	3.6	13.8	73.8	9.30	11.1	3.71
Average	**69.0**	**2.327**	**1250.2**	**696.0**	**1250.9**	**554.8**	**2.253±0.009**	**3.2±0.38**	**13.4±0.34**	**76.4±2.20**	**9.31±0.21**	**11.18±0.43**	**4.15±0.38**

APPENDIX F 4: Asphalt mix with Partial replacement of filter cake powder.

Table F4: Marshall Mix Properties of Asphalt mix with Filter cake powder at 5.3% OBC and 5.5% CSD

Tested by: Buzunesh Gutu | **Test name: ______________** | **Bulk specific gravity of aggregate: 2.61**

Location: Jimma University, JIT | **Test number: _____________** | **Filler material: CSD and FCP**

Sample: Asphalt concrete mix | **Date tasted: ______________** | **Test method: AASTM D 1559/AASHTO T245**

Project: MSc Thesis | **Bitumen grade: 60/70 penetration grade**

Checked by: _____________ | **Spe. gravity of bitumen: 1.03**

% of BC	Sp.ht			Gmm	Mass of specimen(g) Dry Wt.(g)	Subm.wt(g)	SSD Wt.(g)	Volume of specimen(cc)	Gmb	VA	VMA	VFA			
								H	I	J	K	L			
A	B	% CSD	% WFP	D	E	F	G	G-F	E/H	(D-I) *100/D	(100-((100-Pb)/Gsb*Gmb)	(K-J)/K*100	Stability	Flow	peak load
	69	100	0		1240.80	690.50	1241.10	550.60	2.254	4.23	14.03	69.88	10.80	3.81	11.90
	68				1239.50	692.50	1244.50	552.00	2.245	4.57	14.34	68.13	11.40	3.18	12.44
5.3	68.5				1242.10	691.20	1247.30	556.10	2.234	5.07	14.79	65.70	10.30	3.02	12.01
Mean±St.Dev	**68.5**			**2.353**	**1240.80**	**691.40**	**1244.30**	**552.90**	**2.244±0.008**	**4.62±0.35**	**14.39±0.31**	**67.90±1.71**	**10.83±0.45**	**3.34±0.34**	**12.12±0.23**
5.3	69	90	10		1248.00	700.10	1251.70	551.60	2.263	3.93	13.69	71.31	11.19	2.96	12.36
	69				1249.10	697.00	1254.40	557.40	2.241	4.84	14.51	66.63	11.27	3.90	12.52
	68.5				1247.10	698.10	1253.90	555.80	2.244	4.72	14.40	67.22	11.02	2.81	12.86
Mean±St.Dev	**68.83**			**2.355**	**1248.07**	**698.40**	**1253.33**	**554.93**	**2.249±0.009**	**4.5±0.41**	**14.20±0.36**	**68.39±2.08**	**11.16±0.11**	**3.22±0.48**	**12.58±0.21**
5.3	68.5	80	20		1249.10	697.10	1252.70	555.60	2.248	4.25	14.24	70.14	11.58	3.63	13.04
	68				1250.00	701.00	1255.90	554.90	2.253	4.06	14.07	71.13	11.25	2.94	12.5
	68				1250.10	700.50	1254.90	554.40	2.255	3.97	13.98	71.63	11.29	3.20	12.98
Mean±St.Dev	**68.17**			**2.348**	**1249.73**	**699.53**	**1254.50**	**554.97**	**2.252±0.003**	**4.09±0.12**	**14.09±0.11**	**70.97±0.62**	**11.37±0.15**	**3.26±0.28**	**12.84±0.24**
5.3	69	70	30		1250.40	698.10	1255.90	557.80	2.242	4.33	14.49	70.14	11.81	3.31	13.47
	69				1243.00	699.20	1248.50	549.30	2.263	3.42	13.68	75.00	10.79	3.30	11.98

	68.5				1248.40	700.00	1253.80	553.80	2.254	3.79	14.01	72.95	11.86	3.02	13.76
Mean±St.Dev	**68.83**			**2.343**	**1247.27**	**699.10**	**1252.73**	**553.63**	**2.253±0.009**	**3.84±0.37**	**14.06±0.33**	**72.70±1.99**	**11.49±0.49**	**3.21±0.13**	**13.04±0.78**
5.3	69	60	40		1247.30	696.20	1250.20	554.00	2.251	3.87	14.11	72.60	11.66	3.44	13.29
	69				1246.00	694.00	1247.50	553.50	2.251	3.88	14.12	72.53	10.92	3.50	12.16
	69.5				1247.00	696.10	1252.20	556.10	2.242	4.25	14.46	70.58	11.12	3.41	12.97
Mean±St.Dev	**69.17**			**2.342**	**1246.77**	**695.43**	**1249.97**	**554.53**	**2.248±0.004**	**4.00±0.18**	**14.23±0.16**	**71.91±0.93**	**11.23±0.31**	**3.45±0.10**	**12.81±0.48**
5.3	70	50	50		1250.50	696.70	1255.80	559.10	2.237	4.42	14.68	69.90	11.51	3.31	13.47
	71				1250.00	694.50	1253.00	558.50	2.238	4.35	14.62	70.23	10.63	3.60	12.76
	70.5				1251.10	694.80	1253.60	558.80	2.239	4.32	14.59	70.39	11.41	3.51	13.63
Mean±St.Dev	**70.5**			**2.340**	**1250.53**	**695.33**	**1254.13**	**558.80**	**2.238±0.0009**	**4.36±0.04**	**14.63±0.04**	**70.17±0.20**	**11.18±0.39**	**3.54±0.20**	**13.29±0.38**

