JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

Comparative Study on Effect of Using Bagasse ash and Groundnut shell ash as Fillers on the Properties of 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 Master of Science in Civil Engineering (Highway Engineering)

By: Muluken Geremew

Feb 2021

Jimma, Ethiopia

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By: Muluken Geremew

Advisor: Dr. Getachew Kebede (Ph.D.)

Co-Advisor: Eng. Mesfin Dinku(MSc)

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Jimma, Ethiopia

Declaration

I, the undersigned, declare that this thesis entitled:"**Comparative Study on Effect of Using Bagasse ash and Groundnut shell ash as a Filler on the Properties of Hot Mix Asphalt**" is my original work, and has not been presented by any other person for an award of a degree of Masters of Science(MSc.) in this or any other University, and all sources of material used for this thesis have to be duly acknowledged.

Candidate:

Name	Signature	Date
MULUKEN GEREMEW		08/ 02 / 2021

As University MSc. thesis Advisors, we hereby certify that we have read and evaluate this Msc research prepared under our guidance, by Mr. **Muluken Geremew** entitled: **"Comparative Study on Effect of Using Bagasse ash and Groundnut shell ash as a Filler on the Properties of Hot Mix Asphalt"**. We recommend that it can be submitted as fulfilling the MSc Thesis requirements.

	Signature	Date
Dr. Getachew Kebede(Ph.D.) Advisor		08/ 02 / 2021
Eng. Mesfin Dinku(MSc.) Co-Advisor		08/ 02 / 2021

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Abstract

Hot mix asphalt mix design is the process of determining appropriate proportion of the materials that would give long lasting performance paving mixture during its service life. HMA is a mixture of mineral aggregate, binder and air indifferent relative proportions.It is well recognized that the properties of hot-mix asphalt /HMA/ mixture depends up on its different constituent materials. Among which, mineral fillers are one of the constituent element which play an important role on the properties hot-mix asphalt. So, better understanding of the effects of fillers on the properties of HMA mixtures is crucial to good mix design and high performance of HMA mixtures. This paper presents a comparative laboratory investigation into the effects of partially replacing conventional filler /crushed stone dust/ by bagasse ash and groundnut shell ash on some properties of HMA mixtures. A number of trial mixes/120/ have been prepared by the Marshal Mix design procedure using three different percentage of crushed stone dust filler/5%,5.5% and 6%/and five varying bitumen contents 4-6% at 0.5% increment to determine the optimum filler and bitumen contents from which the design bitumen/filler content was selected which was later utilized while crushed stone dust was partially replaced by bagasse ash /at 0,5,10,15,20,25and100%/ and groundnut shell ash/at 0,5,10,15and100%/ all passing No. 200 sieve/0.075mm/ as a filler to determine optimum replacement percent and their effect on hot-mix asphalt properties. The properties of HMA mixtures evaluated include indirect tensile /ITS/ strength, tensile strength ratio /TSR/, marshal and volumetric properties. The results obtained shows that, crushed stone dust, GSA and SCBA mixes exhibit satisfactory trend result with a design bitumen content of 5.248%. However, partial replacement of crushed stone dust with bagasse ash and groundnut shell ash as filler in hot mix asphalt has no significant effect on performance, or volumetric properties of asphalt concrete except on tensile property, Va content, stability and flow at 10% and 15% replacement percentage of GSA and SCBA satisfying the allowed range of control specification requirement. Having this into consideration, in this research it is found that the optimum replacement percentage of GSA and SCBA as a filler is 10% and 15% respectively.

