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

Potential use of 'Enset' Fiber Ash as Partial Replacement of Conventional Filler Material in Hot Mix Asphalt

A Final Thesis Submitted To The School Of Graduate Studies Of Jimma University In Partial Fulfillment Of The Requirements For The Degree Of Masters of Science In Highway Engineering.

By

Yisak Kibru

April 2021

Jimma, Ethiopia

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Main Advisor: (Ass. Professor) Anteneh Geremew (Ph.D Cand.)

Co-Advisor: Mr. Biruk Yigezu (MSc)

April 2021

Jimma, Ethiopia

SCHOOL OF POST GRADUATE STUDIES JIMMA UNIVERSITY

As a member of the examining board of the final MSc open defense, we certify that we have read and evaluated the thesis prepared by Yisak Kibru Entitled: **Potential use of 'Enset' Fiber Ash as Partial Replacement of Conventional Filler Material in Hot Mix Asphalt**; and it is approved as fulfilling the thesis requirement for the degree of master of science (MSc) in Highway Engineering.

Approved By the Board of Examiners

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Declaration

I, the undersign declare that this research entitled by " ***Potential use of 'Enset' Fiber Ash as Partial Replacement of Conventional Filler Material in Hot Mix Asphalt***" is my original work and has not been presented by any other person on an award of degree in this or other university and all sources of materials used for this thesis have been duly acknowledge.

Candidate: Yisak Kibru

Signature: ______________________ Date__________________

As masters research advisors, we hear by certify that we have read and evaluated this MSc research prepare under our guidance, by Yisak Kibru entitled by "Potential use of 'Enset' Fiber Ash as Partial Replacement of Conventional Filler Material in Hot Mix Asphalt"

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

1. (Ass. Prof.) Anteneh Geremew (PhD. Cand.) _______________ 23 / 04 / 2021 G.C
   Principal advisor Signature Date
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Abstract

A large amount of appropriate quality materials is required for road construction and maintenance work in Ethiopia. The main constituent of the bituminous paving mixes are aggregates in coarse, fine and filler fractions. In many construction sites, aggregates in different size fractions are not readily available, necessitating their procurement from long distances, thereby causing an exorbitant increase in construction costs. One of the main problems in constructing the asphalt paving mixture is obtaining a sufficient amount of filler material from crushing fine rock material and low percent using ordinary Portland cement (OPC), hydrated lime (HL) and marble dust. To overcome this problem, it is important to come across alternative filler material to address this gap using naturally available material. Currently, renewed attention has been given to the use of 'waste' materials instead of conventional aggregates in pavement construction. This research study was to investigate the potential use of 'Enset' fiber ash as a partial replacement of conventional filler material in hot mix asphalt supported by experimental laboratory investigation. In order to achieve this study, purposive sampling techniques were adopted to select the sample size and location. The study evaluated the potential of 'Enset' fiber ash as filler for the design of dense-graded hot mix asphalt by referencing traditional filler control mix procedures based on standard specifications, and a crush rock filler was utilized as a conventional filler material as a control for comparison.

The Marshal Stability and Rutting Test (RT) was conducted to determine the HMA specimen's performance. Several HMA specimens were prepared using aggregate blend according to ASTM D 1559 with four different percentages 'Enset' fiber ash (EFA) of 15%, 25%, 35% and 45% filler replacement by the total filler weight used in the control mix. Specimens were prepared and test performed according to EN 12697-22 procedure-B for rutting test. All HMA properties were taken at 4% air void and determined their optimum bitumen content (OBC). Almost the same result with the control mix was observed in the study at 15% and 25% of the 'Enset' fiber ash (EFA) replacement. However, higher Marshall Stability, a lower void filled with asphalt, better flow, a good void in mineral were observed at 25% 'Enset' fiber ash (EFA) replacement. At this rate, the rutting performance is less than that of the control mix but is within the specifications of 2.78mm and 2.9 mm of rutting depth less than 6mm that is satisfy EN 13108 requirement.

As a result, Enset fiber ash filler can replace traditional filler material 25% of the total filler weight used in this study. It is advised to use 'Enset' fiber ash (EFA) as a filler material as a partial replacements in a bituminous paving mixture.

Keywords: *Marshal stability, Ensete Fiber Ash, Bituminous and Crashed rock fine*

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List of Acronyms

AASHTO	American Association of State Highways and Transport Officials
ACRA	Addis Ababa City Road Authority
AC	Asphalt Concrete
ASTM	American Standard for Test Method
BC	Binder Content
BS	British Standard
CEN	Comitée Eeuropéen De-Normalisation
CFC	Control filler content
CSD	Crushed Stone Dust
CRF	Crushed Rock filler
CSDFC	Crushed Stone Dust Filler Content
EN	Eeuropéen De-Normalisation
ERA	Ethiopian Roads Authority
IFH	International First Highway
EF	Enset Fiber
EFA	Enset Fiber Ash
FA	Fly Ash
FC	Filler Content
HMA	Hot Mix Asphalt
HMAC	Hot Mix Asphalt Concrete
HL	Hydrated lime
MTD	Maximum Theoretical Density
NAPA	National Asphalt Pavement Association
NP	Non-Plasticity
OBC	Optimum Bitumen Content
OPC	Ordinary Portland cement
PRD	Proportion of Rut Depth
SMA	Stone Mastic Asphalt
VFA	Voids Filled by Bitumen
VMA	Void in Mineral Aggregate
VTM	Void in Total Mineral
FRT	Fatigue Resistance Test
RD	Rutting Depth
RT	Rutting Test
WTS	Wheel tracking slop

CHAPTER ONE
INTRODUCTION

1.1 Background

Road construction and maintenance in Ethiopia requires a large amount of good quality materials. Fast growth of continual heavy axel traffic demands better quality of material for paving application. The development and use of modified asphalt mix can meet the needs of the communities. Asphalt modification, can be realized primarily through polymer modification. However, this method is expensive due to the high cost of raw polymer, skilled personnel and special equipment. In the other method, asphalt mix modification can be done by replacing common filler like lime, cement and other suitable materials[1]. Aggregates in coarse, fine and filler fractions are the main constituents of the bituminous paving mixes. In many construction sites, aggregates in different size fractions are not easily available, necessitating their procurement from long distances thereby causing exorbitant increase in cost of construction[2]. All road pavements require the efficient use of locally available materials if economically constructed roads are to be built. This requires the design engineer to have a thorough understanding of not only the soil and aggregate properties that affect pavement stability and durability but also the properties of the binding materials that may be added to these[3]. The most important pavement materials are bitumen and tar, cement and lime, soil and rock, gravel and slag aggregates. In more recent years, for economic and environmental reasons, renewed attention has been given to the use of 'waste' materials in instead of conventional aggregates in pavements[3] so this research investigated the suitability of '**Enset' (Ensete ventricosum)** fiber ash as filler in hot mix asphalt.

Ensete ventricosum, commonly called false banana, belongs to the order Scitamineae, the family Musaceae, and the genus Ensete. It is a close relative to the banana plant (genus Musa) and very similar except that the false banana plant does not bear edible fruits. Instead, the pseudo stem and corms are used as a food source in Ethiopia where the plant is an important staple food cultivated in over 300 thousand ha[4–7]. The domesticated form of the plant is only cultivated in Ethiopia, where it provides the staple food for approximately 20 million people[8]. The height of a typical 'Enset' plant may range from 4 to 13 m, the circumference of the pseudo stem from 1.5 to 3.0 m, the length of the pseudo stem from 2 to 5 m and length and width of the leaves from 4 to 6 m and 0.6 to 0.9 m, respectively [9].

Enset is a very important local food source especially in Ethiopia. The Food and Agriculture Organization reports that, "Enset' provides more amount of foodstuff per unit area than most cereals. It is estimated that 40 to 60 Enset plants occupying 250-375 sq. meters can provide enough food for a family of 5 to 6 people."[10]

The Enset plants are usually matured and harvested when the inflorescence appears; the corm is used directly for food production whiles the lower parts of the leaf sheaths from the pseudo stem are scraped to obtain a starchy pulp used in different popular foods [11]. This process yields solid agricultural residual byproducts with fibrous nature, commonly named fibers. These fibers are sun-dried and used traditionally to make sacks, bags, ropes, mats, and sieves but these applications only use a small fraction of the material and very large quantities of these residues are left without commercial value [4,11]. Thus, the proper valorization of these agricultural remnants for more added value products is the eco-friendly approach for agricultural waste management because it prevents the need for their disposal [12]. The study was evaluated the effects of Enset fiber ash filler on the Marshall properties. Based on the experimental results, the feasibility of Enset fiber ash as alternative filler with optimum proportion will be assessed by comparing with the control mixtures and standard specifications.

1.2 Statement of the Problem

Fillers have traditionally been used in asphalt mixtures to fill the voids between the larger aggregate particles [13]. The influence of different types of fillers on the properties of asphalt concrete mixture as it varies with the particle size, shape, surface area, surface texture and other physical - chemical properties were investigated [14].

Conventionally in Ethiopia fine sand, cement, hydrated lime and crushed stone are used as filler material in bituminous mix. One of the main problems in the construction of asphalt paving mixture is obtaining sufficient amount of filler material and high cost of the use of cement or marble dust as filler material. Since OPC and HL are restricted by Asphalt Institution the use of a maximum limit of 2% proportion to improve the adhesion property of the aggregates only, which is not sufficient quantity to achieve the grading requirements [15]. Rock fine, on the other hand, is obtained by grinding rock, and it requires a significant investment in grinding machinery as well as a significant amount of energy to produce adequate quantities. If these fines are not carefully deposited to prevent moisture absorption, it can take a long time for them to dry. Especially in Gurage zone and around Wolkite there is no permanent rock fine production plant.

The aim of this study is to find effective types of cheap and non-conventional filler material to overcome this problem. For this purpose, '**Enset' Fiber ash** was used as non-conventional filler. The characteristics of the mixtures containing different percentage of filler were evaluated by examining fundamental material properties and by performing various laboratory tests.

Therefore, it is important to come across an alternative type of filler materials. This study were investigated the potential use of Enset fiber ash on the Marshall properties of HMA.

1.3 Research Questions

The researcher formulates the following research questions to conduct the study:

1. What are the engineering property of aggregate and filler material around Wolkite?
2. What are the characteristics of 'Enset' Fiber Ash as filler material for hot mix asphalt?
3. What are the effects of Enset Fiber Ash as filler on the Marshall properties?
4. What will be the laboratory test result when compared within standard specification?

1.4 Objectives of the Study

1.4.1 General Objective

The general objective of the study would be to investigate the Potential use of 'Enset' fiber ash a partial replacement of conventional filler material in hot mix asphalt.

1.4.2 Specific Objectives

- ✓ To determine the engineering properties of aggregate and filler material that available in Wolkite.
- ✓ To identify the characteristics of Enset Fiber Ash as partial replacement of filler on hot mix asphalt.
- ✓ To determine the effect of Enset Fiber Ash filler on the Marshall properties.
- ✓ To compare laboratory test result with the standard specification.

1.5 Scope of the Study

The scope of the study was to evaluate the potential use of Enset Fiber Ash as alternative filler material in hot asphalt concrete mix design. This study were carried out by using Enset fiber bundles were collected from private Enset plantation or market located around Wolkite, in south-western Ethiopia at harvest age of the plants for food production and aggregate material sample from selected nearby quarry site.

1.6 Significance of the Study

Enset has been cultivated as a food and fiber crop in Ethiopia for several years [5]. According to Central Statistics Authority (CSA) 2010 report of Ethiopia, a total of 395,632 hectare of land is covered by the crop of Enset[16], which 71.6, 28.2 and 0.2% were grown in the Southern Nations, Nationalities and Peoples Region (SNNPR), Oromia and Gambela, respectively[6]. Wild Enset is also common and widespread in central, eastern and southern Africa[17] and Asia[18]. Ensete fibers are sun-dried and used traditionally to make sacks, bags, ropes, mats, and sieves but these applications only use a small fraction of the material and very large quantities of these residues are left without commercial value[4,11]. Thus, the proper valorization of these agricultural remnants for more added value products is the eco-friendly approach for agricultural waste management because it prevents the need for their disposal[12].

Since SNNP has abundance of available ‘Enset’ fiber that can be used as filler material burning and grinding it. Because, it can minimize transportation cost we offer to import other filler materials like cement, lime and marble dust etc. Society Owners, contractors and consultants will benefit from the study as a source of information for highway projects implementing it throughout Ethiopia and particularly the area those crop ‘Enset’ and there is a shortage of filler material.

1.7 Limitation of the Study

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

- The study examines the use of Enset fiber ash as a filler material in HMA using Marshall Mix design procedures and determines rutting performance.
- Only used newly produced Enset fiber ash and Enset fiber product like chemical treated coffee sack, ropes, mats, and sieves was not include in the study.
- Due to availability problem some useful performance test wasn’t checked.
- Due to time and budget constraints the type of bitumen and filler content used in the experiment is limited.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

A road pavement is a structure made up of superimposed layers of selected and treated materials that are laid down on the subgrade or basement surface. A pavement's primary structural role is to sustain and distribute the wheel loads added to the carriageway to the underlying subgrade. Both in-situ soil uncovered by excavation and additional soil deposited to create the upper reaches of an embankment are often referred to as subgrade. Modern pavement design is concerned with developing the most economical combination of pavement layers that will ensure that the stresses and strains transmitted from the carriageway do not exceed the supportive capacity of each layer, or of the subgrade [3].

At the same time, the pavement materials themselves should not deteriorate to any serious extent within a specified period of time [19] Major variables affecting the design of a given pavement are therefore the volume and composition of traffic, the subgrade environment and strength, the materials economically available for use within the pavement layers, and the thickness of each layer[3,19].

There are three major types of pavements: flexible or asphalt pavements, rigid or concrete pavements, and composite pavements[20]. Flexible pavements' include pavements with unbound granular aggregate layers and pavements with aggregate layers that are bound together with bitumen. It also includes pavements that may contain layers of aggregate that are bound together (or stabilized) with hydraulic binders such as cement and lime, but with relatively low levels of binder. Pavements which include a layer of high strength Portland cement concrete are called 'rigid' pavements and are designed on different principles [19]. This research would be focused on flexible pavement therefor the preceding reviews are concerning on flexible pavement.

2.2. Theoretical Review

The pavement is made up of many components, including the sub-grade, sub-base, base, and surface layer. Aggregate and asphalt binder make up the majority of asphalt concrete. By weight, aggregate makes up approximately 95% of a Hot Mix Asphalt (HMA) mixture, with asphalt binder accounting for the remaining 5%. A standard HMA mixture contains around 85% aggregate, 10% asphalt binder, and 5% air voids by volume. Asphalt binder glues the aggregate together and that means without asphalt binder HMA would simply be screened and grinded stone or gravel. Small amounts of additives and admixtures are added to many HMA mixtures to enhance their performance or workability[21].

2.2.1. Structural Components of Flexible Pavement Layers

Flexible Pavements of the Past Traditional versatile pavements are layered structures with better materials on top where stress level is high and poor materials below where stress intensity is minimal. Following this design concept allows for the use of local materials which typically results in the most cost-effective design. This is particularly true in regions where high-quality materials are expensive but local materials of inferior quality are readily available[20]. This is made up of a series of granular layers with a thin, high-quality bituminous film on top (surface dressing or asphalt concrete).

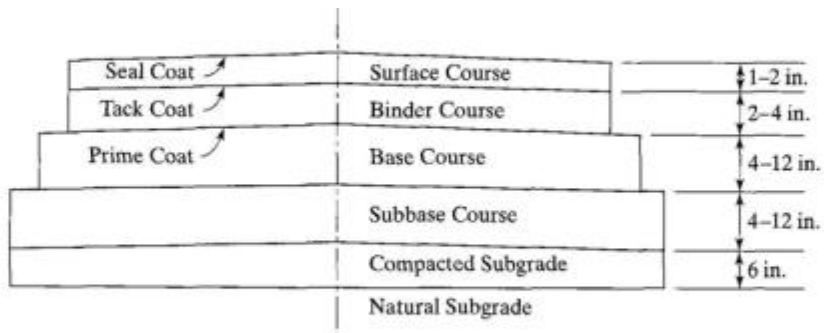

Figure2. 1 Typical cross section of a conventional flexible pavement (1 in. = 25.4 mm)[20]

A. Subgrade (Prepared Road Bed)

The top 6 in. (152 mm) of subgrade should scarify and compress the subgrade to the desired density near the maximum moisture content. The subgrade is the natural layer that runs parallel to the pavement's horizontal orientation and acts as the pavement's base. It also may consist of a layer of selected borrow materials, well compacted to prescribed specifications[20,22]

B. Sub-base Course

The sub-base section, which is located directly above the subgrade, is made of a higher-quality material than is typically used for subgrade construction. Sub-base material specifications are generally expressed in terms of gradation, plastic properties, and weight. The sub-base portion can be excluded if the consistency of the subgrade material satisfies the specifications of the sub-base material. Where a suitable sub-base material is unavailable, the existing material may be treated with other materials to obtain the desired properties. This process of treating soils to improve their engineering properties is known as stabilization[22].

C. Base Course

The base course is situated directly above the sub-base. If a sub-base course is not used, it is set directly above the subgrade. Crushed stone, crushed or uncrushed slag, crushed or uncrushed gravel and sand are common granular materials used in this course. Base course material specifications are typically more stringent than sub-base material specifications, especially in terms of plasticity, gradation, and weight. Materials that lack the required properties may be used as base materials if correctly stabilized with Portland cement, asphalt, or lime. In some cases, high-quality base course materials also may be treated with asphalt or Portland cement to improve the stiffness characteristics of heavy-duty pavements[22].

D. Surface Course

The surface course is the upper course of the road pavement and is constructed immediately above the base course. The surface course is the upper course of the road pavement, built directly over the base course. The surface course of lightweight pavements is usually made up of a combination of mineral aggregates and asphalt. It should be able to withstand high tire pressures, resist abrasive forces caused by traffic, have a skid-resistant driving surface, and prevent surface water from penetrating into the underlying layers. The thickness of the wearing surface can vary from 3 in. to more than 6 in., depending on the expected traffic on the pavement. The quality of the surface course of a flexible pavement depends on the mix design of the asphalt concrete used[23]. It may have two layers which are:-

I. Tack Coat and Prime Coat

A tack coat is a very light application of asphalt, typically diluted asphalt emulsion, used to maintain a bond between the surface being paved and the overlying course. Each layer of an asphalt pavement must be bonded to the layer below. Tack coats are often used to adhere the asphalt coating to a PCC foundation or an existing asphalt pavement. A tack coat must meet three basic requirements: it must be very thin, it must cover the whole surface to be paved evenly, and it must be able to split or cure before the HMA is laid. A prime coat is a thin coating of low-viscosity cutback asphalt applied to an absorbent surface, such as an untreated granular foundation, before an asphalt sheet is applied. Its function is to adhere the granular base to the asphalt sheet. A tack coat differs from a prime coat in that it does not involve asphalt penetration into the underlying layer, while a prime coat penetrates into the underlying layer, fills the voids, and forms a watertight surface. Although the type and quantity of asphalt used are quite different, both are spray applications[20].

II. Binder Course:

The binder course, also known as the asphalt base course, is the asphalt layer beneath the surface course. A binder course is used in addition to the surface course for two reasons. Second, since the HMA is too dense to compress in a single layer, it must be put in two layers. Second, since the binder course typically consists of larger aggregates and less asphalt and does not demand the same degree of consistency as the surface course, replacing a portion of the surface course with the binder course results in a more cost-effective design[20]. Additionally, it facilitates the construction of the surface layer.

ASTM D3515-01 is a standard published by the American Society for Testing and Materials that specifies international gradation limits for the asphalt binder course. Table (2.1) and Figure (2.1) indicates international gradation limits for the dense graded asphalt binder course (ASTM D3515-01) [12].

Table2. 1Gradation Limits of Dense Graded Asphalt Binder Course (ASTM D3515)

Sieve size (mm)	Percentage by Weight Passing	
	Min	Max
25.00	100	100
19.00	90	100
12.50	67	85
9.50	56	80
4.75	35	65
2.36	23	49
0.30	5	19
0.15	3	14
0.075	2	8

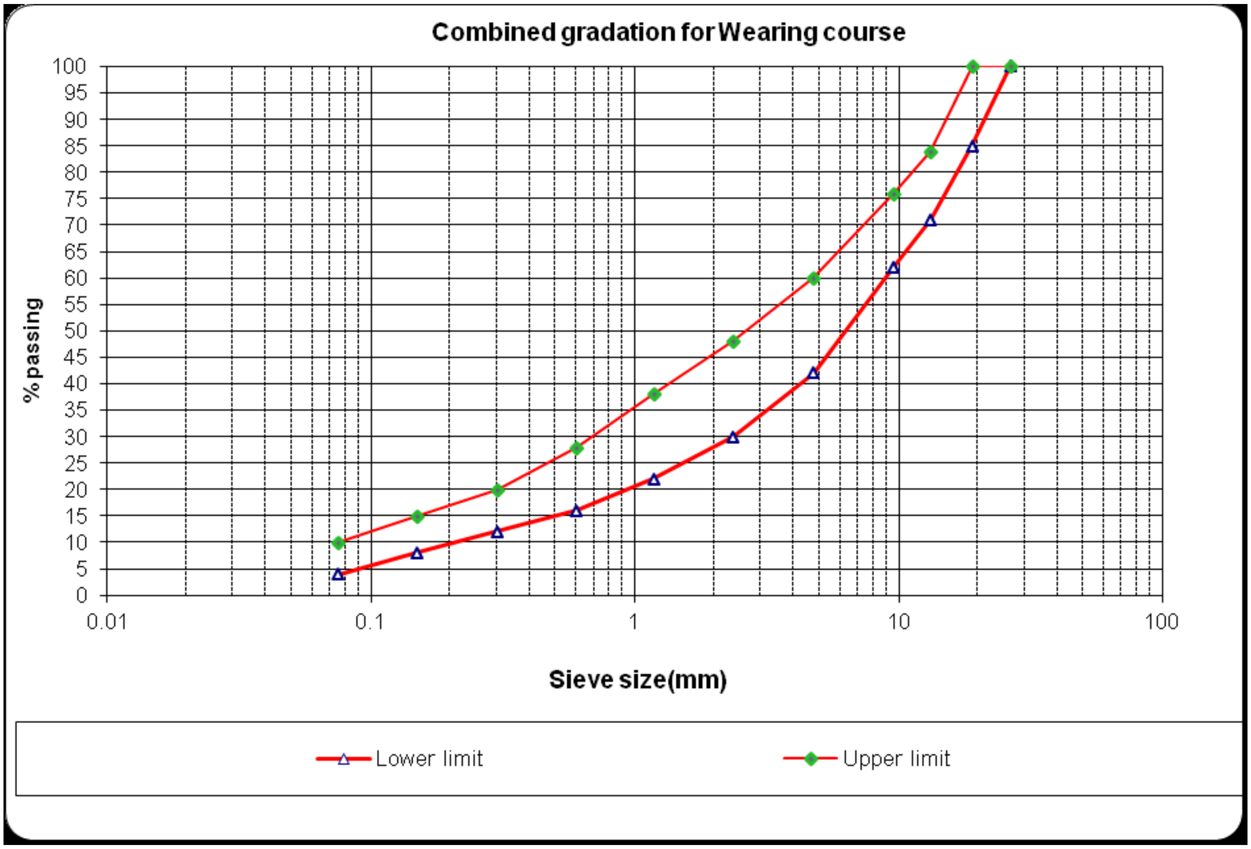

Figure2. 2 Gradation Limits of Dense Graded Asphalt Binder Course (ASTM D3515)

III. Wearing Course:

The surface course is the top course of an asphalt pavement and is often referred to as the surface course. It is usually made of thick graded HMA. It must be rugged in order to withstand traffic distortion and have a flat, skid-resistant riding board. It must be waterproof in order to shield the entire pavement and subgrade from water's eroding effect. If the above requirements cannot be met, the use of a seal coat is recommended[20].

IV. Seal Coat

Seal coat is a thin asphalt surface treatment used to waterproof the surface or offer skid resistance in areas where traffic has polished the aggregates in the surface course and made them slick. Depending on the purpose, seal coats might or might not be covered with aggregate[20].