Where,

BC	Bitumen content
Sp.ht	Specimen height (mm)
M.St	Measured stability
PL	Peak load
Gmb	Compacted bulk specific gravity (kg /m³)
St.Dev	Standard deviation
Gmm	Theoretical maximum specific gravity (kg /m³)
Gsb	bulk specific gravity of total aggregate
SSD	Saturated surface dry

Appendix G: Moisture Susceptibility Test

Table G1: Moisture Susceptibility Test (Test Method: ASTM D 1075).

Sample type	Weight of specimen (gm)			Bulk density(gm/cm³)	Measured Specimen height(mm)	Maximum load (KN)	ITS(Kpa)	Average TSR (%) Cond/uncond	Specification (ASTM D1075)
	in air	in water	SSD						
Un conditioned	1249.5	707.5	1252.5	2.293	67.0	11.2	1.20	83.60	≥75
	1249.4	707.1	1253.1	2.288	66.0	10.1	1.09		
	1248.8	706.1	1252.1	2.287	67.5	9.4	1.00		
Average	**1249.2**	**706.9**	**1252.6**	**2.289**	**66.8**	**10.2**	**1.10**		
Conditioned	1248.0	703.0	1250.5	2.279	68.0	8.8	0.95		
	1249.1	704.2	1251.0	2.284	68.5	8.7	0.92		
	1248.6	699.5	1250.5	2.266	67.0	8.4	0.90		
Average	**1248.6**	**702.2**	**1250.7**	**2.277**	**67.8**	**8.6**	**0.92**		
Un conditioned	1252.0	701.5	1256.0	2.258	69.0	9.9	1.06	90.19	
	1252.5	700.0	1255.2	2.256	69.0	9.6	1.03		
	1253.1	700.8	1254.1	2.265	68.5	9.3	0.99		
Average	**1252.5**	**700.8**	**1255.1**	**2.260**	**68.8**	**9.6**	**1.02**		
Conditioned	1251.5	703.5	1254.5	2.271	68.0	8.6	0.93		
	1252.4	702.8	1255.1	2.268	67.0	8.5	0.91		
	1251.8	703.0	1254.2	2.271	68.0	8.5	0.92		
Average	**1251.9**	**703.1**	**1254.6**	**2.270**	**67.7**	**8.6**	**0.92**		

Appendix H: Photos during the Experimental Study

Source: Muluken.G(Nov-10-2020)

Source: Muluken.G (Nov-10-2020)

Source: Lebeta.G (Nov-07-2020)

Source: Ayantu.B (Dec-01-2020)

Source: Misgana.E(Jan-01-2020)

Source: Mokonen.B (Jan-10-2020)

Source: Jalela.W (Jan-04-2020)

Source: Muluken.G (Dec-18-2020)

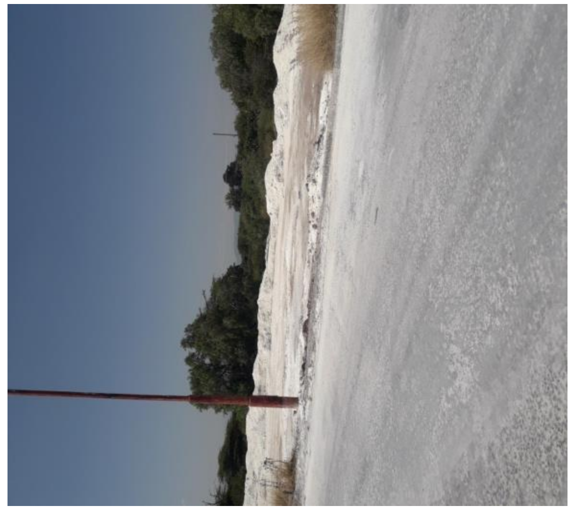
Source: Giza.A (Dec-28-2020)

Source: Eyerusalem.B (Dec-29-2020)

Source:Narob.C Dec-29-2020)

Source:Mokonen.B (Jan-15-2021)

Source: Giza. A(Nov-05-2020)



Source: Buzunesh.G(Oct-15-2020)

Source: Eyerusalem.B (Nov-09-2020)

Source: Eyerusalem.B (Feb -11-2021)

Source: Labeta.B (Jan -04-2021)

Source: Mohamed. A (Jan-12-2021)

Source:Giza.A (Jan-07-2021)

Source:Mokonen.B (Jan-07-2021)

Source:Eyerusalem.B (Feb-01-2021)

Source:Ayantu.B (Feb-02-2021)

Source:Mohamed.B (Jan-14-2021)

Source:Ayantu.B (Nov-06-2021)