Keywords: Bagasse ash, Crushed stone dust, Groundnut shell ash, Hot Mix Asphalt

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Acronyms

AASHTO	American Association of State Highways and Transport Officials
AC	Asphalt Concrete
AIV	Aggregate Impact Value
LAA	Los Angeles Abrasion
ASTM	American Society for Testing and Materials
CSA	Central Statistical Agency
CSD	Crushed Stone Dust
ERA	Ethiopian Roads Authority
ERCC	Ethiopian Road Construction Corporation
FDRE	Federal Democratic Republic of Ethiopia
GSA	Groundnut Shell Ash
HMA	Hot Mix Asphalt
ITS	Indirect Tensile Strength
JIT	Jimma Institute of Technology
Mt	Million ton
NAPA	National Asphalt Pavement Association
OBC	Optimum Bitumen Content
OFC	Optimum Filler Content
PCC	Portland Cement Concrete
PG	Performance grading
SCBA	Sugarcane Bagasse Ash
SHRP	Strategic Highway Research Program
TSR	Tensile Strength Ratio
VFA	Voids Filled with Asphalt
Va	Air Voids
VMA	Voids in Mineral Aggregate

CHAPTER ONE

INTRODUCTION

1.1 Background

Hot mix asphalt mix design is the process of determining appropriate proportion of the materials that would give long lasting performance paving mixture during its service life. It is a mixture of binder, aggregate, and air indifferent relative proportions that determine the physical properties of the mix and, ultimately, how the mix will perform as a finished pavement. Many different, and sometimes conflicting, performance demands are placed up on the asphalt mixtures and this makes it a complex material. Thus, the design of asphalt paving mixes is largely a matter of selecting and proportioning the ingredient materials to optimize all desired properties in the finished paved road.

The construction and maintenance of highway pavement requires a large amount of good quality materials. In order to save the outlay investment and to extend service life of pavement use of modified asphalt mix can meet the needs of the users. 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 using common filler such as lime, cement and other suitable materials (Brown E.Ray and Mallick Rajib B., 2012)

Currently, highway pavements are being subjected to constantly increasing high traffic load. Asphalt concrete pavements are subjected to various types of pavement distresses such as rutting and fatigues cracking that are being observed within a few years after opening the roads for traffic. Subsequently, this damage introduces high maintenance cost and disturbs road user’s activity. For pavements to resist adequately under these increasingly severe conditions, for both present and future conditions, it is necessary that to consider basic design factors such as traffic loading, environment, failure criteria and better understanding about construction materials which includes aggregates, mineral filler, and asphalt binder (Zemicheal, 2007).

The government of the Federal Democratic Republic of Ethiopia (FDRE) has been focusing on improving its national road network in order to connect existing and potential agricultural production areas, industrial corridors with markets and international corridors as major component of its development policy. However, it has been observed that failure of the constructed asphalt concrete road, had occurred within short period before their expected design life, in some roads after few months of completion and others delayed from the contract period during construction due to shortage of HMA ingredients. One of the ingredients, filler which has less amount in the asphalt mixture, has significance on the performance and difficult to get from crushing of aggregates (basalt). It is one of the reasons for the failure and the cause of delays of asphalt road projects. Consequently, it costs additional budgets for maintenance of the roads and cost overrun due to extended time to finish projects which brings a negative impact on the government budget and nation economy. It has been noticed that the premature distress like fatigue cracking and permanent deformation (rutting) and the delays encountered in many road projects is the effect and shortage of fillers production. Even though it is known that the shortage of filler in the construction industry exists in our country, alternative filler proposals are not investigated in depth (Nigatu, 2015).

The performance of bituminous surfaced roads is directly affected by the proportion and quality of ingredient materials in the mixture. Various studies were conducted indicating that the mix design has been a major concern on the performance of asphalt concretes. Among these studies (Birhanu & Feyissa, 2001) revealed that certain modifications in the mixture such as, changing the type, size and gradation of aggregate, varying the filler to asphalt ratio, type and amount of filler alter the physical properties of HMA concrete. Fillers, in particular, as one of the ingredients in HMA, have only been thought to fill voids in the aggregate. However, studies indicated that the role of fillers in asphalt mixture performance is more than filling voids depending on the type used.

In civil engineering works, various by-products/wastes have been used for several purpose amongst which are replacement of filler or binder materials, cement replacement in concrete and stabilization of soil. These waste utilization would not only be economical but also an environmental pollution control. In highway construction technology, efforts are being made in the area of utilizing waste materials instead of discarding or incinerating/dumping/ them. Such wastes include industrial, agricultural and municipal solid waste. Even though, it is the first time research to be conducted on this title in Ethiopia, limited research done in the other country has investigated the performance of asphalt concrete by partially replacing cement with bagasse ash but not groundnut shell ash. They found out that at varying percentage of bitumen content, the stability, flow, voids in mixed aggregates and void in the mix meets the standard specified with an optimum bitumen content.