2.3 Source and preparation of natural fiber ash

Natural fibers have found recent use as reinforcing and extending materials for many materials, mainly in polymeric materials and cements[24]. Wood flour, rice husk, mango, bagasse, sisal, coconut coir, palm, jute, cotton, and bamboo are among the most commonly used natural fibers. Natural fiber based products have many advantages over other materials such as their light weight, low-cost, good mechanical properties[25,26]. Water resistance, better dimensional stability, recyclability, and environmental friendliness[27]. Natural fibers come in a variety of shapes and sizes, including short and long fibers, spun or knitted fibers, particulates, and random fibers. Fibers with chemical and physical surface treatments can also be obtained in order to improve the mechanical properties of final products[28]

The experiment uses Ethiopian fibers from the plant Ensete ventricosum (false banana) and sisal fiber as reinforcing materials for the composite fabrication process. The sisal fibers used in this study came from Wonji in Ethiopia's Oromia region. The fibers were manually harvested from the plant here. However, false banana fiber was purchased from a nearby store. Fibers from plants grown in Ethiopian plantations were chosen for the experiment because they are environmentally sustainable and less costly. Both fibers were then washed cleanly in water to eliminate dirt and other foreign particles and then kept in sunlight up to 12 h to remove water from fibers[29].

Enset fiber bundles were harvested at harvest age from a private Enset plantation near Wolkite, Ethiopia, in the south-western part of the country. The fibers were harvested as long threads after manually scraping the leaf sheaths from the pseudo stem and pushing out and gathering the starchy pulp for food. The fibers were washed and sun-dried[30].

The Enset fiber bundles were chemically characterized previously as reported by Berhanu et al.: 87.5% holocellulose, 59.6% α-cellulose, 8.2% Klason lignin, 2.3% acid soluble lignin, 4.4% extractives and 3.8% ash [31].

Enset fiber is a recycled resource since it is a byproduct of extracting Ensete fiber from the pseudo stem of the Ensete plant. A variety of studies have been conducted to investigate the use of fake banana (Ensete ventricosum) Polyester Composites in the manufacture of bio-based products. It's commonly used in the production of pulp and paper products, as well as in construction materials. The suitability of enset fiber ash as a filler material in hot mix asphalt was explored in this study.

2.4 Components of Mix and Functions

2.4.1 Aggregate Type and Quality Selection

Aggregate properties are critical to the success of hot mix asphalt (HMA) pavements. Pavement pain like rutting, tripping, surface disintegration and a lack of sufficient surface frictional resistance can also be traced back to poor aggregate selection and application. As a result, caution must be applied when choosing mineral aggregates and all quality assurance checks must be performed to ensure that they follow a particular project specification. The aggregate category has a major impact on asphalt mixture fatigue resistance and permanent deformation. Aggregates are thought to give the mixture durability under different traffic loads, resistance to wear from traffic's abrasive action, and frost resistance. As a result, evaluating the physical properties of different mineral aggregates is important in order to produce a combination that performs well.

2.4.1.2. Aggregate Classification

Aggregate for HMA are generally classified according to their formation is divided into three general types: sedimentary, igneous and metamorphic[19].

A. **Sedimentary:** Sedimentary rocks are formed in layers by the accumulation of sediment (fine particles) that deposited by wind and water, it may contain:

- ✓ Mineral particles or fragment (in case of sandstone and shale)
- ✓ Remains or products of animal (certain limestone)
- ✓ Plant (coal)
- ✓ End product of chemical action or evaporation (salt, gypsum)
- ✓ Combination of these types of material

B. **Igneous:** Igneous rock is made up of liquid material (magma) that has solidified since cooling. Extrusive and invasive are the two forms. Extrusive igneous rock, according to the ERA textbook, is shaped debris that has spilled out onto the earth's surface after a volcanic eruption or other geological activity. Since the material cools rapidly when exposed to the atmosphere, the resulting rock has a filler-like look and texture. Extrusive rocks contain rhyolite and basalt. Magma contained deep inside the earth's crust shapes intrusive rock. The magma cools and hardens slowly within the earth, causing a crystalline layer to form. Granite, diorite, and gabbro are examples of igneous rock. Intrusive rock is brought to the surface by soil movement and erosion, where it is quarried and used[19].

C. **Metamorphic**: Metamorphic rock is sedimentary or igneous rock that has been altered by extreme heat and pressure within the crust. Since such formation mechanisms are challenging, identifying the precise origin of a metamorphic rock can be difficult. Many forms of metamorphic rock have a distinct signature feature: the minerals are arranged in parallel planes or layers, according to the ERA manual. Gneisses, schist (igneous rock), and slate are examples of foliated rock (formed from shale, a sedimentary rock)[19].

2.4.1.3. Aggregate Sources

HMA aggregates are usually categorized depending on their origin. Natural aggregate, processed aggregates, and synthetic rock aggregate are also used. Natural Aggregates are those that have been processed minimally or not at all. They are made up of fragments eroded and degraded by natural processes such as wind, water, moving ice, and chemicals. Specific particle form is primarily determined by erosion. Round boulders and pebbles, for example, were often formed by glaciers. Similarly, running water creates particles that are flat and squared. Gravel and sand are the two most common natural aggregates used in pavement construction. Gravel is typically classified as particles with a diameter of 6.35mm or greater. Pericles smaller than 0.075mm are mineral filler, and sand is described as particles smaller than 6.335mm but larger than 0.075mm (No. 200)[32]. Gravels and sands are further divided according to their origin. Pit run goods are materials quarried from an open pit and used without further refining. Materials taken from stream banks are also known as bank-run materials. In order to be used, processed aggregate is quarried, screened, ground, and/or screened. Native gravel that has been screened and graded for use in HMA, as well as bits of bedrock and large stones that must be decreased in size, are the two main suppliers of recycled aggregates[19,33]. Rock is screened and grinded for three reasons;

- To reduce the size and improve the distribution and range of particle size
- To change the surface texture of the particles from smooth to rough
- To change particles shape from round to angular

Aggregates may be either normal or man-made. Natural aggregates are usually collected by open drilling from larger rock formations. Mechanical grinding is usually used to minimize extracted rock to a functional state. Manufactured aggregate is often a waste product in other sectors[34]. The mineral aggregates used in this research were the manufactured one and subjected to various tests in order to assess their physical characteristic and suitability of the road construction. The aggregate was obtained from Shandong Highway Engineering Construction Group Co. Ltd located at SNNP, Gurage zone in Gunchire site. In order to obtain a representative samples for testing, all coarse and fine aggregates were riffled in accordance with AASHTO/ASTM/BS[15]

2.4.1.4 Aggregate Gradation and Size

One of the most influential features of an aggregate is its particle size distribution, or gradation. It defines nearly all HMA properties such as stiffness, flexibility, resilience, permeability, workability, fatigue tolerance, frictional resistance, and moisture resistance. As a result, gradation is the primary consideration in asphalt mix architecture for evaluating aggregate gradation on the creep reaction of asphalt mixtures and estimating pavement rutting. It has been shown that mixtures with aggregate particle size distributions around the mid band of gradation limits, referred to as "medium graded," have slightly greater rutting resistances than mixtures with aggregate gradation below the mid band of aggregate gradation, referred to as "course graded." Kandhal and Allen explored the rutting ability of coarse and fine-grained mixtures. The statistical analysis of the test data revealed that there is no significant difference between the rutting resistance of coarse and fine graded super pave mixtures[35].

A. Aggregate

Aggregates (also known as mineral aggregates) are inert, hard materials such as sand, gravel, crushed rock, slag, or rock dust. HMA pavements are made up of well picked and graded aggregates combined with an asphalt binder. The main load-bearing elements of HMA pavement are aggregates. Since aggregates make up about 95% of the weight of dense-graded HMA, aggregate characteristics have a major effect on HMA pavement performance. HMA aggregates are classified into three categories based on their size: coarse aggregates, fine aggregates, and mineral filler. Coarse aggregates are those that are retained on a 2.36-mm sieve. Fine aggregates pass through the 2.36-mm sieve but stay on the 0.075-mm sieve. Mineral filler is the part of the aggregate that passes through a 0.075-mm sieve. Mineral filler powder, also known as mineral dust or rock dust, is a very thin, inert mineral with a consistency similar to flour that is mixed into hot mix asphalt to increase density and strength of the mixture. It shall be incorporated as part of the combined aggregate gradation [36].

According to (ERA, Pavement Design Manual, 2013) has suggested the following characteristics for aggregates used in HMA. The aggregate should have the following characteristics;

- ✓ Be angular and not excessively flaky, to provide good mechanical interlock;
- ✓ Be clean and free of clay and organic material;
- ✓ Be resistant to abrasion and polishing when exposed to traffic;
- ✓ Be strong enough to resist crushing during mixing and laying as well as in service;

- ✓ Be non-absorptive - highly absorptive aggregates are wasteful of bitumen and also give rise to problems in mix design

B. Mineral Fillers

Mineral filler refers to fine mineral particles that move through a 200-mesh sieve in terms of physical dimension (smaller than 75 microns). Mineral fillers are by-products of different stone crushing operations, demonstrating their suitability for use in hot mix asphalt (HMA) construction[37]. Mineral fillers make the asphalt mortar matrix more rigid. Workability, moisture tolerance, and aging properties of HMA mixtures are all influenced by mineral fillers. Filler, in general, is significant in the properties of bituminous mixtures, particularly in terms of air voids and voids in mineral aggregates[38].

To aid the adhesion of the bitumen to aggregate and fill the hole, mineral fillers such as screened and ground rock fines, Portland cement, or hydrated lime may be used. It should be made of inert materials that move through a 75 micron sieve. Mineral fillers, on the other hand, have a dual purpose as used in asphalt mixtures. As mineral filler that is thinner than the thickness of the asphalt film is mixed with asphalt binder, it forms a mortar or mastic that helps stiffen the blend. The addition of mineral fillers to the binder can cause a change in the properties of the asphalt mixture, such as rutting and cracking. The remaining fillers, which are greater than the asphalt film thickness, work as mineral aggregates, filling voids between aggregate particles and increasing the consistency and strength of the compacted mixture. The properties of HMA mixtures are significantly influenced by mineral fillers. Mineral fillers make the asphalt mortar matrix more rigid. Mineral fillers also affect workability, moisture resistance, and aging characteristics of HMA mixtures.

In general, filler has a major effect on the properties of bituminous mixtures, especially in terms of air voids and mineral aggregate voids. Stone dust, ordinary Portland cement (OPC), slag cement, fly Ash, hydrated lime, and other mineral fillers are used in the SMA mixes.

Marshall Test was used to assess the optimal binder content and waste marble dust collected from the forming phase of marble blocks and lime stone as filler. In stone matrix asphalt mixtures, they used urban solid waste incinerator (MSWI) fly ash as a partial substitute for fine aggregate or mineral filler. They made a comparative study of the performance of the design mixes using Super pave and Marshall Mix design procedures. The amount of natural sand in a blend is often limited because natural sands tend to be rounded, with poor internal friction[39].

2.4.2 Asphalt Binders

Asphalt binders, also known as asphalt cement binders or just asphalt cement, are an essential part of the asphalt concrete mix. They're the binders that tie the composite intact. Asphalt binders are developed as a byproduct of refining crude petroleum to make gasoline, diesel fuel, lubricating oils, and a variety of other petroleum products. The dense, hard residue left over after fuels and lubricants have been separated from crude oil is used to make asphalt binder. Asphalt binders have been mixed with crushed aggregate to form paving materials for over 100 years[36].

Asphalt binders, on the other hand, have a unique set of engineering properties that must be closely managed to ensure good results. The fact that asphalt binders' exact properties almost always depend on their temperature is one of the most critical characteristics that must be discussed in test methods and specifications. At low temperatures, asphalt binders are rigid and brittle, dense fluids at high temperatures and leathery/rubbery semi-solids at moderate temperatures. Pavements can experience performance issues as a result of such drastic changes in properties. A pavement with a too loose binder is vulnerable to rutting and shoving in high temperatures. A pavement with a binder that is too rigid at low temperatures, on the other hand, is vulnerable to low-temperature cracking. The properties of asphalt binders must be regulated at high, medium, and moderate temperatures, according to requirements. Furthermore, research methods used to specify asphalt binders must normally be carried out with extreme caution when it comes to temperature control; otherwise, the findings would be suspect. The time or pace at which asphalt binders are loaded is also very important. An asphalt binder can be much stiffer when measured at a high loading rate than when tested at a sluggish loading rate. Therefore, time or rate of loading must also be specified and carefully controlled when testing asphalt binders[36].

Asphalt binders are difficult to determine and analyze since they are diverse materials. For more than a century, asphalt binders engineers and technicians have worked to produce basic testing and accurate standards. The penetration test, in which a thin, lightly weighted needle was able to penetrate the asphalt for a fixed amount of time, was one of the first experiments for asphalt binders (typically 5 or 60 seconds). The length of the needle's penetration into the asphalt was calculated and used to determine its stiffness. The ring and ball softening point temperature, as well as the ductility test, were other examples of analytical tests. These tests were effective (many are still used in requirements in Europe and elsewhere), but they had flaws. They didn't test any basic properties of the asphalt binder, such as modulus or pressure. The findings were also inconsistent at times, and not necessarily in good alignment between laboratories. Most highway authorities started to follow standards based on viscosity calculations in the 1960s. Viscosity tests outperform prior scientific tests. They have evidence on a fundamental property of the asphalt binder and provide findings that are relatively repeatable through laboratories. There are, however, certain disadvantages of viscosity checking. For starters, it works well at high temperatures, where the asphalt binder's action resembles that of a perfect fluid. Viscosity measurements become difficult to achieve and much more difficult to analyze at low and moderate temperatures. Second, viscosity measurements only reveal a small amount of knowledge about a material's flow properties. At the same temperature, two asphalt binders with equal viscosity values can behave very differently due to variations in the degree of elasticity shown in their behavior. When the asphalt binders are filled, they may all deform the same amount, but when the load is removed, one may spring back to nearly its original shape. The other, on the other hand, might not be able to regenerate at all, remaining in its deformed state. As compared to the other binder with low recovery, the asphalt binder that displayed more recovery that acted in a more elastic manner would appear to have improved rut resistance in paving applications. Viscosity measurements, on the other hand, offer little detail about recovery or the degree of elasticity shown by a substance under pressure.[36].

2.5 Desired properties considered for mix design

2.5.1. Resistance to permanent deformation—stability

The deposition of minor volumes of unrecoverable pressure (small deformations) from repetitive loads applied to the pavement causes permanent deformation. The most popular type of permanent deformation is wheel path rutting. Designing and installing a solid HMA pavement that resists shoving and rutting under traffic provides permanent deformation resistance. Under repeated loading, it will retain its form and smoothness. Ruts and other signs of mixture moving occur on an uneven pavement.

Internal friction produced by aggregate particles and to a lesser degree, stability provided by the asphalt binder determines permanent deformation resistance. The form and surface texture of both the fine and coarse aggregate, as well as the aggregate gradation characteristics, affect inter particle friction among the aggregate particles. The bonding capacity and stiffness characteristics of the asphalt binder cause cohesion. The aggregate particles are prevented from being pushed past one another by the forces exerted by traffic when there is a sufficient amount of inter-particle tension and stability in the mix. The mix's consistency can be improved by using more spherical aggregate particles with a rougher surface texture. As the hardness of the asphalt binder increases or the pavement temperature drops, cohesion increases. Internal tension versus cohesion has a different effect on a mix's resistance to permanent deformation depending on the mix.

Subgrade breakdown and insufficient blend cohesion are the two main causes of rutting. First, rather than the asphalt surface, deformation may occur in the subgrade or underlying layers such as foundation or sub-base (see Figure 2.3). Weak in situ subgrade quality or condition needed for the pavement structure and loading conditions is usually the cause. While stronger paving materials can minimize rutting, it is preferable to address the subgrade or underlying layer instability. Where a combination is unstable, the deformation is confined to the asphalt sheet, resulting in an upheaval at the rut's edge (see Figure 2.4). Although this may lead you to conclude that rutting is an issue with the asphalt binder, it is more accurate to think of rutting in terms of the combined mineral aggregate and binder properties, as well as gradation and volumetric proportioning. The shear strength of an asphalt mixture is mostly improved when using an aggregate with a high degree of internal friction. An angular one has a rough surface texture and is graded to allow particle-to-particle contact to form. When a load is applied to the mixture, the aggregate particles bind tightly together and behave much like a single large, elastic mass. If improving the aggregates does not increase the mixture shear strength enough, a stiffer binder and/or a modified binder can be used[39].

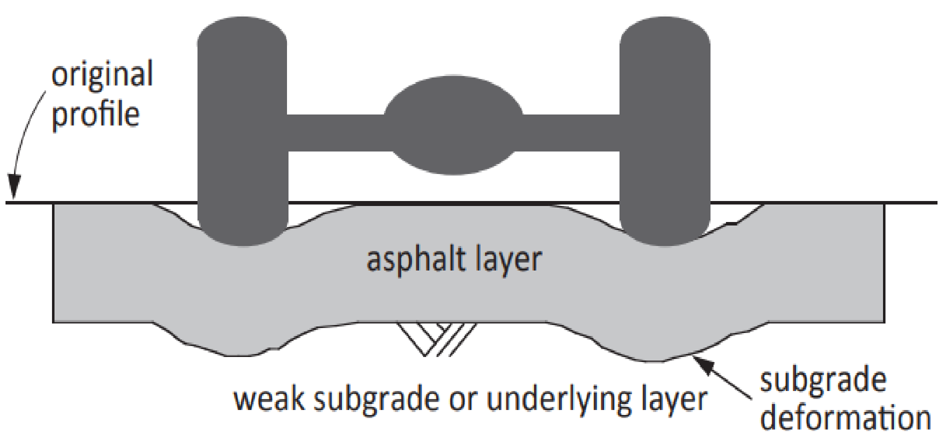

Figure2. 3 Rutting from Weak Subgrade**[39]**

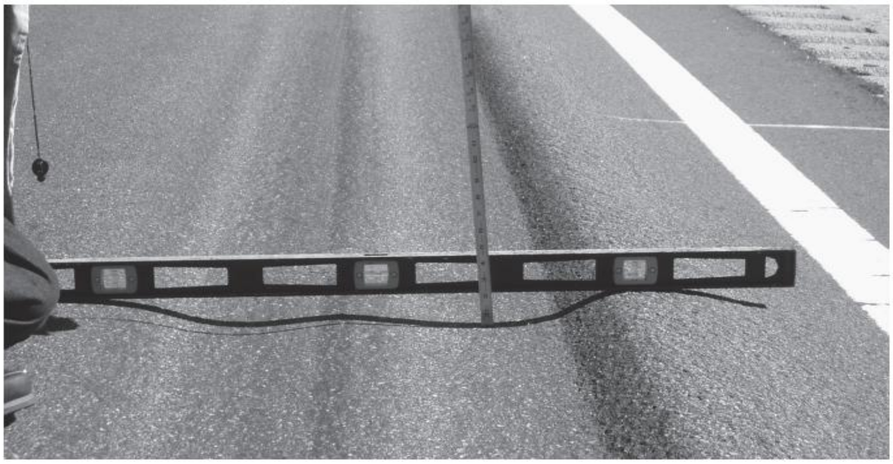

Figure2. 4 Rutting from Weak Mixture**[39]**

2.6 Test that used to determine the performance of HMA

The performance test has become a standard way to assess the behavior of asphalt mixtures and a method to aid in mixture design. The wheel tracking test (WTT) is one method of evaluating rutting success in the laboratory. Various instruments have been designed to carry out this test, which is based on the concept of calculating the irreversible deformations that occur in the mixture as it is placed on a wheel[40]. Several researchers studied the different WTT devices and how they characterize rutting behavior[41–43]. The European Economic Community merged the various WTT principles into the EN 12697-22 standard. Many comparison studies between the old and current WTT standards have been conducted since this standard was established[40].

Permanent deformation (rutting) in asphalt layers develops in three stages (Fig 2.5):

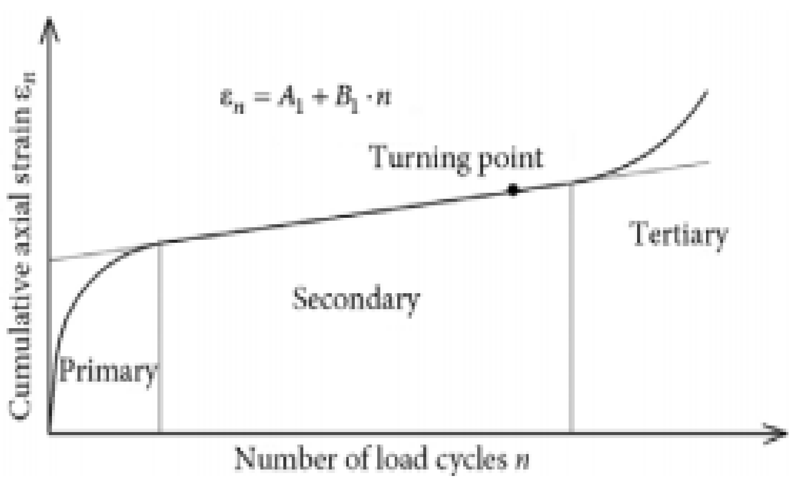

Figure2. 5The typical creep curve of asphalt mixtures according to EN 12697-25:2005 Bituminous Mixtures. Test Methods for Hot Mix Asphalt. Cyclic Compression Test

- The primary (initial) stage of deformation includes the formation and compacting of asphalt mixture by traffic (densification, volume reduction).
- Secondary (middle) stage is thought to be indicative of deformation behavior for the majority of pavement lifespan and continuous rate rutting; traffic load (horizontal and vertical) induces shear stresses in asphalts, resulting in displacement of asphalt mixture and flow rutting;
- The tertiary (last) stage is marked by accelerated rutting and extreme rapid plastic deformations in comparison to the amount of loads; it is a common feature of asphalts that are unsuitable for permanent deformation.

2.6.1 Wheel tracking test

The WTT was used to characterize asphalt mixture rutting performance in the laboratory(40)]. Different types of asphalt mixtures were studied: dense-grade mixtures (course and fine), semi-dense mixtures, M10 and stone mastic asphalts (SMA). These mixtures cover a wide range of grades used as surf mixture in Argentinian roads. In addition, they are made with different types of binders; conventional binders (different viscosity grades) as well as polymer modified binders(40)]. Wheel-tracking test involves the manufacture of 2 parallelepiped test specimens with a roller compactor. The composition of the specimens must be at least 98 percent of the Marshall density. The specimens' height varies based on the maximum aggregate dimension. The specimens are preheated to 60 degrees Celsius before the test. While the European standard lists three kinds of wheel devices, Spain uses Procedure B, which is the smallest[44]

The rut depth assumes that the sample is dense enough for the wheel load to be uniformly dispersed at the bottom of the sample, avoiding more deformation, while the relative rut depth assumes that the whole depth of the sample is deformed. In fact, the truth lies right in the middle of the two hypotheses, but the implication is usually minor if the samples are of equal depths[45].

The deformation resistance is assumed to increase with rut depth and reduced rate of rutting. The categories for specifying deformation resistance by the wheel-tracking test that EN 13108 gives for Europe are listed in Table 2.2. The first ten data points collected were ignored because they had a significant impact on the fit. The deformations in the mixture are unrelated to the shear resistance being studied in this first section. The test conditions have a big impact on the initial settlement (temperature, cycle frequency and load)[40]. The proportional rut depth (PRD) is used as the WTT result in Europe. However, the original deformation of the mixture at the start of the test has an effect on this parameter. This cycle is marked by variations in volume and is independent of the mixture's shear resistance. Current Ethiopian manual suggest to British Standard test (BSI 598: Part 110: 1998) use wheel-tracking test.

Table2. 2 Deformation resistance by the wheel-tracking test (EN13108)**[45]**

European categories for wheel tracking in EN 13108						
Device	Large size	Small size Procedure A		Procedure B		
Measure	Proportional rut depth (%)	Rate (µm/ cycle)	Rut depth (mm)	Rate (µm/ cycle)	Proportional rut Depth (%)	Rut depth (mm)
Categories	<5.0	<5.0	<3.0	<0.02[a]	<1.0[b]	<1.0
				<0.03	<1.5[b]	<1.5
		<7.5	<5.0	<0.04	<2.0[b]	<2.0
	<7.5			<0.05	<2.5[b]	<2.5
		<10.0	<7.0	<0.06	<3.0	<3.0
				<0.07	<4.0	<3.5
	<10.0	<12.5	<9.0	<0.08[c]	<5.0	<4.0
				<0.09[c]	<6.0	<4.5
		<15.0	<11.0	<0.10	<7.0	<5.0
	<15.0			<0.15	<8.0	<6.0
		<17.5	<13.0	<0.30	<9.0	<6.5
				<0.40	<11.0	<7.0
	<20.0	<20.0	<16.0	<0.50	<13.0	<8.0
				<0.60	<16.0	<9.0[d]
		–	–	<0.80	<19.0[b]	<10.0[d]
	–	–	–	<1.00	<20.0[d]	–
	–	–	–	–	<25.0[d]	–
		No requirement				
Asphalt types	AC, BBTM, SMA, PA	HRA	HRA	AC, SMA, PA	AC, SMA, PA	AC, SMA, PA

[a] PA only.
[b] SMA only.
[c] Not for PA.
[d] AC only.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1. Project Location and Topography

The study was conducted at Wolkite town and surrounding Woreda in south-western Ethiopia which is located 158 km away from Addis Ababa. It is the administrative center of the Gurage Zone of Southern Nation Nationalities and Peoples' Region (SNNPR), its geographical coordinates are between 8° 17'N latitude and 37°47'E longitude. Wolkite town is found in an area of average altitude between 1910-1935m above mean sea level. Based on the 2007 Census conducted by the Central Statistical Agency, this town has a total population of 28,866, of whom 15,074 are men and 13,792 women[46].

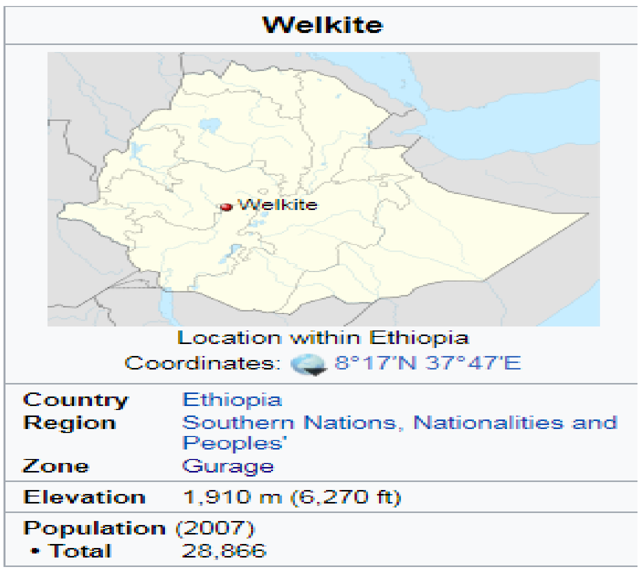

Figure3. 1 Area of study **[Google]**

3.2 Research Design

This research was conduct by using laboratory experimental research design. After organizing literature review of different previously published researches, the study evaluate the suitability of 'Enset' fiber ash as filler for hot mix asphalt design by referencing control mix of conventional filler mixed with bitumen which have 60-70 penetration grade. In this this research conventional filler were used Crushed Rock Fines (CRF) as filler. In particular, AASHTO (T47, T49, T51, T53 and T228-06), ASTM (C13 and C535) and BS (812 part 105(1990), 812 part 3(1995), 812, part 2 (1995)) standard laboratory procedures were perform for all materials properties (bituminous binder, coarse or fine aggregate and fillers. The non-controlled method was used to burn the enset fiber. For the accomplishment of this research goal the applicable practice work research findings and other information on the filler material for the asphalt pavement mixture were reviewed.

Marshal method was used based Asphalt Institute Manual Series MS-02 to determine the suitability of 'Enset' fiber ash as filler. A sample specimen was prepared by compacting 75 blow on both side based on Standard Method (ASTMD1559) having five different bitumen content between 4%, 4.5%, 5%, 5.5% and 6% by total weight of aggregate. Control mixes prepared by using 5.5% crushed rock fine as mineral filler. Furthermore mixes containing 15%, 25%, 35% and 45% by the total weight of control mix filler were replaced by Enset fiber ash for investigation. Be-side with marshal stability test: - Rutting Test (RT) was conducted to determine the performance of the designed mix. The following steps were following for preparation of test specimens:-

a) All materials proposed for use meet the physical requirement standard specifications.
b) Aggregate blend combinations will meet gradation requirements of the specifications.
c) For performing density and voids analyses, the bulk specific gravity of all aggregate will use in the blend and the specific gravity of asphalt cement will determine.

Generally there are four stages to assessing and analyzing data:-

- Characterizing the materials;
  Asphalt binder, Aggregates, Fillers
- Design the mixtures with Enset Fiber Ash (EFA) filler;
  Marshal Mix Design for the fillers
- Evaluation of Enset Fiber Ash (EFA);
  Suitability Evaluation in HMA concrete mixtures
  Determining the performance of the designed asphalt
- Data analysis
  Results were analyzed with Microsoft Office Excel 2007 Program

3.3 Materials

There are different materials were required for producing asphalt specimens. Before designing asphalt mixes; selection, proportioning and characterization of individual material are essential to obtain the desired quality and properties of the finished mix. The Row material used in this study, the crushed course aggregate and fine aggregate are taken from Shandong Highway Engineering Construction Group Co. Ltd located at SNNP, Gurage zone in Gunchire site.

The asphalt cement of 60-70 penetration grades was obtained from ERA (Jimma branch). Enset fiber obtained from markets around Wolkite and nearby Woreda which is located at Gurage Zone, in south-western Ethiopia.

3.4 Tests and Materials Preparation

3.4.1 Aggregate

Asphalt concrete is composed primarily of aggregate and asphalt binder. Aggregate typically makes up about 95% of a Hot Mix Asphalt (HMA) mixture by weight[32]. It can be divided into three types according to their size: coarse aggregates, fine aggregates, and mineral filler. Coarse aggregates are generally defined as those retained on the 2.36-mm sieve. Fine aggregates are those that pass through the 2.36-mm sieve and are retained on the 0.075-mm sieve. Mineral filler is defined as that portion of the aggregate passing the 0.075-mm sieve [36].

3.4.2 Physical properties of Aggregate

3.4.2.1 Particle size distributions for AC wearing courses

The most widely specified aggregate property is particle size distribution. Although only indirectly related to HMA performance, controlling particle size distribution, also called aggregate gradation, is critical to developing an effective mix design. The maximum aggregate size in an aggregate must be matched to the lift thickness used during construction, otherwise the pavement will be difficult to place and compact properly. The distribution of particle sizes in an aggregate must have just the right density so that the resulting HMA will contain the optimum amount of asphalt binder and air voids. Because the shape and texture of aggregate particles vary significantly depending on the aggregate type and the way it is mined and processed, specification limits for aggregate gradation tend to be very broad. This breadth helps technicians and engineers achieve the right blend of aggregates for different applications[36]. The particle size distribution of construction aggregates is usually determined and specified by performing a sieve analysis. For HMA mix design and analysis, an aggregate sieve analysis uses the following standard sieve sizes: 37.5 mm, 25.0 mm, 19.0 mm, 12.5 mm, 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.60 mm, 0.30 mm, 0.15 mm, and 0.075 mm[36]. For this research the nominal size of aggregate was 19 mm. Therefor the arrangement of sieve were used 25mm, 19mm, 9.5mm, 4.75mm, 2.36mm, 0.3mm and 0.075mm. Aggregate gradations are compared to a universal specification ASTM D3515 and a gradation test according to specification (ASTM C136) was performed on a sample of used aggregate for each type of aggregate in a laboratory and the results are presented in Table 4.5 and 4.6. For those aggregate material physical property was determined and their laboratory result was presented in table 4.1.

Determine the job-mix formula, the aggregate analysis will be somewhat governed by the number of aggregate stockpiles and the type of hot mix asphalt mixing facility being used. This phase of mix design establishes the job-mix formula that defines the actual gradation and asphalt content to be obtained in the finished construction. For this research, there were three types of stockpiles which are 13.2-20mm, 7-13.2mm, 3-7mm, 0-3mm and filler. The aggregate gradation is expressed as the percentage by weight of total sample that passes through each sieve. It is determined by weighing the contents of each sieve following the sieve analysis and then calculating the percentage passing in each sieve by one of several mathematical procedures. The method used here was subtracting the weight of the contents of each sieve from the weight of the material passing the previous sieve resulting in the total weight passing each sieve.

Table3. 1 Composition of Asphalt Paving Mixture Specification ASTM D3515[39]

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"	50mm	100				
1 1/2"	37.5mm	90 to 100	100			
1"	25mm	…………	90 to100	**100**		
3/4"	19mm	56 to 80	……..	**90 to100**	100	
1/2"	12.5mm	………..	56 to 80	**……..**	90 to 100	100
3/8"	9.5mm	……….	………..	**56 to 80**	……..	90 to100
No 4	4.75mm	23 to 53	29 to 59	**35 to 65**	44 to 74	55 to 85
No 8	2.36mm	15 to 41	19 to 45	**23 to 49**	28 to 58	32 to 67
No 16	1.18mm	…….	……..	**……..**	………	………
No 30	0.6mm	………	……..	**……..**	………	…….
NO 50	0.3mm	4 to 16	5 to 17	**5 to 19**	5 to 21	7 to 23
No 100	0.15mm	……………	…….	**…….**	……….	……..
No 200	0.075mm	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

3.4.2.2 Aggregate Specific Gravity and Water Absorption

Aggregate specific gravity is determined using different techniques for coarse and fine aggregate. Obtaining accurate specific gravity values for aggregates prior to performing an HMA mix design is essential[36]. Proper laboratory techniques must be taken for these procedures.

Since we have three aggregate type, there would be three different techniques was used to determine specific gravity of each aggregate. For coarse aggregate, specific gravity is determined using the weight-in-water method. In this procedure, coarse aggregate is weighed in air, and then in water, in a mesh basket suspended from a balance. For fine aggregate the pycnometer methods is used and for filler aggregate material were used as a method of determining specific gravity of soil. That means AASHTO T85, AASHTO T84 and AASHTO T 100 standard test procedure were used respectively. All test results were listed on appendix A

Figure3. 2 Determining specific gravity of filler material [Photo by Desta Moshe]

3.4.2.3 Los Angeles Abrasion

Aggregate against wear is an important test for aggregate to be used for road constructions. The Los Angeles (L.A) abrasion test is a common test method used to indicate aggregate toughness and abrasion characteristics. Aggregate abrasion characteristics are important because the constituent aggregate in HMA must resist crushing, degradation and disintegration in order to produce a high quality HMA.

This test give a measure of the resistance of aggregate to surface wears by abrasion. The most widely used abrasion test is the Los Angeles abrasion test. Where aggregate sample is placed in a steel drum with a number of steel balls of 4.8mm diameter and the drum is set to rotate a specified number of times at a specified speed. The Los Angeles abrasion value is the percentage of fines passing the 1.18mm (BS) or1.7mm (ASTM) sieve that gives the abrasion resistance of the aggregate. Soft aggregates are quickly ground to dust while hard aggregates lose little mass. For this research grade B aggregate was used.

Table3. 2 Los Angeles abrasion lab test result

Loss Angeles Abrasion Test for grade B aggregate (AASHTO T-96)					
Sieve Size		Weight of Sample before test ,gm (A)	Weight of Retained on SieveNo.12 ,gm (B)	Weight of passing SieveNo.12 ,gm (C)	LAAV (%) = (C/A)*100
Passing	Retained				
19mm	12.5mm	2500.84			
12.5mm	9.5mm	2500.73			
Total weight		5001.57	4316.47	685.1	14%

3.4.2.4 Aggregate Impact Value

The aggregate impact value gives a relative measure of the resistance of an aggregate to sudden shock or impact which in some aggregates differs from its resistance to a slowly applied compressive load. Also aggregate sizes larger than 14mm are not appropriate for aggregate impact test. The standard aggregate impact test is done on aggregates passing on No. 14mm and retained on No. 10.0mm AASHTO test sieves.

Table3. 3 Aggregate impact value lab test result

AGGRGATE IMPACT VALUE TEST BS 812 Part 112:1990				
S.NO	Weight of aggr.t in before test g(A)	Aggregate passing through 2.36 ASTM sieve in g(B)	Aggregate retained on 2.36 ASTM sieve in g(c)	AIV = (B/A)*100%
1	379	54.8	324.2	14.46
2	381	56.2	324.8	14.75
Average AIV = (AIV1+AIV2)/2				14.605

3.4.2.5 Aggregate Crushing Value (ACV)

Aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under a gradually applied wheel load as compressive load. The standard aggregate crushing test was done on aggregates passing on No. 12.5mm and retained on No. 9.5mm AASHTO test sieves as shown below in table

Table3. 4 Aggregate crushing value Lab test result

AGGRGATE CRUSHING VALUE TEST BS 812 Part 110:1990		
Sample No.	1	2
Size of aggregates ,mm	10 - 14	10 – 14
Maximum load applied ,KN	400	400
Duration of testing ,min	10	10
Weight of sample tested ,gm	2646.6	2663.5
Wt. of sample ret. on 2.36 sieve ,gm	2191.2	2201.1
Aggregate crushing Value ,%	17.21	17.36
Average aggregate. crushing value,%	17.3	

3.4.2.6 Flakiness and Elongation of aggregate

Rounded particles create less particle-to-particle interlock than angular particles and thus providing better workability and easier compaction. However, in HMA less interlock is generally a disadvantage as rounded aggregate will continue to compact, shove and rut after construction. Thus angular particles are desirable for HMA despite their poorer workability, while rounded particles are desirable for PCC because of their better workability. These particles tend to impede compaction or break during compaction and thus may decrease strength.

Figure3. 3 Flakiness and Elongation gages

Those methods is based on the classification of aggregate particles as flaky and elongate when they have a thickness (smallest dimension) of less than 0.6 of their nominal size, this size being taken as the mean of the limiting sieve apertures used for determining the size fraction in which the particle occurs. The flakiness and elongation Index of an aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample tested. The test is not applicable to material passing a 6.30 mm BS test sieve or retained on a 63.0 mm BS test sieve. The sample for this test shall be taken in accordance with BS 812. It shall comply with the appropriate minimum mass, for sieve analysis with due allowance for 63.0 mm BS test sieve and passing a 6.30 mm BS test sieve.

Table3. 5 Elongation index lab test result

Nominal Aperture Size		length Gauge			
100% Passing	100% Retained	Mass passing(g) M_4		Mass retained (g) M_3	
Trial No		1	2	1	2
total sample weight (g)		1998.7	2001	1998.7	2001
63.0mm	50.0mm	0	0	0	0
50.0mm	37.5mm	0	0	0	0
37.5mm	28.0mm	0	0	0	0
28.0mm	20.0mm	0	0	0	0
20.0mm	14.0mm	710.1	715.5	69.3	72
14.0mm	10.0mm	446.5	441	56.9	65
10.0mm	6.30mm	647.2	632.5	68.8	73
total weight (g)		1803.8	1789	195	210
		Trial 1		Trial 2	
total of all weight (g) M2		1998.8		1999	
Elongation index in (%) = (M3/M2)*100		10%		11%	
Average EI= (trial+trial2)/2		10.50%			

Table3. 6 Flakiness index lab test result

Nominal Aperture Size		Thickness Gauge			
100% Passing	100% Retained	Mass retained(g) M4		Mass passed (g) M3	
Trial No		1	2	1	2
total sample weight (g)		2002	2000	2002	2000
63.0mm	50.0mm	0	0	0	0
50.0mm	37.5mm	0	0	0	0
37.5mm	28.0mm	0	0	0	0
28.0mm	20.0mm	0	0	0	0
20.0mm	14.0mm	793.2	729	97.3	98
14.0mm	10.0mm	320.6	348	45.6	58
10.0mm	6.30mm	669.3	682	74.8	83
total weight (g)		1783.1	1759	217.7	239
		Trial 1		Trial 2	
Total of all weight (g) M2		2000.8		1998	
Flakiness index in (%) = (M3/M2)*100		11%		12%	
Average FI=(trial+trial2)/2		11.50%			

3.4.3 Asphalt Binder Selection and Test

The desirable properties of bitumen depend on the mix type and construction. In general, Bitumen should possess following desirable properties.

- The bitumen should not be highly temperature susceptible: during the hottest weather the mix should not become too soft or unstable, and during cold weather the mix should not become too brittle causing cracks.
- The viscosity of the bitumen at the time of mixing and compaction should be adequate. This can be achieved by use of cutbacks or emulsions of suitable grades or by heating the bitumen and aggregates prior to mixing.
- There should be adequate affinity and adhesion between the bitumen and aggregates used in the mix.

In general asphalts can be classified into three general types:

Asphalt cement, Asphalt emulsion and Cutback asphalt. For this experimental research works bitumen of penetration grade 60-70 was used and collected from ERCC (Ethiopian Road Construction Corporation) laboratory. As stated in ERA manual 2013, appendix F it have a better capacity to prevent the possibility of plastic deformation in the new mix, rather than using a soft binder[19] and which is good resistance under heavy traffic and higher temperature[39].

3.4.3.1 Tests on bitumen

There are a number of tests to assess the properties of bituminous materials. For this research the following tests are conducted to evaluate different properties of bituminous materials.

A. Penetration test

It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. ASTM had standardized the equipment and test procedure. The standard penetration test begins with conditioning a sample of asphalt cement to a temperature of 25^{o}C in a temperature controlled water bath and a needle assembly with a total weight of 100g.

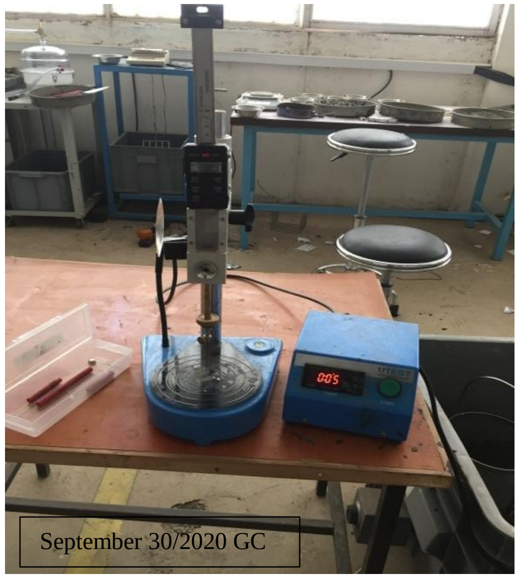

Figure3. 4 Digital bitumen penetration apparatus in Wolkite University

B. Ductility test

Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking.

C. Softening point test

Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. The test is conducted by using Ring and Ball apparatus. A brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature.

D. Specific gravity test

In paving jobs, to classify a binder, density property is of great use. In most cases bitumen is weighed, but when used with aggregates, the bitumen is converted to volume using density values. The density of bitumen is greatly influenced by its chemical composition. Increase in aromatic type mineral impurities cause an increase in specific gravity. The specific gravity can be measured using either pycnometer or preparing a cube specimen of bitumen in semi-solid or solid state. The specific gravity of bitumen varies from 0.97 to 1.02.

E. Flash and fire point test

At high temperatures depending upon the grades of bitumen materials leave out volatiles. And this volatile catches fire which is very hazardous and therefore it is essential to qualify this temperature for each bitumen grade. BIS defined the flash point as the temperature at which the vapor of bitumen momentarily catches fire in the form of flash under specified test conditions. The fire point is defined as the lowest temperature under specified test conditions at which the bituminous material gets ignited and burns.

Before continuing with the hot mix design for this study, the above-mentioned properties of bitumen were determined.

3.4 Mineral filler

Crushed rock fine and enset fiber ash were used as fillers in the study. To replace conventional filer material, enset fiber was cleaned, dried, and burned in a non-controlled manner. Enset fiber was collected from the market around the town of Wolkite. Crushed rock fine that used as conventional filler was collected from Shandong Highway Engineering Construction Group Co. Ltd located at SNNP, Gurage zone in Gunchire site as per ERA and AASHTO standards. This study had followed purposive sample selection process. The sample selections were dependent on the types of tests required as per standards and for each tests quartering and weighting sampling technique were used.

Figure3. 5 Enset fiber ash preparation [Photo by Desta Moshe]

3.5 Asphalt Mix design

Asphalt paving mix design demands attention to the details outlined in standard test procedures. Primarily, this means following specific, written instructions. But it also means having proper training in laboratory technique and the relation of mix design testing to pavement field specification requirements. While mix design often is treated as an isolated subject, it cannot be separated from the other related items of the material specifications[39]. There are three commonly used design procedures for determining suitable proportion of asphalt and aggregate in a mixture. They are Marshall Method, the Hveem method and the Super pave system method.

3.5.1 Objectives of Mix Design

The overall objective of the design mix procedure is to determine (within the qualification limit of standard specifications) an economical blend and gradation of aggregates and asphalt that yield a mix having:

- ✓ Sufficient asphalt to ensure a durable pavement.
- ✓ Adequate mix stability to satisfy the demands of traffic without distortion or displacement.
- ✓ Void content high enough to allow for a slight amount of additional compaction under traffic loading without flushing, bleeding, and loss of stability.
- ✓ Sufficient workability to permit efficient placement of the mix without segregation

3.5.2 Marshall Mix Design

The Marshall method of designing paving mixtures was developed by Bruce Marshall, who is Bituminous Engineer at Mississippi State Highway Department[15]. The Marshall method is applicable only to hot mix asphalt using asphalt binder and containing aggregate with maximum size of 25mm or less.

The purpose of Marshal Method is to determine the optimum asphalt content for a particular blend of aggregate. And also it provides information about the properties of the resulting pavement mix including density and void content which are used during pavement construction.

The Marshall method uses standard test specimen 63.5mm high and 101.6mm internal diameter. The two principle features of the Marshall method of mix design are a density-voids analysis and a stability-flow test of the compacted test specimens[39]. A series of specimens were prepared, each containing the same aggregate blend but varying in asphalt content of 4%, 4.5%, 5%, 5.5%

and 6% was prepared using ASTM D 1559 specific procedure to heat, mix and compact the asphalt aggregate mixtures.

3.5.3. Laboratory Work

As shown in Table (4.1) the test designed to achieve the research objectives is a material quality test, Marshall Stability Test and performance tests like Rutting. Materials were collected from Jimma zone ERA office and Shandong Highway Engineering Construction Group Co. Ltd located at SNNP, Gurage zone in Gunchire site. The material quality test was conducted on all selected materials to identify its physical and mechanical properties.The Marshall Mix design is used for the design of hot mix asphalt after the quality test of the material was getting acceptance according to standard specification. Samples were prepared with some Specified percent of EFA blended with crushed aggregate, fine aggregate, and fillers by Using Job Mix Formula (JMF) for all four percent of replacement. Then five mix samples from (M1-M5) were prepared with EFA percent of (0%, 15%, 25%, 35% and 45%) blended with Crushed aggregates. There was 35 mix design prepared with three trials for each mix design. from this 15 mix design with three different aggregate gradation as shown in table 4.5 for control mix design and 20 mix design for replacement there gradation shown in table 4.5. Then Marshall Test were conducted on all specimens by applying 75 blows on each face according to the Marshall procedure specified in ASTM D1559 to obtain the optimum asphalt content for each mix with different proportion of EFA and bitumen content of (4%, 4.5%, 5%, 5.5% and 6%) for each mix design with 3 trail. There were about 105 mix specimens that were prepared to determine optimum bitumen content and corresponding volumetric properties of HMA. Then optimum bitumen content of each mix EFA replacement was determined according to National Asphalt Pavement Association (NAPA) which was bitumen content which corresponds to the specification's median air void content (4 % typically) of the specification. This is the optimum bitumen content. Final analyses were performed by using Regression Analysis. Figure 3.6 shows the overall research designs for the accomplishment of the research objectives.