This study was intended to evaluate the effect of partially replacing crushed stone dust, with sugarcane bagasse ash and groundnut shell ash all passing 0.075mm sieve at various contents on HMA properties. A laboratory tests such as Marshal test and moisture susceptibility tests were used to investigate their effect on asphalt concrete mixes. Different asphalt mixtures were prepared by varying contents of respective filler type and different bitumen content in accordance with the Marshal Mix design procedure for heavy traffic. Further test specimens were prepared using design asphalt content in order to investigate the marshal properties and the moisture susceptibility of asphalt concrete mixes with bagasse ash and groundnut shell ash at varying replacement percentage.

1.2 Statement of the Problem

Researches show that modification made in the ingredients of bituminous mixtures such as type of ingredient materials and relative proportion has altered and sometimes improved the properties of HMA. Among these researches, some studies (Zemichael, 2007; Eltaher & Ratnasamy , 2016) proved that mineral fillers have important role in the performance of HMA. Depending on the fillers characteristics, it was found that their purpose was not only to fill the voids but also modifying the mixture.

In the construction of highway pavements, one of the main problems is insufficiency of the amount of mineral fillers from crushing of aggregates. Moreover, there is also environmental deterioration resulting from blasting of more quarry areas to produce the required amount of mineral fillers and its mode of production has made it to be expensive. Therefore, it is important to find an alternative type of mineral filler materials. Thus, this study was made with this intention.

There are different fillers which are used in hot mix asphalt to improve the mechanical properties of asphalt concrete in developed countries. Limestone dust, hydrated lime, Portland cement are some of the fillers which are used to impart greater stability and strength in the construction of asphalt concrete. However, there are no alternative fillers recommended in our country to improve or modify the quality of asphalt concrete roads (Nigatu, 2015).

Bagasse is an abundant waste produced in sugar factories after the extraction of juice from Sugarcane. There is a continuous increase in the production of sugar worldwide and approximately 1500 million tons of sugar cane are annually produced all over the world, which leaves about 40-45% bagasse and12.5% bagasse ash after juice extraction. Therefore, the average annual production of bagasse and its ash is estimated to be 600 and 72 million tons, which is a bulky waste from sugar industry(Goyal and Anwar,2007).

The government of Ethiopia has given prime priority to the sugar sector and is expanding the sector to all regional states by constructing a large scale projects. It is estimated that these projects leave 14-15 million tons of bagasse and around 2 million tons of bagasse ash after the juice is extracted. However, due to lack of research, most of the bagasse ash is disposed off in landfills which may cause severe environmental and human health concerns unless it is properly managed (Ethiopian Sugar Corporation, 2016).

Groundnut shell is an agro-waste generated from milling of groundnut. Groundnut production worldwide had reached about 42.31 million tons in 2014, and it was projected to continuously increase annually (FAO, 2014). China, India and Nigeria are the first three leading countries that contributed about 37.3%, 15.5% and 8.1% of the total global groundnut production, respectively. These countries are still leading in the production of groundnut. Approximately, groundnut constitutes about 25-40% shells. And in every one ton of the shells, 2.5% ash is produced (Abdulrazak, et al.,2014). Therefore, the total global groundnut ash produced could be up to 0.42 million tons.

Groundnuts are becoming increasingly important in Ethiopian agriculture and domestic demand that has been a steady increase. It is estimated that around 129,636 tons per annum of groundnut is harvested (Nega, et.al., 2015). However, groundnut produce waste such as groundnut husk and ground nut shell ash which are usually dumped or burned in the open site. So far, the ash has less economic value; instead, it becomes a human and an environmental nuisance when disposed off in landfills, causing soil, groundwater and air pollutions. With the use of groundnut shell ash in HMA the cost will decrease and also it reduces the environmental pollution and saves the energy.