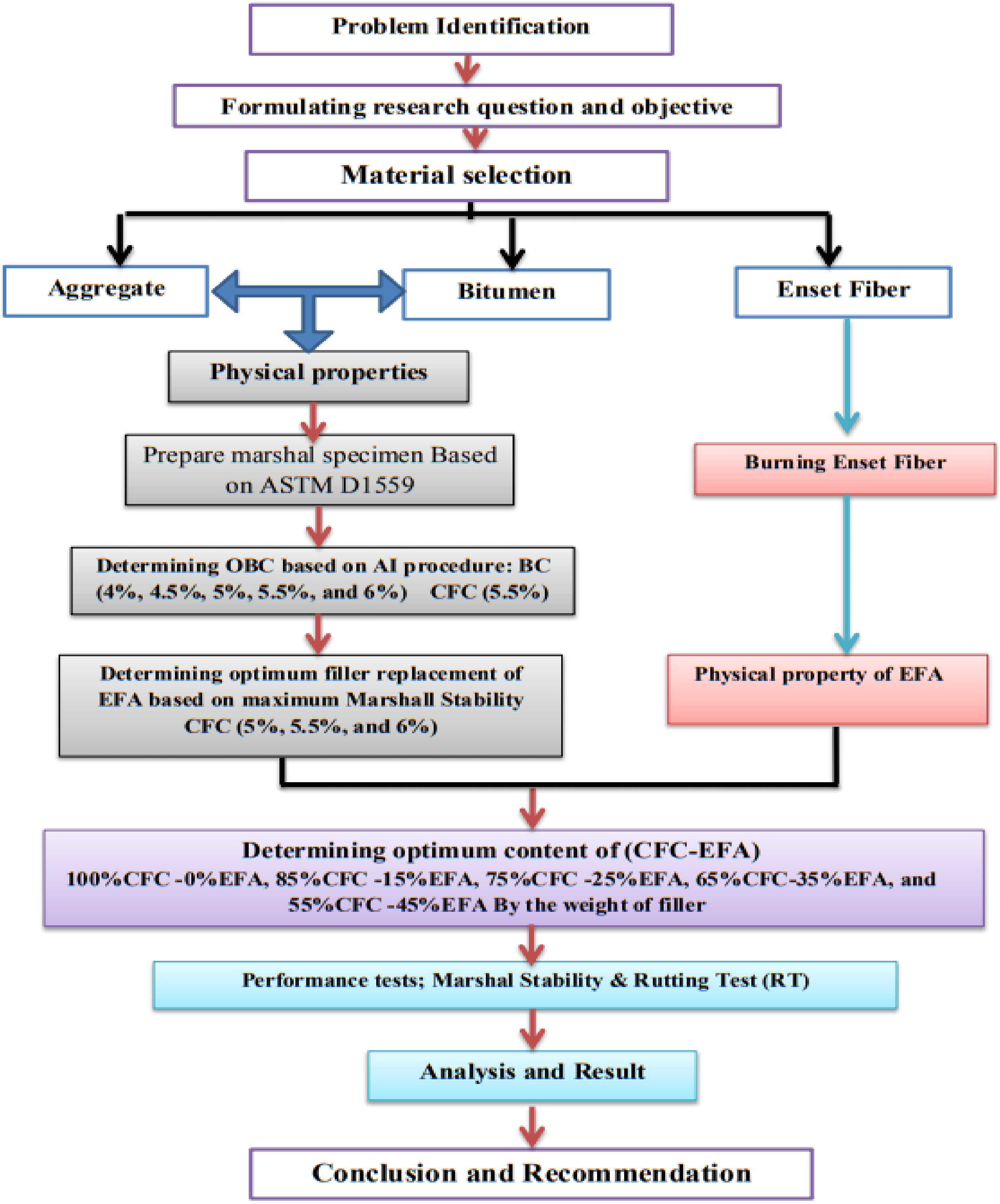

Figure3. 6 Flow chart of experimental work

3.5.4. Preparation of Mixtures

In determining the design asphalt content for a particular blend or gradation of aggregate by the Marshall method, a series of test specimens were prepared for a range of different asphalt contents.

According to ASTM specifications using mathematical trial method aggregates were blended together in order to get a proper gradation. Mathematical trial method depends on suggesting different trial proportions for each type of aggregate. The percentage of each type of aggregate was computed and compared with the specification limits. The figure (3.7) below shows a preparation of aggregates for Marshall Test

Figure3. 7 Aggregate preparation; A. EFA filler and B. Mixed aggregate

3.5.5. Marshall Test Method

Marshall Stability test was used in this study for both determining the optimum binder content (OBC) and evaluating the specimens were prepared by partial replacing Enset fiber ash as filler. This method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus according to ASTM D1559-89. The prepared mixture was placed in preheated mold at a temperature of 95 and 150°C (200 and 300°F) which has 101.6mm inside diameter and 63.5mm height and both face of specimen was compacted with 75 blows. The specimens were then left to cool at room temperature for 24 hours. Marshall Stability and flow tests were performed for each specimen. The cylindrical specimen was placed in water path at 60ºC for 30 to 40 minutes then compressed on the lateral surface at constant rate of 50.8mm/min. until the maximum load (failure) was reached. Then the maximum load resistance and the corresponding flow values were recorded. Three specimens for each combination were prepared and the average results were reported. The bulk specific gravity, density, air voids in total mix and voids filled with bitumen percentages were determined for each specimen.

3.5.6. Replacement of Enset Fiber Ash

A number of laboratory investigations were performed in order to determine the mix properties of Enset fiber ash filler using Marshall Test procedure. The best replacing percentage of Enset fiber ash that can be replace conventional filler in the mixture was determined by investigating four percentages of washed, burned and sieved Enset fiber ash. The replacements were performed by replacing 15%, 25%, 35% & 45 % of EFA by the total weight of filler that used in the control mixes with 15 samples for each percentage.

The steps followed to prepare the EFA filler samples are summarized as:

A. Purposive sampling technique was utilized to obtain Enset fiber ash material from the nearby market then washing, burning and then sieving.
B. The Enset fiber ash which passed on number 200 sieve was checked for PI test.
C. Four replacing percentages of EFA were used
D. The "Enset fiber ash (EFA) filler was mixed according to standard designated in ASTM D1559- 89 with other aggregates using the aforementioned percentages and then heated at a temperature of not exceeding 28°C (50°F) above the mixing temperature before mixing with asphalt.
E. Prior mixing with aggregates, asphalt was heated between 125^{0}C and 140^{0}C. Pre-heated asphalt was avoided and excess heated asphalt was disposed of to avoid variability in the asphalt properties.
F. The required amount of asphalt was weight then added to the heated aggregate and mixed by using mechanical mixer for two minutes.
G. Standard Marshall Molds were heated in an oven at a temperature of 125ºC; then place filter paper at the base of the mold, the hot mix was placed in the mold and cover by filter paper. Finally each face of the specimen was compacted with 75 blows.

H. Specimens were prepared, compacted and tested according to Marshall Method designated in ASTM D1559-89.

3.5.7. Determination of Optimum Bitumen Content

There are a number of methods used to select the optimum bitumen content once the data is developed. Each agency that is involved with pavement construction has its own method for selecting optimum. According to (Asphalt Institute, 2014) the following two methods are commonly used to determine the optimum bitumen content from the plots:

Method 1-NAPA (National Asphalt Pavement Association) Procedure

One commonly used procedure is that recommended by NAPA, in which they suggest preparing the plots. Then the optimum bitumen content is determined by:

The bitumen content which corresponds to the specification's median air void content (4 % typically) of the specification. This is the optimum bitumen content.

The bitumen content is then used to determine the value for Marshall Stability, VMA, flow, bulk density and percent voids filled from each of the plots.

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

Method 2-Asphalt Institute Method Series, MS-02

1. Determine:
   - ✓ Bitumen content at maximum stability
   - ✓ Bitumen content at maximum density
   - ✓ Bitumen content at midpoint of specified air void range (4 percent typically)
2. Average the three bitumen contents selected above
3. For the average bitumen content, go to the plotted curves and determine the following properties: Stability, Flow, Air voids, and VMA.
4. Compare values from Step 3 with criteria for acceptability given in table 3.5

For this research the NAPA procedure method is selected to determine the best bitumen content that satisfy standard specification. The marshal properties of the asphalt mix such as stability, flow, density, air voids in the total mix, and voids filled with bitumen with recommended ERA Marshall Criteria as shown in table

Table3. 7 AC Wearing Course Specifications for up to 5 million ESA[19]

Category and design traffic (million ESA)	No. of blows of Marshall compaction hammer	Min. Stability (N)	Flow (mm)	VFB (%)	VIM at optimum bitumen content (%)
Heavy (1 - 5)	75	8000	2-3.5	65-75	4
Medium (0.4 – 1)	50	5300	2-4.0	65-78	4
Light (< 0.4)	35	3300	2-4.5	70-80	4

3.5.8. Determination of Rutting

Rutting is the most common form of permanent deformation. Resistance to permanent deformation is provided by designing and constructing a stable HMA pavement that will resist shoving and rutting under traffic. It will maintain its shape and smoothness under repeated loading. An unstable pavement develops ruts and shows other signs of mixture shifting(39).

For this research Wheel-tracking test was used to evaluate the rutting resistance of mixtures according to UNE-EN 12697-22 after determined the best performed percent of replacement (0% & 25%) of Enset fiber ash by all marshal criteria. All the asphalt concrete samples were subjected to 10,000 passes of a loaded wheel. The load applied is 700 N at the rate of 26.5 revolutions per minute i.e. 53 passes per minute. For each mix type, two samples were tested at a temperature of 60 °C.

The deformation slope is determined based on the rut depth between 5,000 and 10,000 cycles.

$$WTS_{AIR} = \frac{(d_{10000} - d_{5000})}{5} \qquad \text{Eq-3.1[40]}$$

Where:

WTS_{AIR} = is the wheel-tracking slope (mm/10^3 load cycles);

d_{5000}, d_{10000} = is the rut depth after 5 000 load cycles or 10 000 load cycles respectively (mm).

Mean rut depth RD_{AIR} in air

The rut depth for the material under test at N cycles is the mean rut depth of the two specimens

$$RDair = \frac{\sum_{i=1}^{2} d_{10000,i}}{2} \qquad \text{Eq-3.2}$$

Where:

RD_{AIR} is mean rut depth at 10^4 load cycles (mm);

$d_{10000,\,i}$ is the rut depth after 10 000 load cycles (mm

Mean proportional rut depth PRD_{AIR} in air

The proportional rut depth for the material under test at N cycles is the mean proportional rut depth of the two (or more) specimens rounded to ±0.1 %.

$$\text{PRDair} = \frac{\frac{\sum_{i=1}^{2} d_{10000,\text{i}}}{hi}}{2} \qquad \text{Eq-3.3}$$

Where:

RD_{AIR} is the mean proportional rut depth at 104 load cycles (%)

$d_{10000,\ i}$ is the rut depth after 10 000 load cycles in specimen i (mm)

h_i is the thickness of test specimen i (mm).

Asphalt mixtures for compaction shall be prepared according to ATM D1559-89. The sample was compacted by using roller compacter. Each specimen subjected to 10 full cycles of compaction. The specimens have a minimum density of 98% of the Marshall density. The height of the specimens varies, depending on maximum aggregate size (2.5 times of nominal aggregate size. Before the test, the specimens are preheated at a temperature of 60^0C. Although the European standard specifies 3 types of wheel device, for this research were used the smallest or single wheel tracker, namely, Procedure B.

The total mass of the asphalt mixture to be introduced in the mould shall be:

$$M = 10^{-6} L.\, l.\, e.\, \rho_{mv} . \left(\frac{100 - v_m}{100}\right).\, \xi.\, ז \qquad \text{Eq-3.4}$$

Where:

M is the mass of the slab from the asphalt mixture (kg);

L interior length of mould (mm);

l interior width of mould (mm);

e thickness of slab (mm);

ρmv maximum bulk density determined using procedure A under AASHTO T 85;

Vm void content determined according to ASTM (%); Vm = 4%

ξ degree of compaction determined according to ASTM, taken as 98 %, ξ = 0.98;

Figure3. 8 During ARC roller compacter operation for rutting specimen preparation

(Photo by Tiruwork Mulatu)

Dimensions of specimens

A laboratory-produced test specimen in the shape of a slab shall have a minimum length L = 300 mm and a minimum width l = 260 mm. The thickness of the slab shall vary depending on the grain size of the stones. 320*260*50mm^3 mould sizes were used for this research.

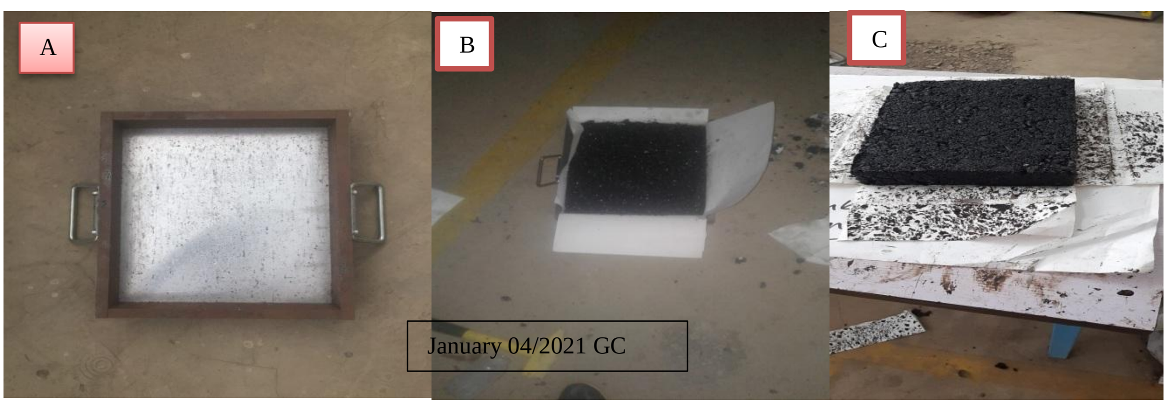

Figure3. 9 Rutting test specimen;"A" 320*260*50mm^3 mould "B" before compaction and "C" after compaction

3.5.9. Volumetric characteristics of asphalt mixtures

Since the fundamental performance properties are not directly measured in a normal mix design, asphalt content is selected on the basis of a measured parameter that best controls the pavement performance. Volumetric analysis is typically conducted on all mixtures regardless of the particular mix design methodology employed[39]. Since weight measurements are typically much easier, are taken and then converted to volume by using specific gravities. The following is a discussion of the important volumetric properties of bituminous mixtures. 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), percentage voids filled with asphalt (VFA), and Effective bitumen content (Pbe).

1. 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 at a stated temperature to the weight of an equal volume of gas free distilled water a stated temperature. The maximum specific gravity (Gmm) at different bitumen contents was measured to calculate air voids. The theoretical maximum specific gravity of a mix is defined as: -

$$\text{Gmm} = \frac{A}{A-(C-B)} \qquad \text{Eq-3.5}$$

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

2. Bulk specific gravity of compacted specimen (Gmb)

According to (Asphalt Institute, 2014) the bulk specific gravity of a mixture refers to the specific gravity of a specimen of compacted mixture, including the volume of air voids within the mixture. It is equivalent to the mass of a given specimen in grams, divided by its total volume in cubic centimeters. This value, as stated at ASTM D1189 and D2726, is used to determine weight per unit volume of compacted mixture. The standard procedure for determining the bulk specific gravity of compacted asphalt concrete involves weighing the specimen in air and in water. The bulk specific gravity (Gmb) of a compacted mix is equal to:

$$\text{Gmb} = \frac{A}{B-C} \qquad \text{Eq-3.6}$$

Where:

Gmb= Bulk specific gravity of compacted specimen

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

3. Air Voids (Va)

According to (Asphalt Institute, 2014), the total volume of the small pockets of air between the coated aggregates particles throughout a compacted paving mixture, expressed as percent of the bulk volume of the compacted paving mixture. The air voids, Va, in the total compacted paving mixture consists of the small air spaces between the coated aggregates particles. The voids in a compacted mixture are obtained in accordance with ASTM D3203- 94 standard test method. The voids in a compacted mixture are obtained as follows.

$$Va = 100 * \left(\frac{Gmm - Gmb}{Gmm}\right) \qquad \text{Eq-3.7}$$

4. Voids in Mineral Aggregates (VMA)

According to (Asphalt Institute, 2014), the voids in the mineral aggregates, are defined as the inter-granular void space between the aggregate's particles in a compacted paving mixture that includes the air voids and the effective bitumen content, expressed as a percent of the total volume of the 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:

$$VMA = 100 - \frac{Gmb}{Gsb} * Ps \qquad \text{Eq-3.8}$$

Where:

VMA = voids in the mineral aggregate,

Gsb= bulk specific gravity of total aggregate,

Gmb = bulk specific gravity of the compacted mixture,

Ps = aggregate content, percent by mass of total mixture

5. Voids Filled with Asphalt Voids filled with asphalt (VFA)

The percentages of inter-granular void space between the aggregate particles (VMA) that contains or is filled with asphalt cement. VFA is used to ensure that the effective asphalt part of the VMA in a mix is not too little (dry, poor durability) or too great (wet, unstable). The acceptable range of VFA varies depending upon the traffic level for the facility. Higher traffic requires a lower VFA, because mixture strength and stability is more of a concern. Lower traffic facilities require a higher range of VFA to increase HMA durability. A VFA that is too high, however, will generally yield a plastic mix. VFA is the effective binder content expressed as a percentage of the VMA:

$$VFA = 100 * \frac{VMA-Va}{VMA} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Eq-3.9}$$

Where

VFA = voids filled with asphalt, as a volume percentage

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

Va = Air void content, % by total mixture volume

6. Binder Content

Binder content is one of the most important characteristics of asphalt pavement mix. Use of the proper amount of binder is essential to good performance in asphalt concrete mixtures. Too little binder will result in a dry stiff mix that is difficult to place and compact and will be prone to fatigue cracking and other durability problems. Too much binder will be uneconomical, since asphalt binder is, by far, the most expensive component of the mixture and will make the mixture susceptible to rutting and shoving. Asphalt binder content can be calculated in four different ways: total binder content by weight, effective binder content by weight, total binder content by volume, and effective binder content by volume.

- Total asphalt content by volume is calculated as the percentage of binder by total mix mass:

$$Pb = 100 * \left[\frac{Mb}{Ms+Mb}\right] \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Eq-3.10}$$

Where:

Pb = Total asphalt binder content, % by mix mass

Mb = Mass of binder in specimen

Ms = Mass of aggregate in specimen

- Total asphalt binder content by volume can be calculated as a percentage of total mix volume using the following formula:

$$Vb = \left[\frac{Pb*Gmb}{Gb}\right] \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Eq-3.11}$$

Where

V_b = Total asphalt binder content, % by total mix volume

P_b = Total asphalt binder content, % by mix mass

G_{mb} = Bulk specific gravity of the mixture

G_b =Specific gravity of the asphalt binder

- The absorbed asphalt binder content by volume is also calculated as a percentage of total mix volume:

  $$Vba = Gmb * \left[\left(\frac{Pb}{Gb}\right) + \left(\frac{Ps}{Gsb}\right) - \left(\frac{100}{Gmm}\right)\right] \quad \text{Eq-3.12}$$

Where

Vba = Absorbed asphalt content, % by total mixture volume

Gmb= Bulk specific gravity of the mixture

Pb= Total asphalt binder content, % by mix mass

Gb= Specific gravity of the asphalt binder

Ps = Total aggregate content, % by mix mass = 100 – Pb

Gsb= Average bulk specific gravity for the aggregate blend

Gmm= Maximum specific gravity of the mixture

- The effective asphalt by volume is found by subtracting the absorbed asphalt content from the total asphalt content:

  $$Vbe = (Vb - Vba) \quad \text{Eq-3.13}$$

Where

Vbe= Effective asphalt content, % by total mixture volume

Vb= Total asphalt binder content, % by mixture volume

Vba, = Absorbed asphalt content, % by total mixture volume

- The effective and absorbed asphalt binder contents can also be calculated as percentages by weight, once the volume percentage has been calculated:

  $$Pba = (Pb - Pbe) \quad \text{Eq-3.14}$$

  $$Vb = Pb * \left(\frac{Vbe}{Vb}\right) \quad \text{Eq-3.15}$$

Where

Pbe = Effective asphalt binder content, % by total mass

Pb = Asphalt binder content, % by total mass (see Equation 3.10)

Vbe = Effective asphalt binder content, % by total mixture volume (see Equation 3.13)

Vb = Asphalt binder content, % by total mixture volume (see Equation 3.11)

Pba = Absorbed asphalt binder, % by total mixture mass

3.6 Test procedure

In the Marshall method, after prepared and compacted specimen were tested and analyzed in the following manner:

Specimen height determination;

Bulk specific gravity determination;

Density and voids analysis; and

Stability and flow test.

3.6.1 Bulk specific gravity determination

The bulk specific gravity test may be performed as soon as the freshly compacted specimens have cooled to room temperature. This test is performed according to ASTM D1188, "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Paraffin-Coated Specimens" or ASTM D2726, "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens[39].

For this research bulk specific gravity of compacted specimen were determined according to ASTM D2726, "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens.

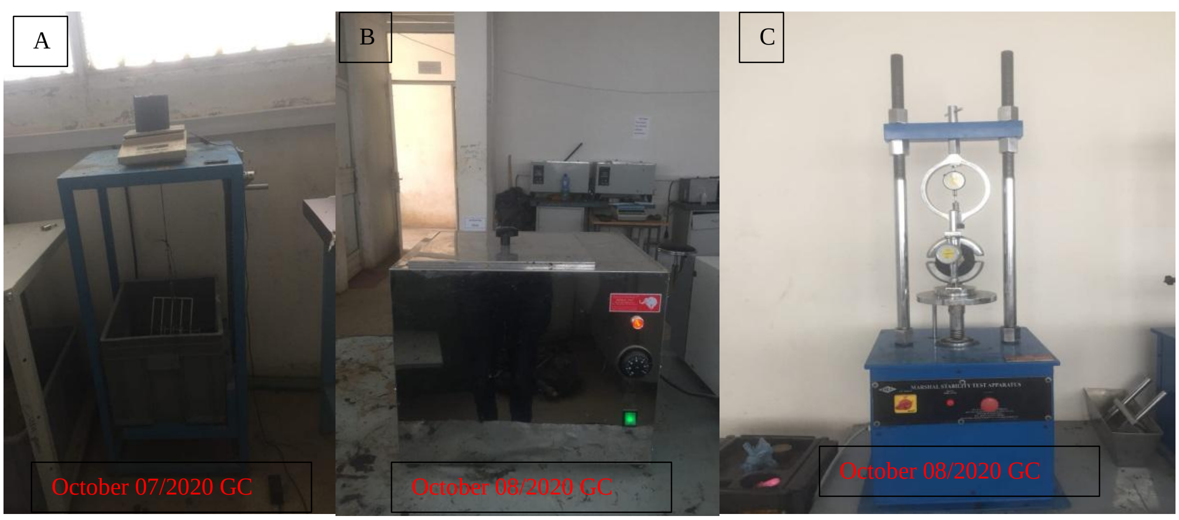

Figure3. 10 Marshal Test procedure; A. bulk specific gravity determination, B. water bath and C. Flow and Stability testing

CHAPTER FOUR
RESULT AND DISCUSSIONS

4.1 Introductions

All prepared sample were evaluated as per specifications. In this study, seventy five compacted mix, ten loss mix and four test sample were prepared for; marshal, maximum theoretical density and rutting test respectively at different percentage of mineral fillers were evaluated using the Marshal Mix design method and UNE-EN 12697-22. These mixtures were prepared using crushed stone aggregates and Enset Fiber Ash (EFA) fillers with varying contents of asphalt binder by the total mixture and their effect on Marshal Properties and rutting performance were assessed thoroughly. Different useful researches information's on the effect of fillers on bituminous mixtures were reviewed in literature review part which included the type and amount of fillers that affect the performance of HMA. All other test results obtained from laboratory for this research are discussed under these subsequent sections.

4.2. Interpretation of Test Data

4.2.1 Aggregate Physical properties

To determine physical properties of the aggregates and their suitability in road construction, various tests were conducted and the results are indicated in Table 4.1. The specific surface area was determined, for each of the aggregate size distribution; by multiplying surface area factors by the percentage passing the various sieve sizes and adding together. As can be seen from the results, as the filler content increases in the aggregate proportion, the specific surface area will also increase. The detail work for physical properties of aggregate show in Appendix A

Table 4.1 Aggregate Physical properties

No	Test Description	Test Method			Result	Specification (ERA Manual 2013)
		ASTM	AASHTO	BS		
1	Los Angeles Abrasion, %	AASHTO T 96			14	< 30
2	Aggregate Crushing Value, ACV, %	BS 812 Part 110:1990			17.3	<25
3	Aggregate Impact Value, %	BS 812 Part112:1990			14.605	<25
4	Flakiness Index	BS 812, Part 105 (1990)			11.5	< 35
5	Elongation index in (%)	BS 812, Part 105 (1990)			10.5	< 35
6	Coarse Aggregate Specific Gravity (Bulk)(kg/m^3)	AASHTO T 85			2.736	N/A
7	Fine Aggregate Specific Gravity (Bulk)(kg/m^3)	AASHTO T 84			2.705	N/A
8	Coarse Aggregate Specific Gravity (Apparent)(kg/m^3)	AASHTO T 85			2.824	N/A
9	Fine Aggregate Specific Gravity (Apparent)(kg/m^3)	AASHTO T 84			2.831	N/A
10	Water Absorption, %	ASTM C 127			1.37	<2
Where;- N/A -Not Available						

4.2.2. Mineral filler (CRF & EFA)

Crushed Rock fine and Enset fiber ash were used as mineral filler in this research. Their physical properties affect the bituminous mixture property such as bulk specific gravity and plasticity index, were determined as shown in Table 4.2.

Table4. 2 Physical properties of filler material

No	Test Description	Test Method	Result	Specification (ERAManual2013)
1	Specific Gravity of Filler(CRF)	AASHTO T-100	2.898	N/A
2	Specific Gravity of Filler (EFA)	AASHTO T-100	2.720	N/A
3	PI, (Plastic Index)	AASTO T 89 or T 90	NP	< 4
Where:- NP- Non Plastic, N/A -Not Available				

4.2.3. Asphalt Binder Test Results

A series of bitumen quality tests were conducted before the start of the mix design. These tests included penetration, specific gravity, softening point, flash point, ductility, and solubility to characterize the properties of 60/70 penetration grade binder. Table 4.3 presents the summary of the various properties of the 60/70 penetration grade binder which complies with the requirement of ERA specifications.

Table4. 3 Physical properties of bitumen

No	Test Description	Unit	Test Method	Test Result	ERA, 2013 Specification Limit
1	Penetration @25°C25◦ c, 100g, 5sec	1/10mm	AASHTO T 49	64	60 –70
2	Specific gravity @25°C	kg/cm^3	AASHTO T228-06	1019	1023
3	Ductility @25 °C	cm	AASHTO T51	100+	100+
4	Loss on heating (%)	%	AASHTO T 47	0.18	Max 0.5
5	Softening Point	0C	AASHTO T 53	49	46-56
6	Flash Point	0C	AASHTO T 48	562	Min 232

4.2.4. Aggregate Gradation of Mix Design

HMA is graded by percentage of different-size aggregate particles it contains. Table 4.7 illustrates HMA gradations without blending with Enset fiber ash or filler which is the normal gradation used as a control for the study. Certain terms are used in referring to aggregate fractions: Course aggregate-G- 1, (13.2-20), Coarse Aggregate-G-2, (7-13.2), Coarse Aggregate-G-3, (3-7), and Fine Aggregate- G-4, (0-3). To determine the optimum filler content of control mix, three different percentages of fillers (5.0 percent, 5.5 percent, and 6.0 percent) by weight of total mix were added to the mix aggregate gradation for the study. Table 4.4 shows three different aggregate stock combinations for the contents of the specified filler. All gradation marshal criteria were met in the trial with 5.5 percent filler content.

Table4. 4suggested percentage combination of stockpile aggregate

suggested percentage combination of stockpile aggregate						
Stock pile aggregate size	**13.2-20**	**7-13.2**	**3-7**	**0-3**	**Filler**	sum
Trial 1	**14.0%**	**22.0%**	**27.0%**	**36.0%**	**1.0%**	100.00%
Trial 2	**10.0%**	**36.0%**	**25.5%**	**26.0%**	**2.5%**	100.00%
Trial 3	**15.0%**	**21.0%**	**26.0%**	**36.0%**	**2.0%**	100.00%

Table4. 5 Aggregate gradation for determining optimum filler content

Sieve Size (mm)	25.00	19.00	9.50	4.75	2.36	0.30	0.075
Trial 1	100	96.9	73	58.5	40.9	9.3	5
Trial 2	100	97	67.5	49.1	30.8	8.8	5.5
Trial 3	100	96.3	73.1	59.2	30.6	10.3	6
Spac.	100	90-100	56-80	35-65	23-49	5-19	2-8

Table4. 6 Aggregate Gradation and Blending without Filler material

Suggested combination %	**10.50%**	**36.50%**	**26.00%**	**27.00%**	**100.0%**				
	13.2-20	**7-13.2**	**3-7**	**0-3**	**Blend**	**Lower Limit**	**Upper Limit**	**Spec Median**	**FWHA Max Density Curve**
Sieve Size (mm)	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**
25.0	100	100	100	100	**100.0**	100	100	100	**100.0**
19.0	70	100	100	100	**96.9**	90	100	95	**88.4**
9.5	9	35	100	100	**66.7**	56	80	68	**64.7**
4.75	0.1	1.9	78	100	**48.0**	35	65	50	**47.4**
2.36	0.1	1.1	30	78	**29.3**	23	49	36	**34.6**
0.30	0.1	0.4	2	21.4	**6.5**	5	19	12	**13.7**
0.075	0.1	0.3	1.2	10.1	**3.2**	2	8	5	**7.3**
Pan									

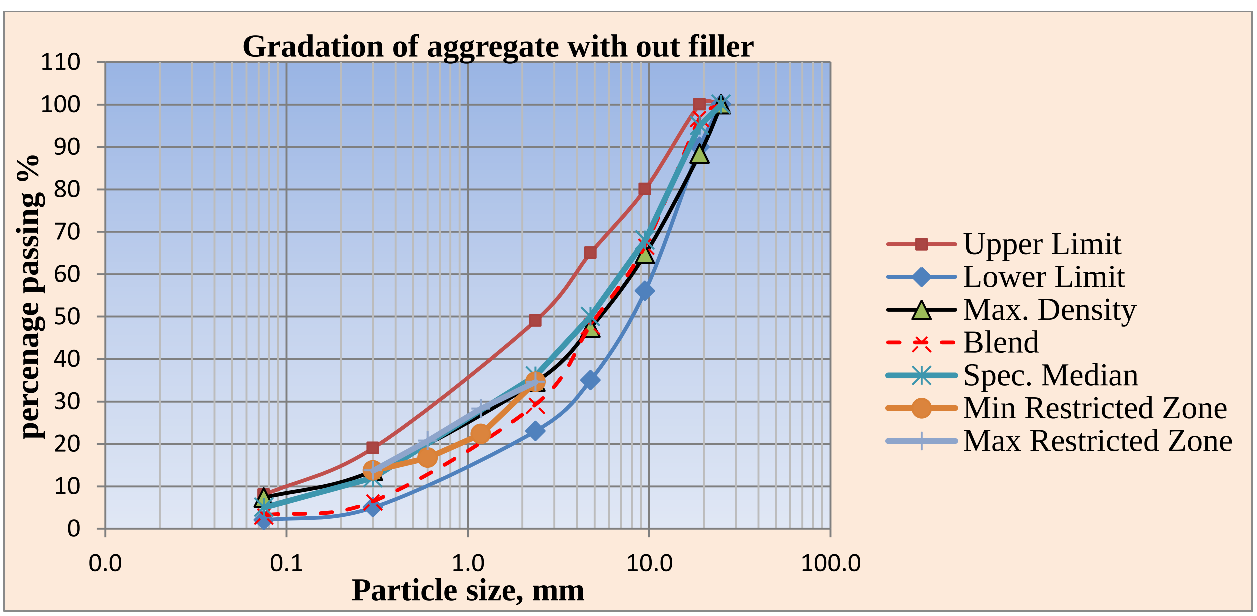

Figure4. 1 Gradation of Aggregate without Filler Material

Note: - Mineral filler such as mineral dust occur naturally with many aggregates and are produced as a by-product of crushing many types of rock. The above figure shows that the aggregate blend shows additional mineral filler were need to satisfy the gradation requirement for Marshall Mixture preparation, which shows the blend G-1, 10.5%, G-2, 36.5%, G-3, 26%, G-4, 27% meet the requirement but the fillet percent almost touch lower limit which shows there were need of additional filler.

Table4. 7 Aggregate Gradation Blending with Filler material

Suggested combination %	**10.0%**	**36.0%**	**25.5%**	**26.0%**	**2.5%**	**100.0%**				
	13.2-20	**7-13.2**	**3-7**	**0-3**	**Filler**	**Blend**	**Lower Limit**	**Upper Limit**	**Spec Median**	**FWHA Max Density Curve**
Sieve Size (mm)	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**
25.0	100	100	100	100	100	**100.0**	100	100	100	**100.0**
19.0	70	100	100	100	100	**97.0**	90	100	95	**88.4**
9.5	9	35	100	100	100	**67.5**	56	80	68	**64.7**
4.75	0.1	1.9	78	100	100	**49.1**	35	65	50	**47.4**
2.36	0.1	1.1	30	78	100	**30.8**	23	49	36	**34.6**
0.30	0.1	0.4	2	21.4	100	**8.7**	5	19	12	**13.7**
0.075	0.1	0.3	1.2	10.1	100	**5.5**	2	8	5	**7.3**

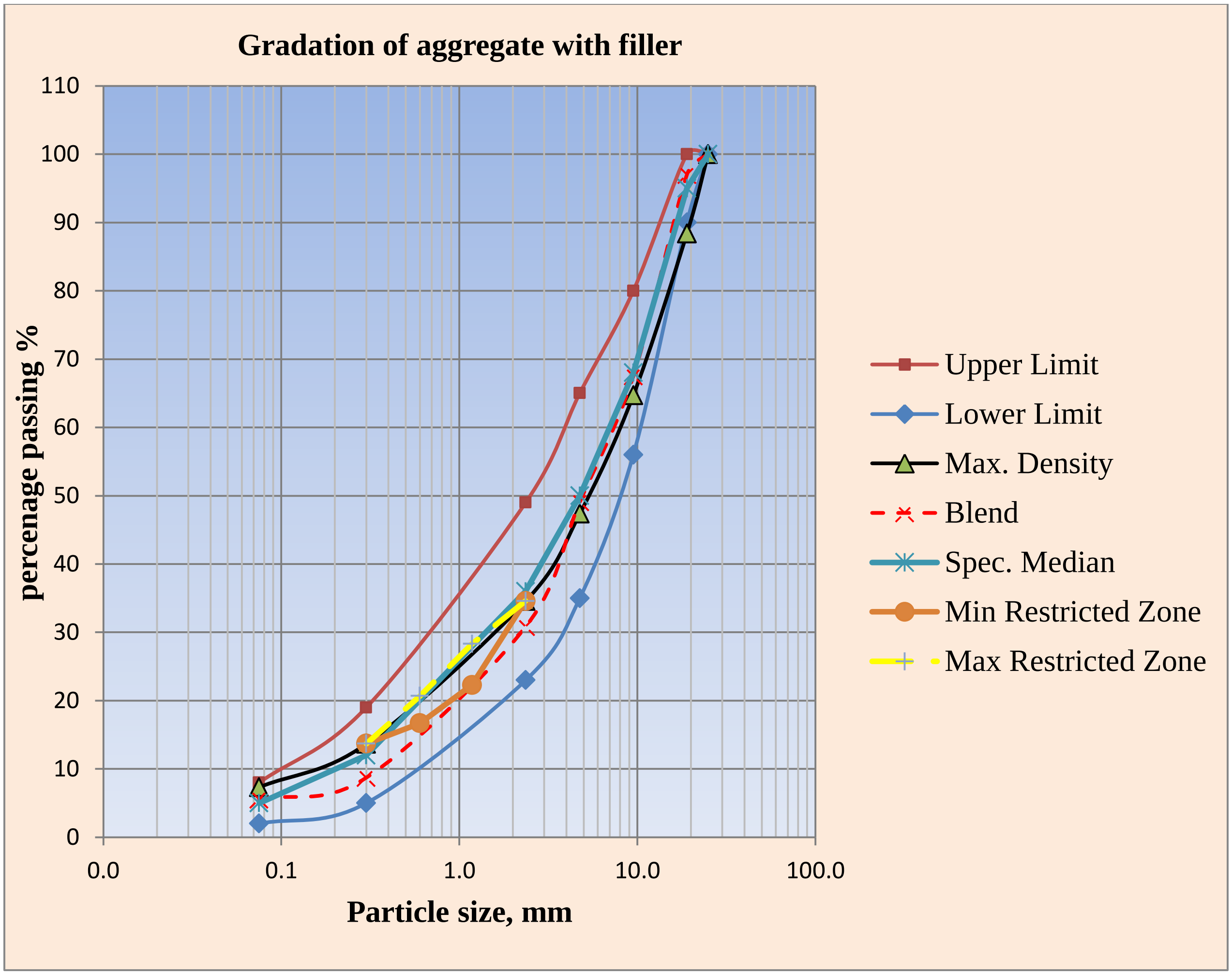

Figure4. 2 Aggregate Gradation blending with 5.5% Filler material

As shown in above figure to meet the specification of job mix and to gate smooth job mix curve there were blended with 2.5% of additional mineral filler with aggregate of G-1, 10%, G-2 36%, G-3 25.5% and G-4, 26% gives better aggregate blend for the Marshall mix design. The detail works of gradation for this study were shown in Appendix B.

4.3 Marshall Test Results

In order to accomplish the research goals, the laboratory experimental work product of asphalt mix laboratory work was collected and analyzed. For the result of Marshall Properties total 45 specimens with each weight of 1190.1 grams were prepared using five different bitumen contents (4 percent, 4. 5 percent, 5 percent, 5.5 percent, and 6 percent) and with three varying proportion of aggregate gradation trail 1, trial 2 and trial 3 of the total weight in order to determine optimum bitumen content for control mix. Table (4.8) showed the total batch weight of aggregate hot mix asphalt that used in this study. Further details are presented in Appendix (B). Seventy five specimens were used to assess the optimal bitumen content for each EFA proportion and to recommend the highest use of EFA aggregate in hot-mix asphalt. The Marshall Mix design process, according to the Asphalt Institute, MS-2 has five mix design requirements. These are maximum Marshall Stability, range of acceptable Marshall Flow, range of acceptable air voids, percent voids filled with asphalt (VFA), and a minimum. amount of VMA and ERA, pavement design Manual, (2013) Marshall design criteria for heavy traffic, Minimum stability must be 8KN at 60 C0, flow value must be ranged between 2-3.5mm, Air void must be between 3 to 5%, Void filled with bitumen (VFA) must be between 65 to 75 % and minimum value of VMA for 19mm nominal particle size is 13%. Marshall Test results of control and 25% EFA replaced mixtures with different binder content are presented in Table (4.10 and 4.11) and figure (4.3 and 4.4) represent marshal result at optimum bitumen content 5.1% and 5.15% respectively with 4% AV. The relationships between binder content and the mixture properties such as Stability, Flow, VFB, VMA, VA, Stability, Flow and Bulk Density are presented in Figures (_4.5 – 4.10). Further details are presented in Appendix (C).

Table4. 8 Bitumen batch weight for Marshal and MTD

Bitumen Batch Weights (gm) for Marshall			Bitumen Batch Weights (gm) for MTD		
Bitumen % by Wt. of Total Mix	Bitumen (gm) = A-1190.1	Total Batch (gm)(A) $\frac{1190.1}{(1-\frac{Bit.Con}{100})}$	Bitumen % by Wt. of Total Mix	Bitumen (gm) = B-1500	Total Batch (gm)(B) $\frac{1500}{(1-\frac{Bit.Con}{100})}$
4.00	49.6	1239.60			
4.50	56.1	1246.09	4.50	70.7	1570.68
5.00	62.6	1252.65	5.00	78.9	1578.95
5.50	69.3	1259.27			
6.00	76.0	1265.97			

The process of measuring the stability values from the standard 63.5mm compacted height. For those have greater compacted thickness were converted to an equivalent 63.5mm value by multiplying conversion factor. The applied correlation ratio to convert the measured stability values are set in Table (4.9). The conversion was made on the basis of either measured thickness or measured volume.

Table4. 9 Correlation ration for adjusting the stability values**[39]**

Volume of Specimen cm^3	Approximate Thickness of Specimen, mm	Correlation Ratio
380 to 392	47.6	1.67
393 to 405	49.2	1.56
406 to 420	50.8	1.47
421 to 431	52.4	1.39
432 to 443	54	1.32
444 to 456	55.6	1.25
457 to 470	57.2	1.19
471 to 482	58.7	1.14
483 to 495	60.3	1.09
496 to 508	61.9	1.04
509 to 522	63.5	1
523 to 535	64	0.96
536 to 546	65.1	0.93
547 to 559	66.7	0.89
560 to 573	68.3	0.86
574 to 585	71.4	0.83
586 to 598	73	0.81
599 to 610	74.6	0.78
611 to 625	76.2	0.76

Notes:

1. The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 63.5-mm (2.5-in.) specimen.
2. Volume-thickness relationship is based on a specimen diameter of 101.6 mm (4 in.)

Table4. 10 Marshall Test Result for control Mixes or mixes with 0% EFA Filler Content

MARSHALL PROPERTIES OF BITUMINOUS MIXTURES					Control mix 0% EFA Replacement
S.G of Aggregate			**Bitumen**		
Size	**Bulk**	**Apparent**	**Source**	**IRAN**	
Coarse(4.75 Retain)	**2.736**	**2.831**	**Grade**	**60/70**	
Fine(4.75 Pass)	**2.705**	**2.824**	**Specific Gravity**	**1.019**	
Filler	**2.898**	**2.898**	Ring Factor		
Combined Sp.Gr	**2.73**	2.831	Ring Factor	1.17	

Test Method-Asphalt Institute Manual Series MS-02

Trial No.	**Bitumen % by Weight of Total Mix**	**Height of Specimen**	**Weight: In air (A)**	**Weight: In water (B)**	**Weight: S.S.D in air (C)**	**Bulk volume D=C-B**	**Gmb E=A/D**	**Gmm (G)**	**AV**	**VIM 2.730**	**VFA**	**Stability: Dial Reading (mm)**	**Stability: Dial R.*RF**	**Stability: Adjusted Stability (kN)**	**Flow (mm)**
A	4.0	65.30	1233.30	716.00	1236.90	520.90	2.368					14.01	11.97	11.50	1.88
B	4.0	65.80	1229.90	715.70	1234.20	518.50	2.372					12.18	10.41	9.99	1.71
C	4.0	65.50	1230.70	714.40	1234.00	519.60	2.369					14.43	12.33	11.84	1.38
Average		65.53				519.67	2.389	2.580	**2.577**	**7.32**	**16.00**	**54.25**		11.11	1.66
A	4.5	64.90	1240.20	723.30	1241.50	518.20	2.393					14.71	12.57	12.07	1.83
B	4.5	65.60	1241.50	724.50	1244.80	520.30	2.386					12.64	10.80	10.37	2.12
C	4.5	64.90	1243.10	725.30	1245.30	520.00	2.391					13.95	11.92	11.45	1.56
Average		65.25				519.50	2.412	2.560	**2.557**	**5.97**	**15.89**	**62.44**		11.76	1.98
A	5.0	64.80	1245.40	725.80	1245.60	519.80	2.396					14.87	12.71	12.20	1.99
B	5.0	64.90	1253.00	731.60	1253.60	522.00	2.400					13.34	11.40	10.95	2.00
C	5.0	64.40	1249.10	731.80	1249.70	517.90	2.412					16.60	14.19	14.19	2.33
Average		64.80				519.90	2.431	2.543	**2.526**	**4.25**	**15.82**	**73.12**		12.44	2.11
A	5.5	64.00	1250.30	735.60	1250.30	514.70	2.429					15.43	13.19	13.19	1.90
B	5.5	65.50	1267.90	743.20	1268.10	524.90	2.416					14.42	12.32	11.83	1.99
C	5.5	64.90	1254.00	734.10	1254.00	519.90	2.412					15.32	13.09	12.57	2.36
Average		64.80				519.83	2.441	2.516	**2.527**	**3.78**	**15.82**	**76.08**		12.53	2.18
A	6.0	64.40	1257.10	739.90	1257.20	517.30	2.430					14.09	12.04	12.04	3.01
B	6.0	64.50	1256.00	740.40	1256.10	515.70	2.436					13.95	11.92	11.92	2.63
C	6.0	64.60	1259.50	741.30	1259.70	518.40	2.430					12.72	10.87	10.44	2.95
Average		64.50				517.13	2.445	2.500	2.497	**2.08**	**15.78**	**86.85**		11.47	2.86

Where;
Gmb= Bulk specific gravity, Gmm= Theoretical maximum specific gravity, Va= Air Void in the total mix, VMA= Voids in the Mineral Aggregate, & VFA% = % Voids Filled with Asphalt

The above table (4.10) shows the laboratory test results of control mixtures or 0% EFA mixture and the corresponding values of Marshall Properties with different bitumen contents.

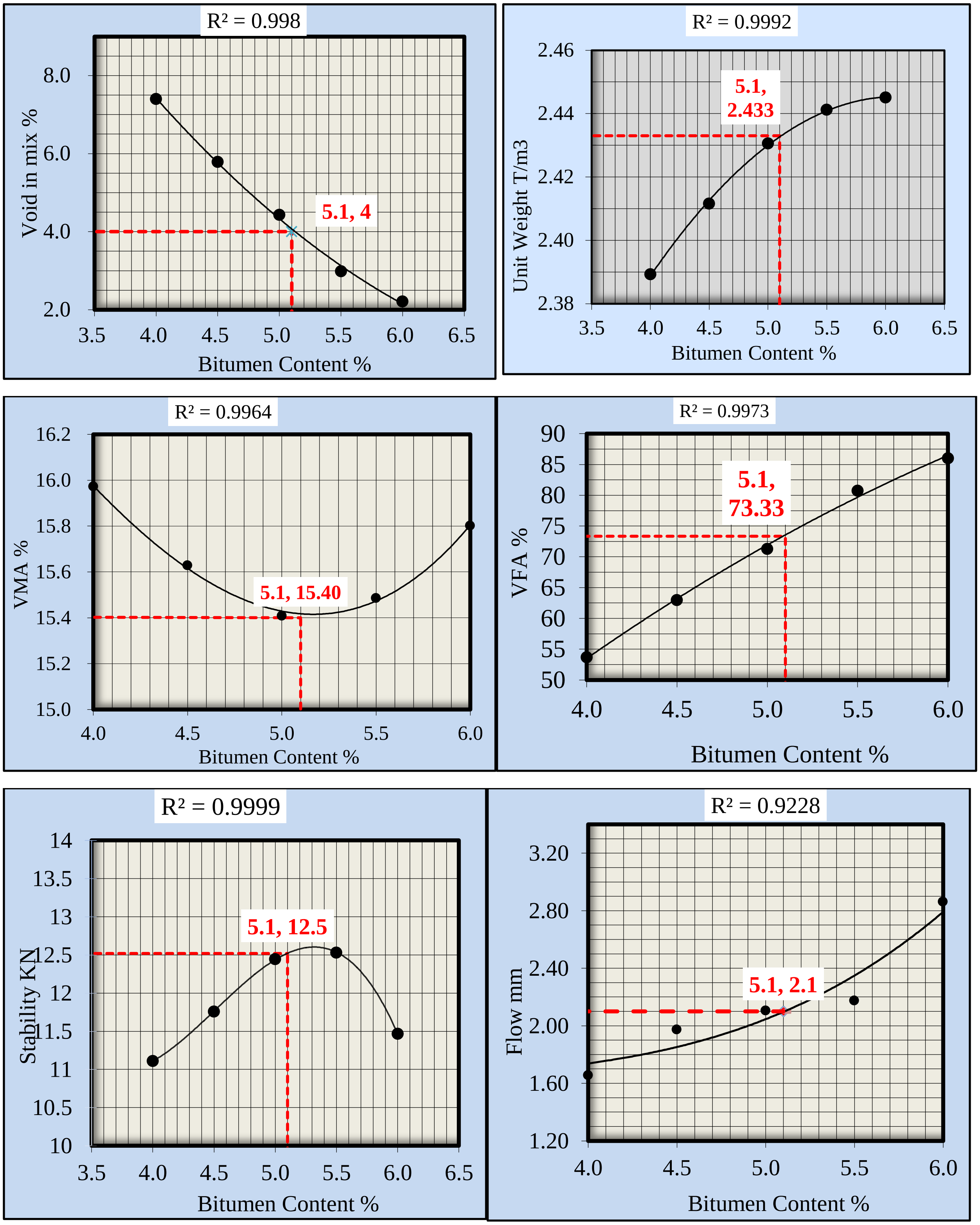

Figure4. 3OBC and the properties of mixtures with 5.5% mineral filler

Table 4. 11 Marshall Test result mixes with 25% filler content

MARSHALL PROPERTIES OF BITUMINOUS MIXTURES						
S.G of Aggregate			Bitumen			
Size	Bulk Gsb	Apparent Gsa	Source	IRAN	Replacement	25% EFA
Coarse(4.75 Retain)	2.736	2.831	Grade	60/70	Compaction	75 Blows
Fine(4.75 Pass)	2.705	2.824	Specific Gravity	1.019	AC Grade	60/70
Filler	2.898	2.898	Ring Factor			
Combined Bulk & Apparent Sp.Gr	2-Jan-00	2.831	Ring Factor	1.17		
Test Method-Asphalt Institute Manual Series MS-02						

Trial No.	Bitumen % by Weight of Total Mix	Height of Specimen	Weight			Bulk volume (m3)	Gmb	Gmm	AV	VMA	VFA	Stability			Flow
			In air (A)	In water (B)	S.S.D in air (C)	D=C-B	E=A/D	(G)		2.730		Dial Reading (mm)	Dial R.*RF	Adjusted Stability (kN)	(mm)
A	4.0	65.50	1235.20	720.58	1236.00	515.42	2.396					13.50	11.54	11.08	1.95
B	4.0	65.81	1234.80	717.90	1235.90	518.00	2.384					12.90	11.03	10.58	2.30
C	4.0	65.40	1234.50	717.65	1235.26	517.61	2.385					13.56	11.59	11.13	2.12
Average		**65.57**				**517.01**	**2.388**	**2.577**	**7.32**	**16.00**	**54.25**			**10.93**	**2.12**
A	4.5	65.00	1239.00	724.80	1240.60	515.80	2.402					14.00	11.97	11.49	2.31
B	4.5	64.50	1243.50	728.50	1244.60	516.10	2.409					13.56	11.59	11.59	2.25
C	4.5	64.30	1240.20	725.80	1242.36	516.56	2.401					13.54	11.57	11.57	1.56
Average		**64.75**				**516.15**	**2.404**	**2.557**	**5.97**	**15.89**	**62.44**			**11.53**	**2.28**
A	5.0	65.10	1246.25	729.56	1248.00	518.44	2.404					14.45	12.35	11.86	2.32
B	5.0	64.50	1248.90	735.60	1249.80	514.20	2.429					15.00	12.82	12.82	2.20
C	5.0	65.00	1247.30	734.20	1248.87	514.67	2.423					15.32	13.09	12.57	2.58
Average		**65.10**				**515.77**	**2.419**	**2.526**	**4.25**	**15.82**	**73.12**			**12.42**	**2.37**
A	5.5	65.30	1254.50	738.90	1255.90	517.00	2.426					15.23	13.02	12.50	3.20
B	5.5	65.50	1255.00	742.60	1257.10	514.50	2.439					15.10	12.91	12.39	2.51
C	5.5	65.10	1254.36	738.20	1254.60	516.40	2.429					15.12	12.92	12.41	2.42
Average		**65.30**				**515.97**	**2.432**	**2.527**	**3.78**	**15.82**	**76.08**			**12.43**	**2.47**
A	6.0	65.60	1260.30	746.50	1262.00	515.50	2.445					14.96	12.79	12.27	3.25
B	6.0	65.10	1258.70	745.10	1259.60	514.50	2.446					13.50	11.54	11.08	3.12
C	6.0	65.71	1259.30	745.90	1260.80	514.90	2.446					13.21	11.29	10.84	3.50
Average		**65.47**				**514.97**	**2.446**	**2.497**	**2.08**	**15.78**	**86.85**			**11.40**	**3.29**

Where;
Gmb= Bulk specific gravity, Gmm= Theoretical maximum specific gravity, Va= Air Void in the total mix, VMA= Voids in the Mineral Aggregate, & VFA% = % Voids Filled with Asphalt

The above table (4.11) shows the laboratory test results of mixtures with 25% EFA and the corresponding values of Marshall Properties with different bitumen contents.

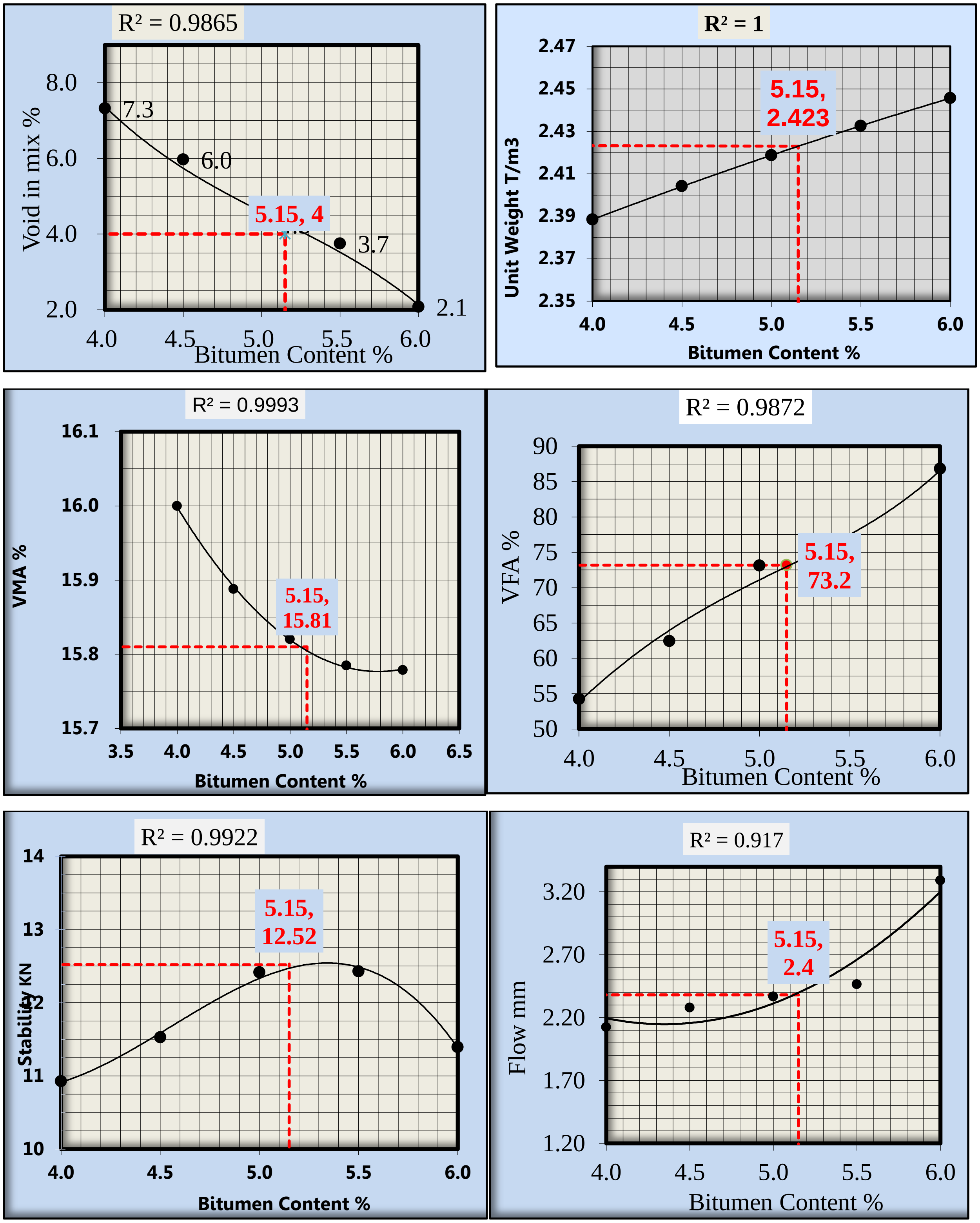

Figure4. 4OBC and the properties of mixtures with 5.5% mineral filler with 25% EFA replacement

4.3.1. Marshall Stability

Stability is generally a measure of the mass viscosity of the aggregate-asphalt cement mixture and is affected significantly by the angle of internal friction of the aggregate and the viscosity of the asphalt cement. As we see on table (4.12) and figure (4.5) the addition of EFA as filler in the hot asphalt mix result decrees the stability performance comparing with control mix. But there is stability fluctuation when we observed 15% and 25% EFA replacement. 25% EFA replacement better stability result than 15% replacement but Increasing percent of EFA content decreased stability performance of the mix.

Table4.12 Stability Value of different percent of EFA replacement

Stability value					
%Bit.	0% EFA	15%EFA	25% EFA	35% EFA	45% EFA
4	11.1	10.9	10.9	9.4	9.6
4.5	11.8	11.5	11.5	11.0	10.4
5	12.4	12.3	12.4	11.8	10.8
5.5	12.5	12.4	12.4	11.6	10.6
6	11.5	11.3	11.4	10.4	10.2

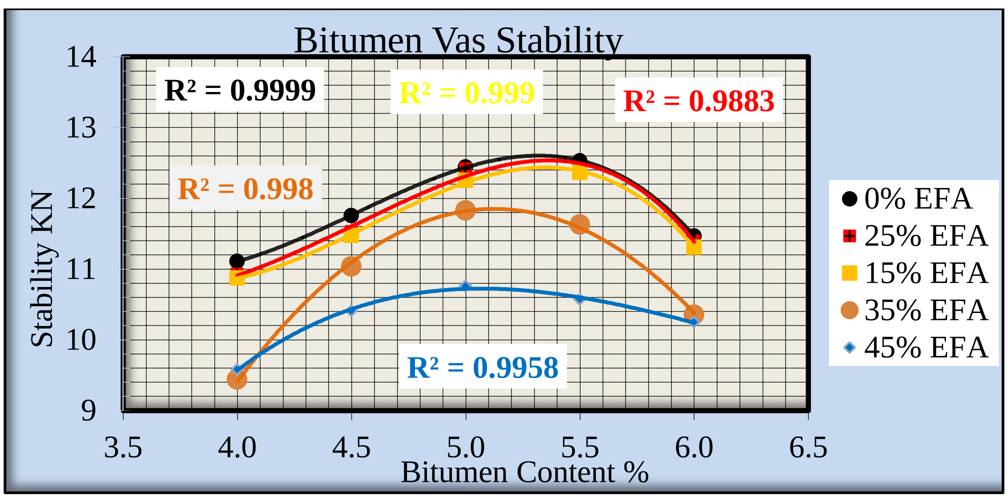

Figure4. 5 Stability Vs Bitumen Content

4.3.2. Flow

Flow is the total amount of deformation which occurs at maximum load. From figure (4.6) below it is noticed that the maximum flow of the asphalt mix was at 6% bitumen content which shows flow was increased with increasing bitumen content. High flow values was indicate a plastic mix that will Caused permanent deformation under traffic, whereas low flow values may indicate a mix with higher air void in the mix than acceptable voids and insufficient asphalt and may experience premature cracking due to mixture brittleness during the life of the pavement. Figure (4.6) shows bitumen flow results with different bitumen contents. The flow value has a consistent increase with increasing asphalt content were within the range of (1.6 – 2.86mm) for 0%, (2-3.06mm) for 15%, (2.1-3.29mm) for 25% (2.04-3.55mm) for 35% and (2.6-4.14mm) for 45% EFA replacement. The result shows flow, bitumen and EFA direct relationship which means that flow increased with increasing bitumen and EFA content.

Table4. 13 Flow Value of different percent of EFA replacement

Flow in (mm)					
%Bit.	0% EFA	15%EFA	25% EFA	35% EFA	45% EFA
4	1.66	2.09	2.12	2.04	2.60
4.5	1.98	2.23	2.28	2.18	3.10
5	2.11	2.43	2.37	2.43	4.00
5.5	2.18	2.55	2.47	2.90	4.12
6	2.86	3.06	3.29	3.55	4.14

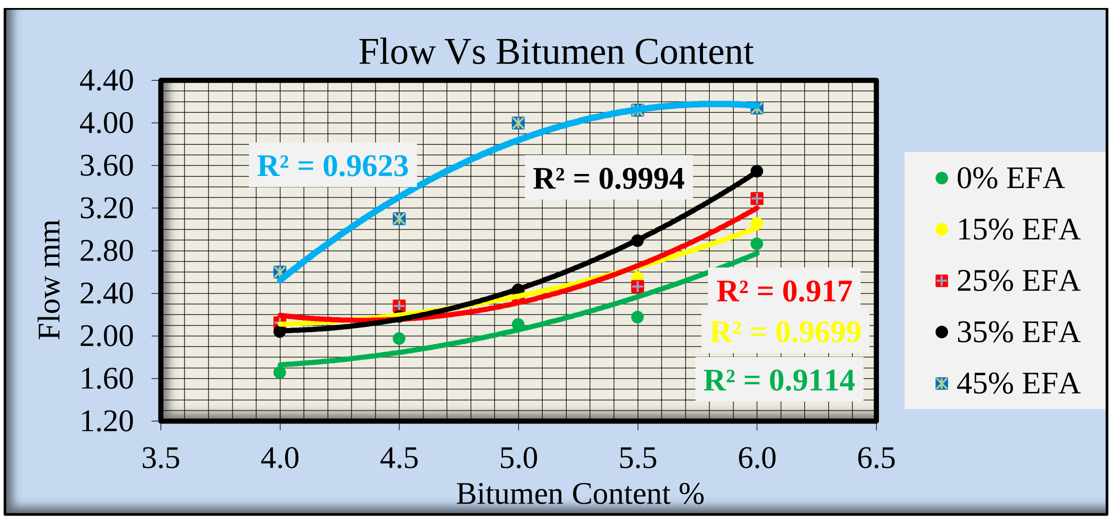

Figure4. 6 Flow Vs Bitumen Content

4.3.3. Unit Weight (Density)

The density of the compacted mix is the unit weight of the mixture. Density in the finished product is essential for lasting pavement performance. Mix properties are required to be measured in volumetric terms as well as weight. The addition of EFA was decreased the unit weight of compacted mixture as showed in below figure (4.7). The figure (4.7) also showed density was increased with increasing percent of EFA. However, at higher content the mix became stiffer that needs greater compaction effort then consequently lower dense mixture obtained.

Table4. 14 Unit weight value of compacted mixture for different percent of EFA replacement

Unit Weight (Density)					
%Bit.	0% EFA	15%EFA	25% EFA	35% EFA	45% EFA
4	2.389	2.372	2.388	2.384	2.385
4.5	2.412	2.392	2.404	2.401	2.406
5	2.431	2.405	2.419	2.420	2.420
5.5	2.441	2.420	2.433	2.446	2.453
6	2.445	2.433	2.446	2.461	2.466

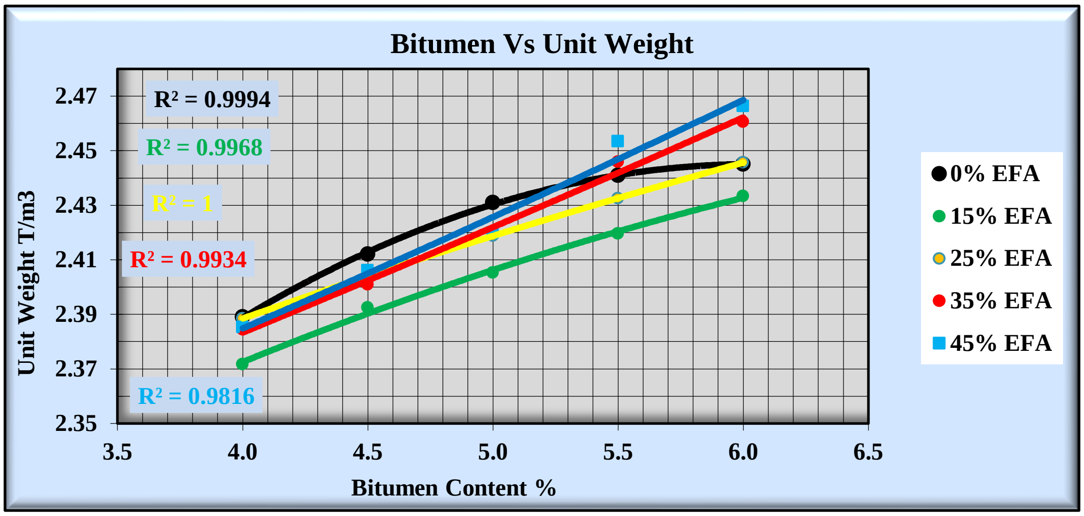

Figure4. 7 Unit Weight Vs Bitumen Content

4.3.4. Air Voids Content (VA)

The air voids (VA) is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture. It is expressed as a percentage of the bulk volume of the compacted paving mixture. From figure (4.8) below it is showed that the air voids content gradually decreases with increasing the bitumen content and addition of EFA. That is due to the increase VFA in the asphalt mix and the EFA was finer than CRF or EFA may have higher absorption capacity than CRF. Figure (4.8) shows results of air voids content with different bitumen contents.

Table4. 15 Air void value for different percent of EFA replacement

Air Voids Content AV in %					
%Bit.	0% EFA	15%EFA	25% EFA	35% EFA	45% EFA
4	7.4	7.6	7.3	7.2	6.9
4.5	6.1	6.1	6.0	5.8	5.3
5	4.9	4.3	4.3	4.1	3.1
5.5	3.4	4.0	3.7	2.7	2.9
6	2.2	2.2	2.1	1.2	0.7

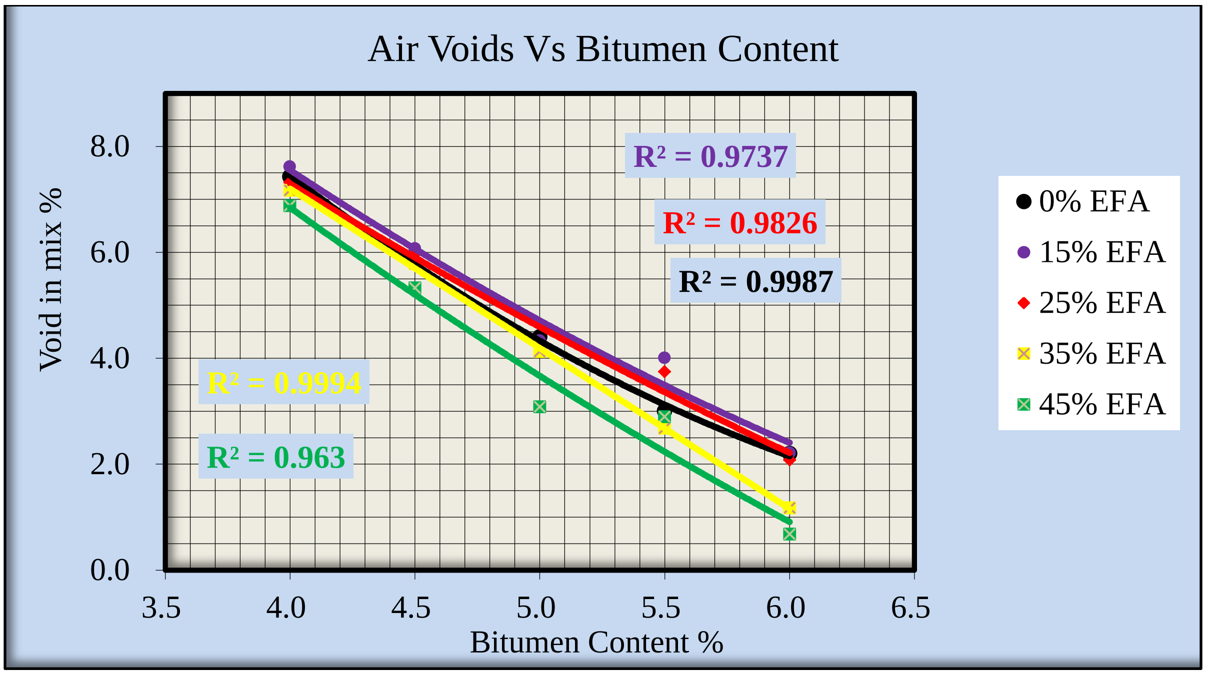

Figure4. 8 Air Void Vs Bitumen Content

4.4.3. Voids in Mineral Aggregate (VMA)

The voids in the mineral aggregate (VMA) are defined as the inter-granular void space between the aggregate particles in a compacted paving mixture that includes the air voids and the effective bitumen content, expressed as a percentage of the total volume. From the figure (4.9) below it is noticed that the VMA decreased gradually as EFA and bitumen content increased.

It is common that as filler content in the mix increases, the voids in mineral aggregate decreases up to minimum value then increases at higher filler content. As it can be seen from the figure below, mixtures blended with EFA filler exhibited the same manner. Figure (4.9) shows the result of VMA with different bitumen contents and different EFA content.

Table4. 16 Void in mineral aggregate for different percent of EFA replacement

Voids in Mineral Aggregate (VMA)%					
%Bit.	0% EFA	15%EFA	25% EFA	35% EFA	45% EFA
4	16.0	16.6	16.0	16.1	16.1
4.5	15.6	16.3	15.9	16.0	15.8
5	15.4	16.3	15.8	15.8	15.8
5.5	15.5	16.2	15.8	15.3	15.1
6	15.8	16.2	15.8	15.3	15.1

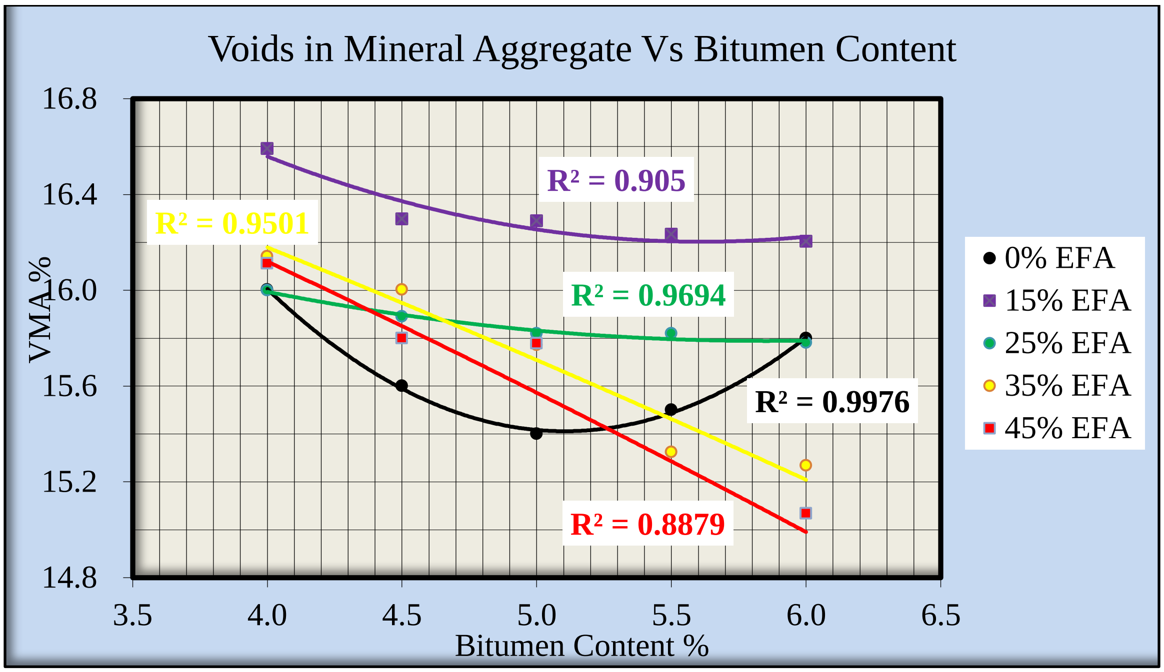

Figure4. 9 VMA Vs Bitumen Content

4.3.6. Voids Filled with Asphalt (VFA)

The voids filled with asphalt (VFA) are the percentage of the inter-granular void space between the aggregate particles. From figure (4.10) it is noticed that the VFA% increases gradually as bitumen and EFA content increased due to increase of the voids percentage filled with bitumen in the asphalt mix.

VFA represents the volume of effective bitumen content in the mixture. It is inversely related to air voids hence, as air voids decrease, the VFA increases. From the result it can be concluded that the addition of EFA filler on the bituminous mixture has goes as the same trend resulting the decrease of both air void and increase asphalt content. Figure (4.10) shows the results of VFA at different bitumen contents for different percent of EFA.

Table4. 17 Void filled with asphalt for different percent of EFA replacement

Voids Filled with Asphalt (VFA) in %					
%Bit.	0% EFA	15%EFA	25% EFA	35% EFA	45% EFA
4	53.6	54.1	54.3	55.6	57.3
4.5	61.8	62.8	62.4	63.8	66.3
5	69.1	73.4	73.1	73.9	80.5
5.5	78.7	75.4	76.3	82.6	80.8
6	86.0	86.3	86.8	92.3	95.5

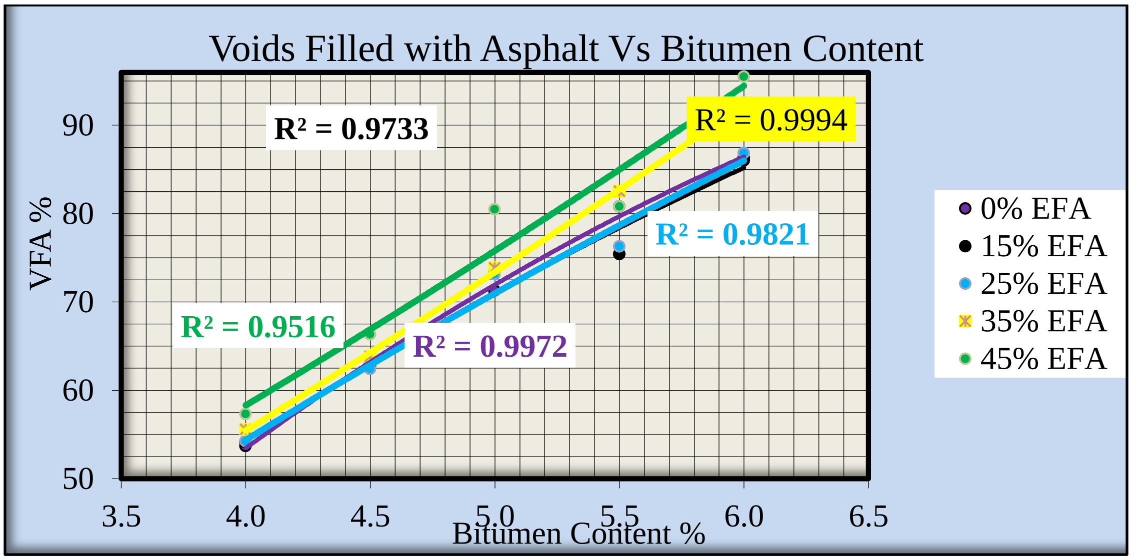

Figure4. 10 VFA Vs Bitumen Content

4.3.7. Optimum Asphalt Content Determination

It is expected that the effective asphalt content determines the performance of the mixtures. This is expressed as the effective asphalt content which makes the asphalt film around the aggregate particles. If the asphalt film thickness around the aggregate particles is thick enough, various desirable characteristics such as better durability, more fatigue resistance and higher resistance to moisture induced damage can be achieved from bituminous mixtures. But there should be a maximum limit where up on an increase in temperature and loading, the asphalt content in the mix get increased and resulting bleeding on the surface of paved road.

The figure (4.11) below is plotted for determination of the effective asphalt content for mixes blended with 0% EFA filler. As the effective asphalt content decreases, the filler content increases in the mix. This is because more voids are filled with mineral fillers as the filler content in the mix increases resulting increase total asphalt content and hence, increasing the effective asphalt content. Besides, as the filler content increases, more asphalt is absorbed by fine aggregates due to higher proportion of fines in the mixture. The properties of the mix design at this design binder content with Marshall Criteria were shown in Table (4.10and4.11)

Table4. 18 properties summery for control mix design

% of Asphalt	Unit Weight	Air Void	Stability	Flow	VMA	VFA
4.00	2.389	7.4	11.1	1.66	16.0	53.7
4.50	2.412	5.8	11.8	1.98	15.6	63.0
5.00	2.431	4.4	12.4	2.11	15.4	71.3
5.50	2.441	3.0	12.5	2.18	15.5	80.8
6.00	2.445	2.2	11.5	2.86	15.8	86.0

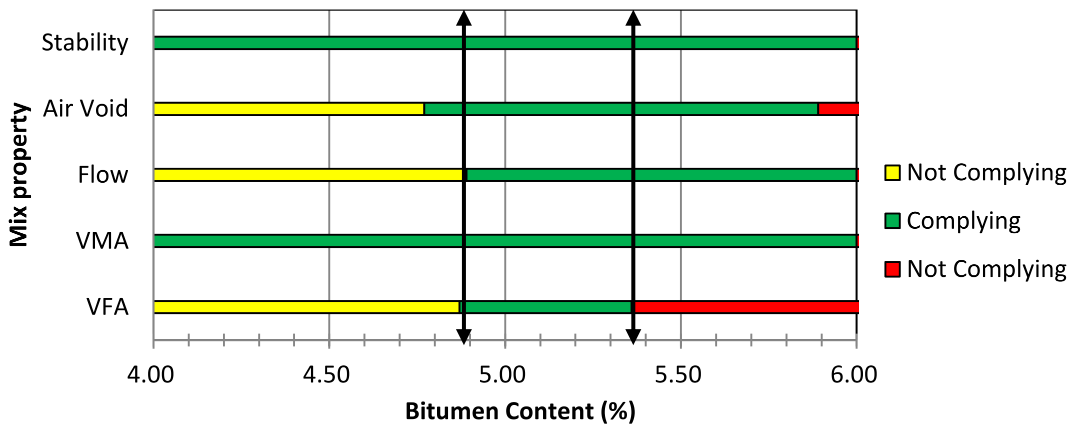

Figure4. 11 Acceptable Bitumen range complying with design criteria

The Target AC = 5.1%

Therefore Acceptable Asphalt Limit can be Min. 4.89 and Max. 5.36

Table4. 19 Mechanical Properties of Asphalt Mixes with EFA at 5.5% Filler Content and 4% air void

Specification Requirement as per ERA 2013 &MS-2		Test result for different % of EFA replacement				
		0%	15%	25%	35%	45%
Bitumen Content (%)	4.89-5.36	5.1	5.2	5.15	5.05	4.85
Stability(KN)	Min. 8	12.5	12.4	12.52	11.81	10.7
Flow(mm)	2-3.5	2.1	2.41	2.4	2.43	3.6
AV (%)	4	4	4	4	4	4
VMA (%)	Min.13	15.4	16.22	15.81	15.65	15.63
VFA (%)	65-75	73.33	73.5	73.2	75.1	73
Bulk Density(g/cm^3)	-	2.433	2.411	2.423	2.424	2.429

Table (4.19) above shows the asphalt mixtures laboratory test results with different EFA filler content replacement and the corresponding values of Marshall Properties at 4% air void. From the table at 25% satisfied all requirements of standard specification and comparing with control mix. From table; the rest test result EFA replacement not satisfy specification requirement.

4.4. The relationship of Marshall Properties with EFA Filler Material

4.4.1. Marshall Stability – EFA Filler Content Relationship

From Figure (4.12) below it is showed that all values of stability with different replaced percent of EFA filler content has achieved the specification requirements. As shown below the stability of mixes with EFA has decreased as the replaced filler content increases except 25% replacement had better stability result than control mix replacement.

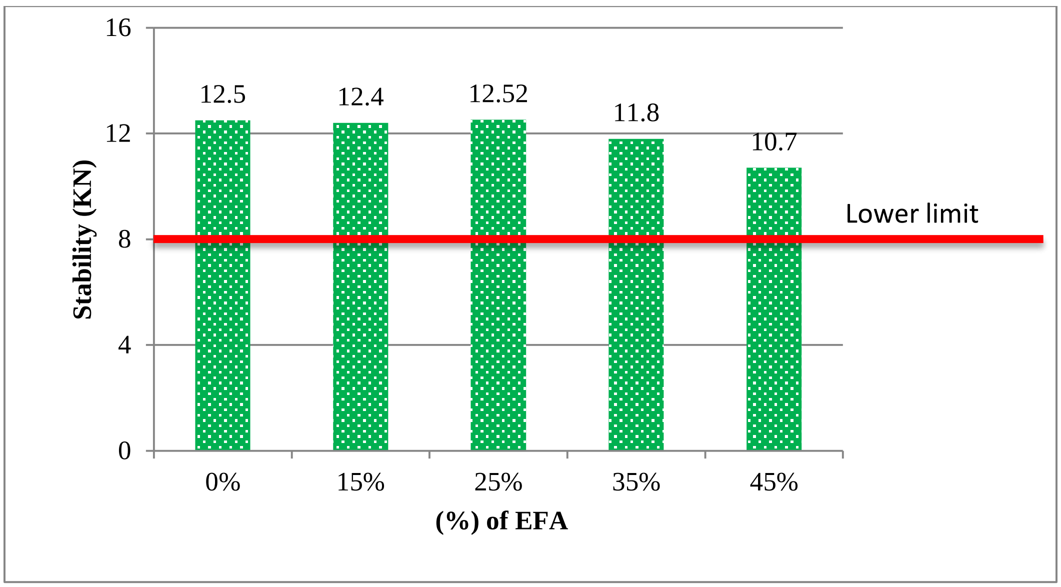

Figure4. 12 Relationship between Stability and replacement rate of EFA fillers at 4% air void

4.4.2. Flow – EFA Filler Content Relationship

The flow of mixes with 45% EFA filler replacement had the value more than maximum limit but all other results within the range of the specifications. Figure (4.13) shows flow value results of HMA at different replacement percent of filler content.

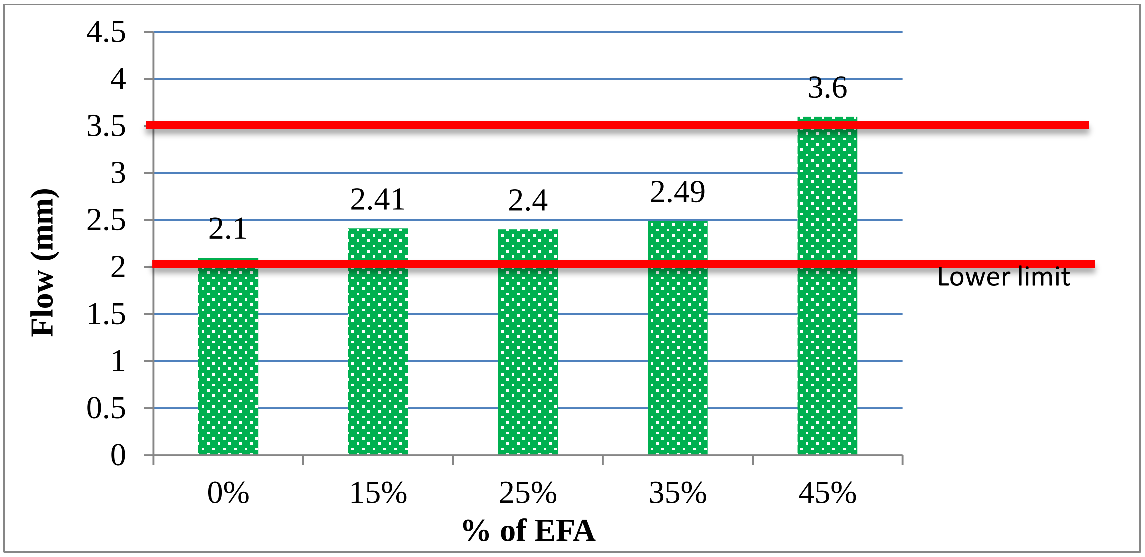

Figure4. 13 Relationship between flow and replacement rate of EFA fillers at 4% air void

4.4.3. Bulk Density – EFA Filler Content Relationship

The bulk density of HMA mixes with different replacement percentages of EFA filler content achieves the specification requirements. The test result shows that the bulk density increases as the EFA filler content increases. Figure (4.14) represents asphalt mix bulk density at different filler content.

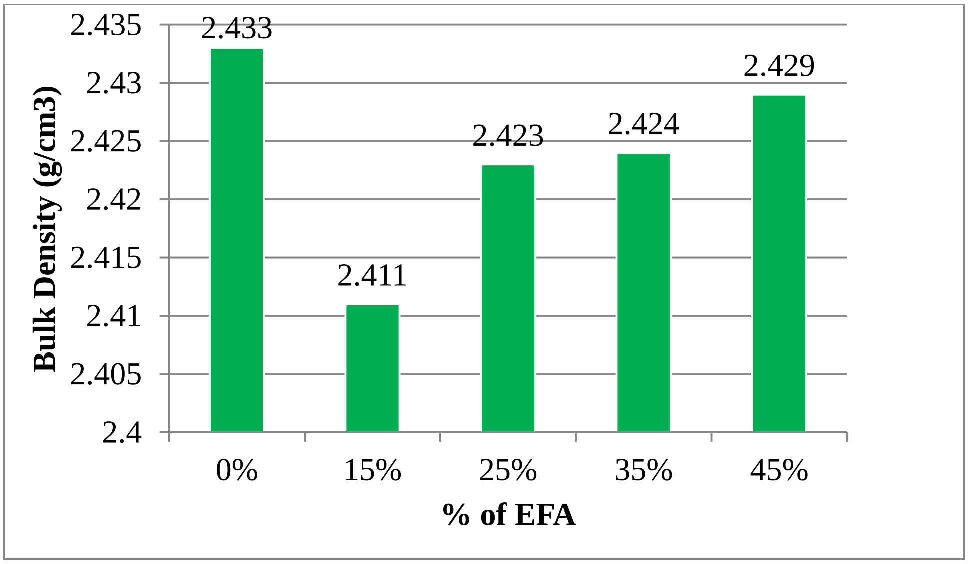

Figure4. 14 Relationship between bulk density and replacement rate of EFA fillers at 4% air void

4.4.4. Air Voids (VA) – Bitumen and EFA Filler Content Relationship

The bitumen content value of the mixes decreased gradually as the EFA filler content increases. But the figure below showed that at 25% filler content the bitumen content percentage was 5.15% which was more approached to OBC at 4% air void than others but all results were at the specification range except 45% EFA replacement. Figure (4.15) represents the bitumen content values of asphalt mixes at constant air void and different EFA filler content.

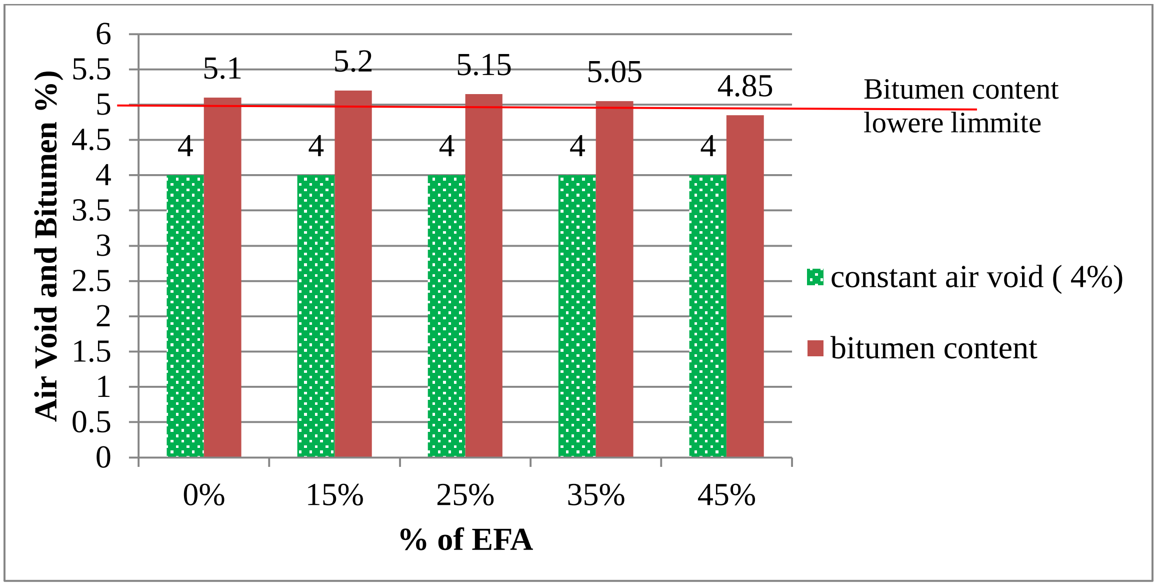

Figure4. 15 Relationship between bitumen content and replacement rate of EFA fillers at 4% air void

4.4.5 Voids in mineral aggregates (VMA) – EFA filler content relationship

From below figure (16) showed voids in mineral aggregates decrease with increases EFA content up to a minimum value. The minimum VMA value is 15.75% of asphalt samples prepared with 65% CRF and 35% EFA but CRF had a minimum value than all other replacement. The voids in mineral aggregates value all are within the permissible limits specified in the ERA Pavement Design Manual (2013).

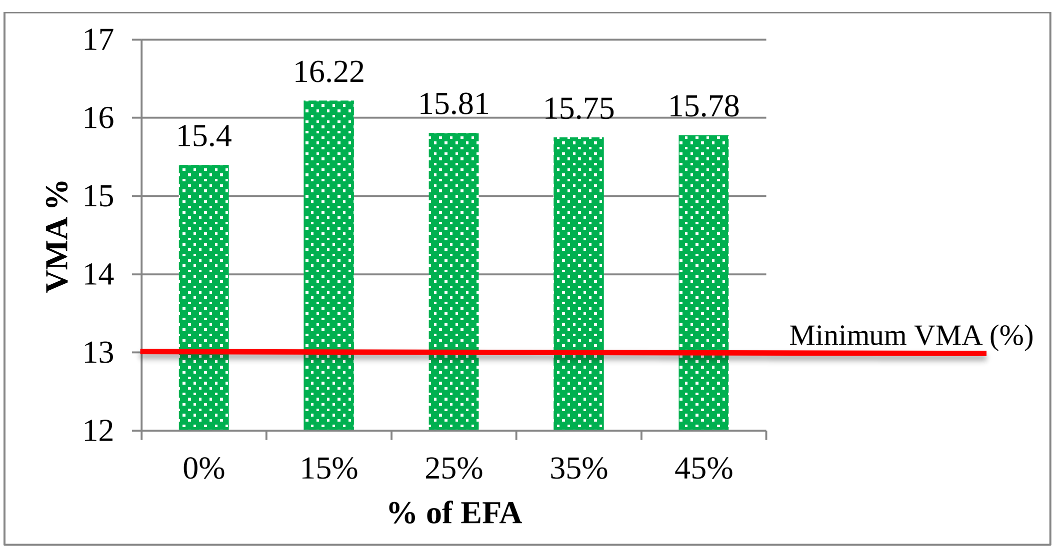

Figure4. 16 Relationship between VMA and replacement rate of EFA fillers at 4% air void

4.4.6 Percent Voids filled with Asphalt (VFA)–EFA content relationship

Voids filled with asphalt value increase with increase replacement percent of EFA. Figure (4.17) showed that VFA for replaced mixes with 0%, 15, 25% and 45% EFA was within the range of 65% - 75% specified by (ERA, Pavement Design Manual, 2013). But at 35% replacement were laid outside the specifications. At 45% replacement of EFA filler content the VFA in the mix is approached to the median value of VFA in the specifications. The VFA for the control mix is higher than the 25% and 45% of replaced mix. This was due to the fact that more effective bitumen content was present in the mix to filled available voids between the inter-granular spaces. But when VFA increase it was Couse for failure of HMA.

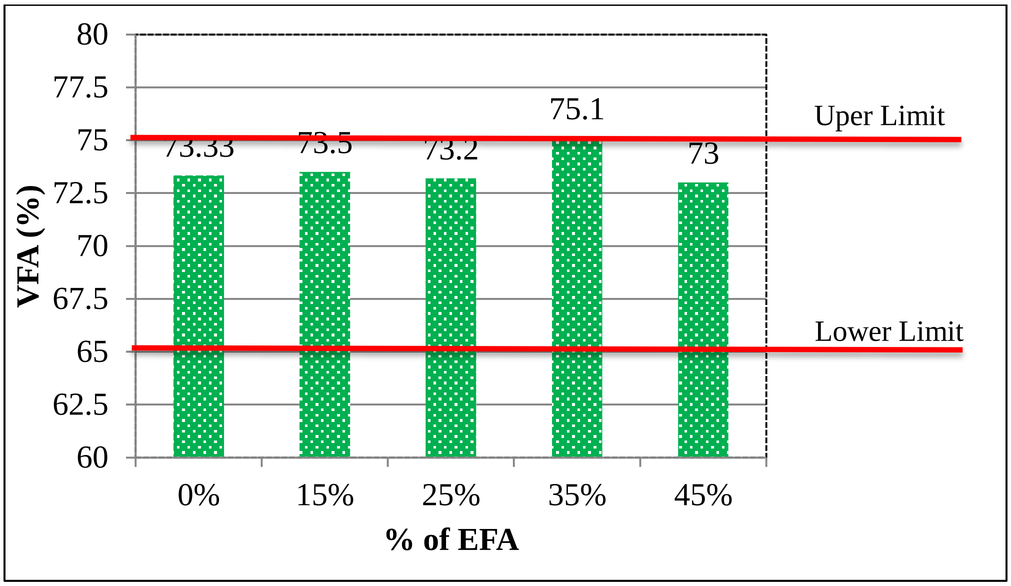

Figure 4. 17 Relationship between VFA and replacement rate of EFA fillers at 4% air void

4.4.7 Summary of HMA Properties

The table (4.20) indicated below summarizes the properties of HMA with different filler content.

Table4. 20 Summary of Marshall Test Result of the Study

Specification Requirement		Test result for different % of EFA replacement				
		0%	15%	**25%**	35%	45%
Bitumen Content (%)	4.89-5.36	5.1	5.2	5.15	5.05	4.85
Stability(KN)	Min. 8	12.5	12.4	12.52	11.8	10.6
Flow(mm)	2-3.5	2.1	2.4	2.4	2.43	3.6
AV (%)	4	4	4	4	4	4
VMA (%)	Min.13	15.4	16.22	15.81	15.65	15.63
VFA (%)	65-75	73.1	74	73	75.1	73.3
Bulk Density(g/cm^3)	-	2.433	2.49	2.423	2.43	2.412

Table (4.20) above shows the asphalt mixtures laboratory test results with different EFA filler content replacement and the corresponding values of Marshall Properties at 4% air void. From the table at 15% and 25% satisfied all requirements of standard specification and comparing with control mix. From those two result 25% EFA replacement had better stability result than 15%EFA.

4.5 Optimum Filler Content replacement

From table (4.20) it is noticed that all values of 15% and 25% replacement satisfied all specifications requirements which is 8KN minimum. But the result for 25% replacement of EFA better in Marshall Stability with 12.52KN. Figure (4.15) represents the bitumen percentage with 4% air void at different filler content and at 25% filler content the corresponding bitumen content value was 5.15% which is very close to the median bitumen content in the specifications. From Figure (4.14) it is noticed that all values of bulk density at different filler content were very close to each other and all of them are consistent with the specifications requirements. At 35% and 45% VFA and flow were laid outside the range as showed in table 4.20 respectively which means that those replacement out consideration. Therefore 25% of EFA replacement better in all criteria.

4.6 Performance of test Hot Mix Asphalt

In this study asphalt performance test were performed beside with marshal stability test. For both control and modified mix performance to resist rutting was determined. Wheel tracking test were performed to determine the performance of the mix which laboratory results showed in table (4.21) below.

Table4. 21 Laboratory result of wheel-tracking test

<table>
<tr><td colspan="9">Results of the UNE-EN 12697- 22 wheel-tracking test</td></tr>
<tr><td></td><td colspan="4">Enset fiber replacement (25% EFA)</td><td colspan="4">Crushed rock fine(100% CRF)</td></tr>
<tr><td>Mix Name</td><td colspan="2">WTS_{AIR} =(d10000 −d5000)/5 (mm/10^3load cycles)</td><td>$PRD_{AIR} = \frac{\sum_{i=1}^{n=2}\left(100 * \frac{RDi}{Hi}\right)}{2}$</td><td>Mean RD (mm)</td><td colspan="2">WTS_{AIR} =(d10000−d5000)/5 (mm/10^3 load cycles)</td><td>PRD (%) =((RD)*100/ h)/2))</td><td>Mean RD (mm)</td></tr>
<tr><td>Trial one</td><td>0.156</td><td rowspan="2">Average =0.138</td><td>2.87</td><td rowspan="2">2.9</td><td>0.118</td><td rowspan="2">Average =0.142</td><td>2.68</td><td rowspan="2">2.78</td></tr>
<tr><td>Trial two</td><td>0.12</td><td>2.93</td><td>0.166</td><td>2.88</td></tr>
<tr><td>Sum</td><td colspan="2"></td><td>5.8</td><td></td><td colspan="2"></td><td>5.56</td><td></td></tr>
<tr><td colspan="9">Where;
WTS wheel tracking slop, PRD- proportional rut depth , RD- rut depth and h – height of specimen(50mm)</td></tr>
</table>

From the above table (4.21) illustrated the laboratory test result for both control mix and modified mix by Enset fiber ash. 100% CRF or control mix had a better rutting resistance performance than mix blend with Enset fiber ash. Further detail information listed in appendix D. Wheel tracker test were performed for all prepared sample after determine the optimum percent of EFA replacement. Figure (4.18) illustrate rut depth with respect to the number of passes. The comparison showed that the rutting occurred in the samples blended mix with Enset fiber ash of temperatures 60^{o}C is less than that of control mix or conventional filler of crushed rock fine. But the result was almost the same average rutting depth. The figure also showed rate of deformation decrease as depth of rutting increase.

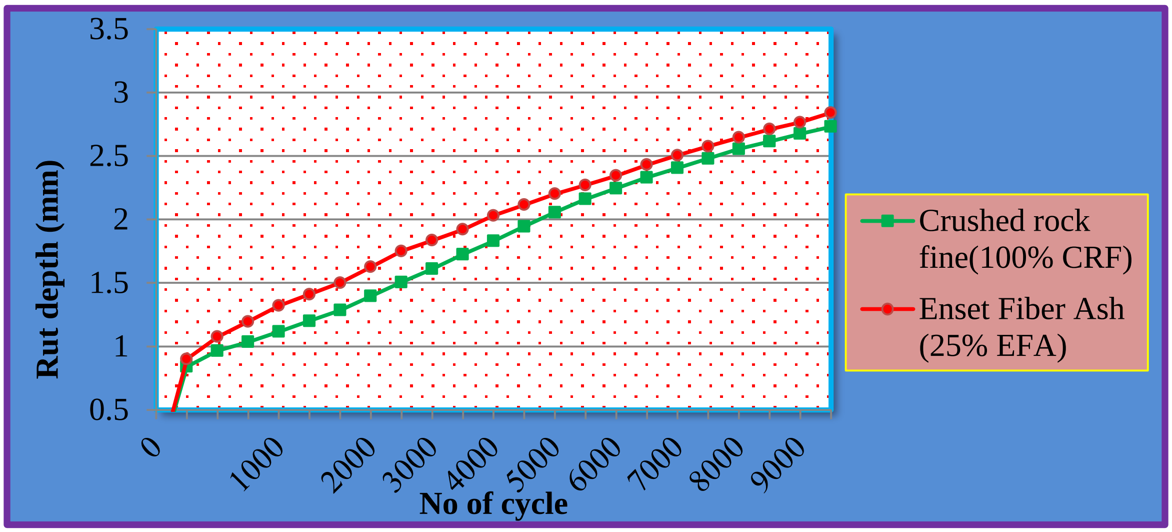

Figure4. 18: Wheel Tracking Test results for conventional and modified HMA

4.6.1 Comparison of rutting result with specifications

Table4. 22 Comparison rutting performance of asphalt mix control and 25% EFA content with standard specification

Results of the UNE-EN 12697- 22 wheel-tracking test						
Mix Name	Rate or WTS_{AIR}	PRD (%)	Mean RD (mm)	specification as per EN 13108		
				Rate (μmm/cycle)	PRD (%)	RD(mm)
100%CRF	0.142	5.56	2.78	<0.15	<8	<6
75%CRF&25%EFA	0.138	5.8	2.9	<0.15	<8	<6

Table (4.22), shows that the conventional or control mix and as well as the modified mix, meet the requirements. It was discovered that Enset fiber ash could replace up to 25% of the crushed rock fine filler content by weight in the control mix.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

This study evaluated the performance of Enset fiber ash as filler for HMA. Using standard testing procedures, aggregate was tested for all the necessary quality tests including specific gravity, absorption, abrasion resistance, impact, crushing, and gradation. Similarly important quality tests of bitumen were conducted in a laboratory and all the results were pass the necessary specifications. The analysis also answers the question of whether Enset fiber ash is effective using in the HMA mixtures irrespective of which application method is used. On the basis of test results and analysis obtained in a controlled laboratory, the following conclusions and recommendations are presented.

5.1 Conclusions

- The physical property of all aggregate material was evaluated related to the preparation of the marshal test specimen. All specification requirements have been passed on the laboratory test result of the aggregate which used in this research.
- The laboratory result for ‘Enset’ fiber ash gives specific gravity 2.72 and plastic index was non-plastic, satisfying the specification for using as partial replacement filler in hot asphalt mix, so Enset fiber can replace conventional filler in hot asphalt mix design.
- The optimum asphalt content value were required to fulfill the Marshall requirement is 5.15 and 5.1% for mixture contain 25% ‘Enset’ fiber ash (EFA) filler and the mixture which contain 100% CRF filler content respectively.
- Hot Asphalt Mix produced using blend with ‘Enset’ fiber ash (EFA) Filler performed better under load than HAM made without blend mix with EFA filler. Stability value of mixes prepared without EFA filler with gives 12.5 KN and mix prepared with EFA filler gives 12.52KN with their optimum asphalt content.
- The void in mineral aggregate (VMA) values obtained indicate relatively increase due to additional of EFA in the mixture i.e. for mixture blend without EFA filler gives 15.4% and for mixture blend with EFA filler result 15.81%.
- Void filled with asphalt (VFA) values of mixture blend without EFA filler result 73.1% and mixture blend with EFA filler gives 73% were found the max value of marshal criteria this was showed void is filled by the EFA filler and CRF almost the same area coated by bitumen.

- The flow and bitumen content in the mixture value obtained generally indicate increasing and decreasing trend due to the addition of EFA as filler in the mixture than mixture blend with Enset fiber ash respectively. At 15% and 25% bitumen content slightly increase (5.2% and 5.15%) but decrease as increase EFA, 5.05% and 4.85% for 35% and 45% EFA replacement respectively. Flow were improved by adding EFA, results were give 2.4 and 2.1mm.
- Rutting test result were describe blend without Enset fiber ash better than blend with Enset fiber ash. Results were gives 2.78mm and 2.9mm respectively within the specification of less than 6mm respectively.
- Filler replacement at 25% EFA passed all standards specifications which conducted in this study.

From this study, the mixture had better performance obtained by blending the mixture without replacing the Enset fiber ash filler. The test result obtained from the mixture blend with 15% and 25% of the Enset Fiber ash (EFA) filler by the weight of the filler used in the control mix had almost the same effect on the control mix and satisfy all specification requirements. Therefore 25 percent of the total weight of conventional filler used in this study, which is crushed rock fine, can be replaced by ‘Enset’ fiber ash.

5.2. Recommendation

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

- From the above finding it is evident Enset fiber ash as partial replacement of crushed rock fine filler in hot mix asphalt concrete production with a up to percentage of 25% by the total weight of a crushed rock fine filler.
- For future research, it is recommended that detailed or in-depth investigation should be carried out on related project; compliance with quality of materials and construction methods in accordance with ERA Standard Specifications and investigate related material.
- The researcher suggests that further research be conducted on Enset fiber ash, such as chemical compositions and chemical properties, which are not covered in this study.
- The researcher who interested to use this research us reference, I recommend to further investigate on other bitumen grade and other aggregate quarry that doesn’t cover in this research.

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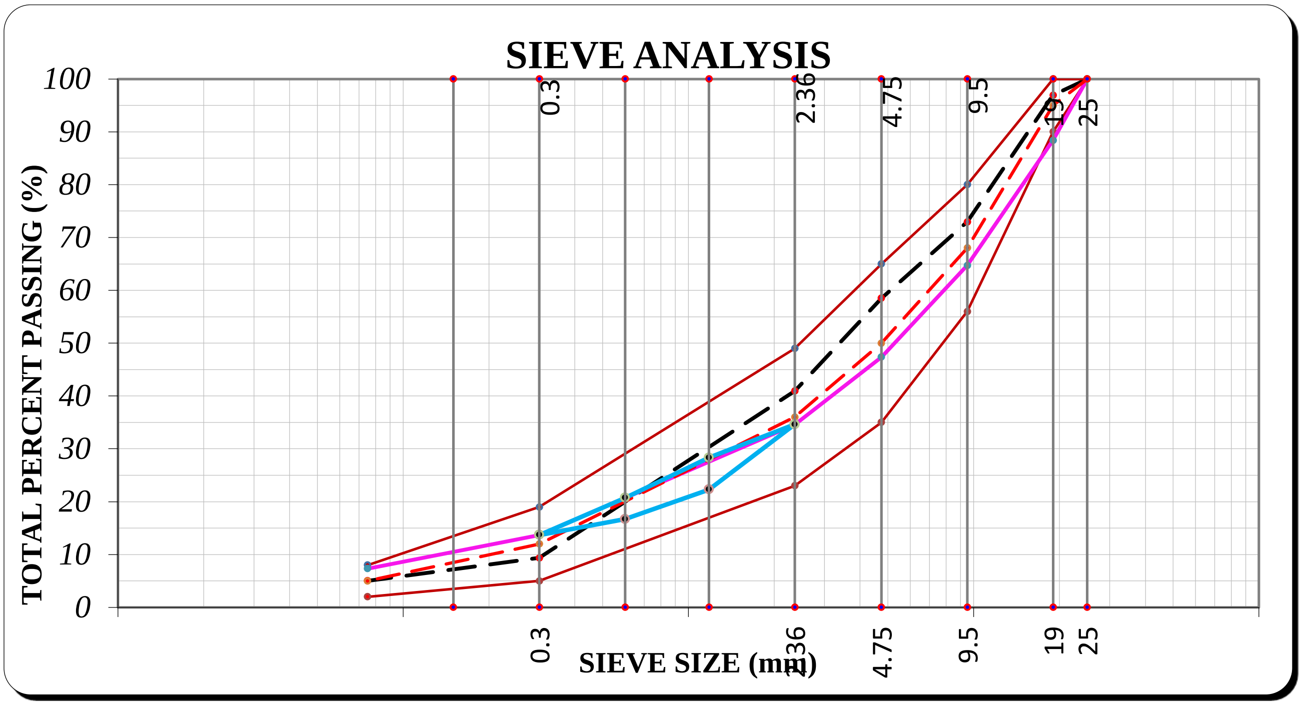
46. Based on the 2007 Census conducted by the Central Statistical Agency, this town has a total population of 28,866, of who.

Appendix A physical properties of aggregate

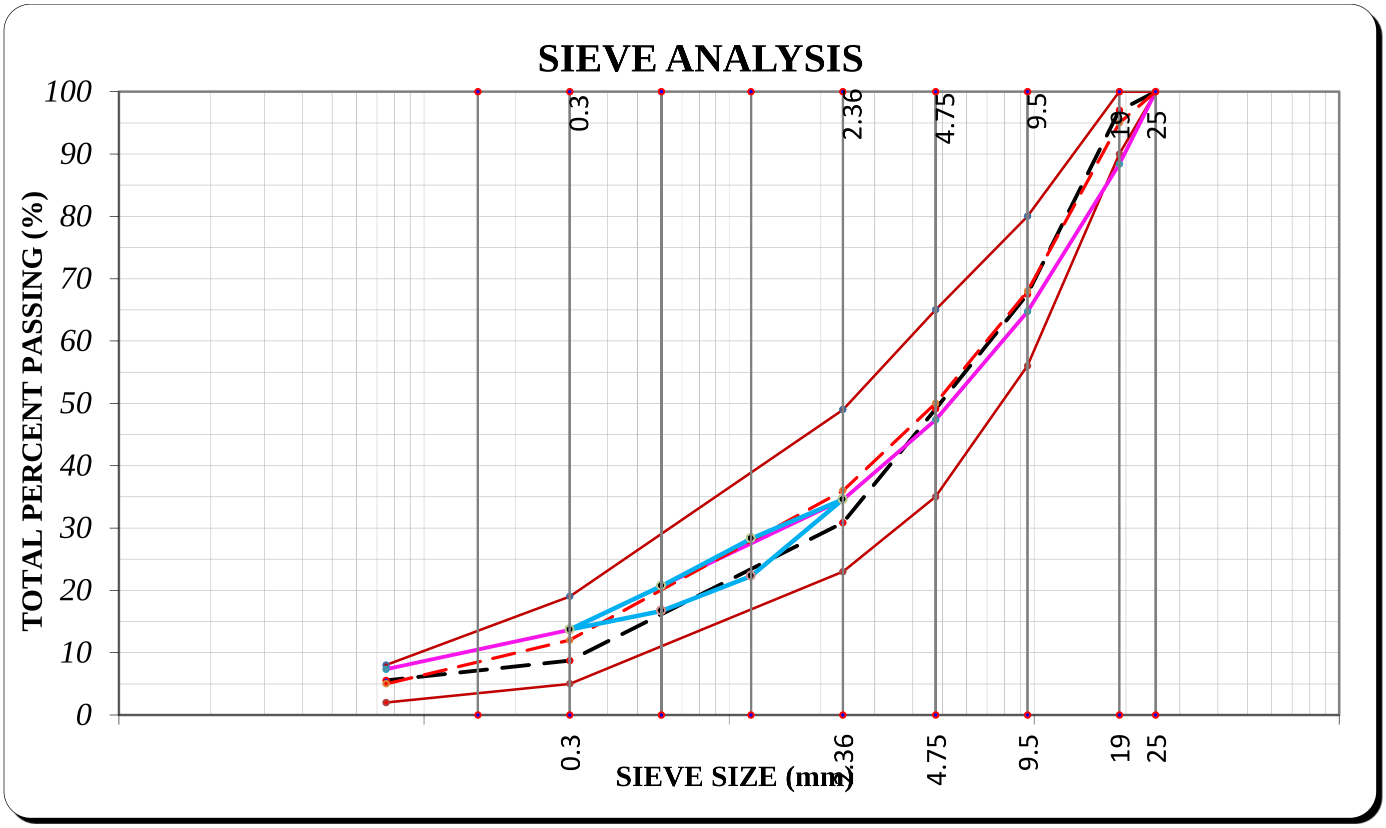
Appendix B Mix design result

Appendix B-1 Gradation for mix design

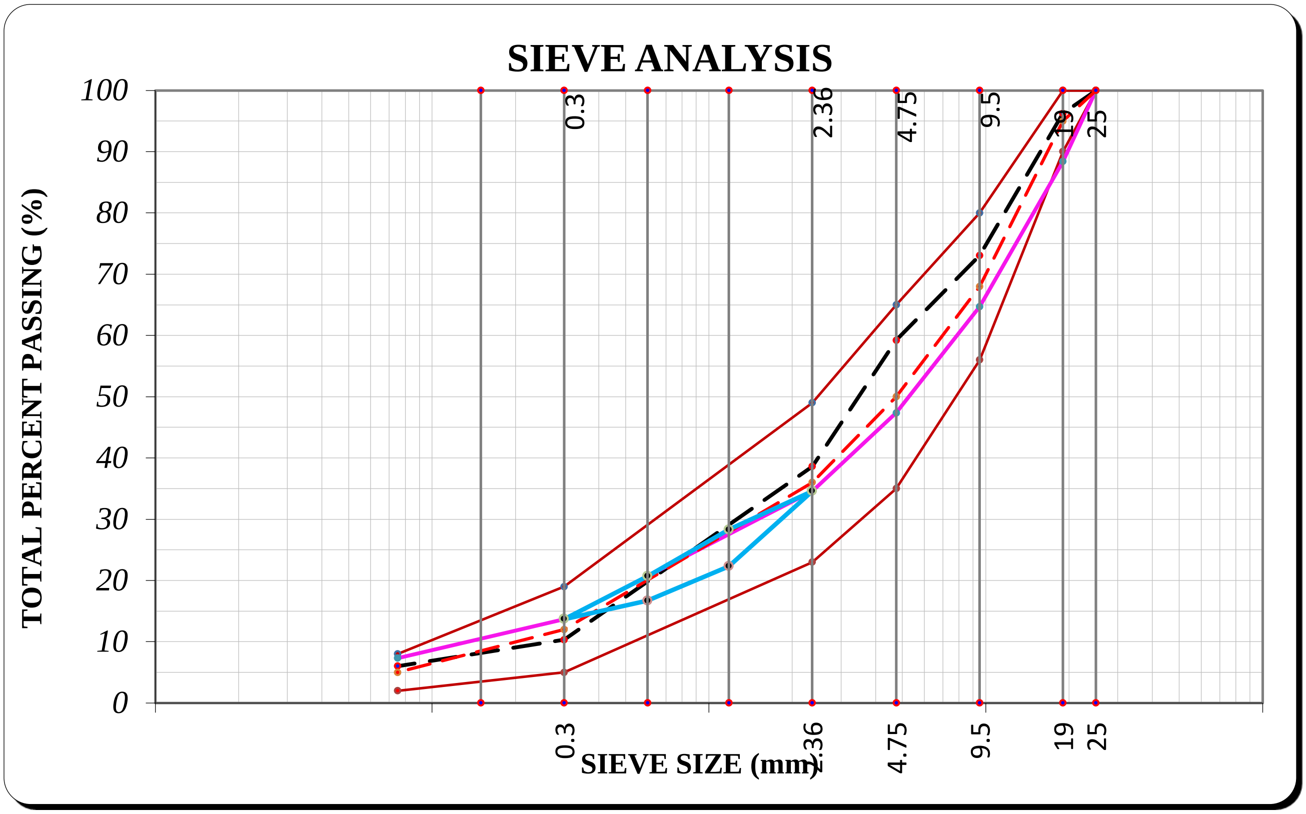
Trial one



Trial two for gradation



Trial three


SIEVE ANALYSIS
TOTAL PERCENT PASSING (%)
SIEVE SIZE (mm)
100
90
80
70
60
50
40
30
20
10
0
0.3
2.36
4.75
9.5
19
25

Appendix B-2 Laboratory Mix Design Batch Weight for Trial two that passes all marshal criteria

Appendix C Marshal Test result

Appendix C.1 Marshal and volumetric property of control mix

Appendix C.2 Marshal and volumetric properties for 25% Enset fiber ash filler replacement

Volumetric and marshal test result of 15% EFA replacement

Volumetric and marshal test result of 35% EFA replacement

Volumetric and marshal test result of 45% EFA replacement

Appendix D Rutting test laboratory test data

Appendix E pictures for the whole procedure

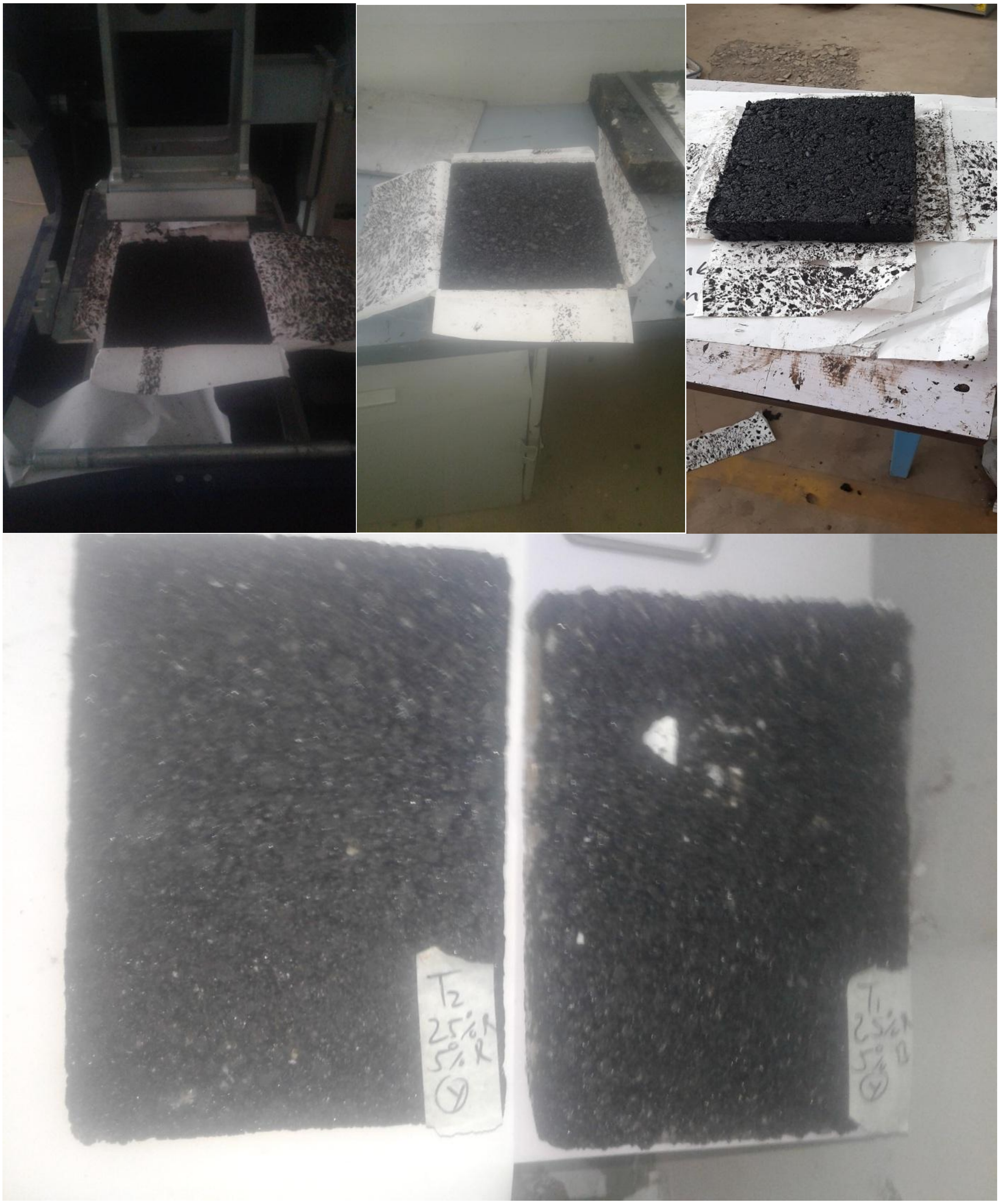
Appendix E.1 Pictures for Material preparation (by Desta Moshe)

Appendix E.2 Pictures for Marshal Test procedure (by Tiruwork Mulatu)

Appendix E.3 Pictures for Rutting test procedure


By Tiruwork Mulatu


HEATED

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