So, making use of these industrial by-product and agricultural wastes/SCBA and GSA/ will reduce cost of construction and eliminate or minimizes an environmental/human health nuisance caused by depositing the waste. In addition to these, it will also help to reduce environmental damage caused by blasting of quarries during the production of rock dust and reduction of land filled by wastes.

Thus, an investigation was made to find effective types of cheap and non-conventional fillers on the behavior of bituminous mixes. For this purpose, bagasse ash and groundnut shell ash were used as non-conventional filler replacing crushed stone dust.

1.3 Research Question

1. What are the physical properties of bagasse ash and groundnut shell ash as filler material in hot mix asphalt?
2. What are the effects of bagasse ash and groundnut shell ash on the Marshall properties of HMA?
3. What are the effects of bagasse ash and groundnut shell ash on the tensile properties/moisture susceptibility/ of HMA?
4. What is the most favorable replacement quantity of conventional fillers with bagasse ash and groundnut shell ash?

1.4 Research Objective

1.4.1 General objective

The main objectives of this research work is to determine the effect bagasse ash and groundnut shell ash on properties of hot mix asphalt as filler material.

1.4.2 Specific objective

- To identify the physical properties of sugarcane bagasse ash and groundnut shell ash to use as filler in hot mix asphalt.
- To analyze the effects of various amount of sugarcane bagasse ash and groundnut shell ash on the Marshall properties of HMA.
- To analyze the effects of various amount of sugarcane bagasse ash and groundnut shell ash on the tensile properties/moisture susceptibility/of HMA.
- To find the most favorable replacement quantity of conventional fillers with sugarcane bagasse ash and groundnut shell ash

1.5 Scope and limitation of the study

The research herein focused on evaluating the effect of bagasse ash and groundnut shell ash on the asphalt concrete characteristics such as the Marshal Properties/flow, stability, void filled by bitumen, void in the total mix, bulk density/ and moisture susceptibility/tensile properties/. The materials for this study were collected from different sources such as aggregate and bitumen from Jimma however, bagasse & groundnut shell/husk/ were delivered from Wonji shoa Sugar Factory and Shebe respectively . An asphalt binder of grade 60/70 penetration was used in this research work for preparation of asphalt concrete mixes and mineral fillers all passing 0.075mm sieve that were separated when the aggregates are dry for the production of asphalt concrete.

The mixtures were prepared using each type of fillers with different amount. The results in this research were based on the Marshal Mix design and moisture susceptibility test procedures.

1.6 Significance of the study

The significance of the research is to determine the mechanical properties and performance of HMA concrete that was done with the replacement of conventional fillers with bagasse ash and groundnut shell ash. The emphasis of the work is based on ascertain the performance of HMA concrete containing bagasse ash and groundnut shell ash and to compare it with conventional filler /crushed stone dust/ on the performance of HMA concrete properties.

The study is expected to provide environmental friendly disposal of bagasse ash and groundnut shell ash in HMA concrete pavements as well as encouraging the use of non-conventional materials which are typically of local condition which will result in job opportunity and economic benefits to farmers and sugar factories cultivating peanut and sugar cane. In addition to that, it will also help other researchers to use the findings as a reference for further research on bagasse ash and groundnut shell ash filler for HMA mix design and lessons that will help the concerned body can come up with appropriate measures to address problems resulting from using bagasse ash and groundnut shell ash and compared with other fillers in marshal mix design.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Introduction

Asphalt concrete is a mixture of coarse aggregate, fine aggregate, filler and asphalt binder hot mixed in an asphalt plant and then hot lay to form the surface course of flexible pavement. The properties of asphalt concrete depend on; the quality of its components /asphalt binder and aggregates/, mix proportions and construction process (Asphalt Institute, 1994). Flexible asphalt pavement layers consist of mineral filler, coarse, and fine aggregates all cemented by the asphalt binder and blended at pre specified weight proportions determined from the mix design method. The blend of mineral filler and asphalt binder forms the asphalt mastic destined to play a major role in controlling the mechanical behavior of its mixture (Roman, 2017).

Evaluation of hot mix asphalt properties by applying minor changes in the basic ingredients has been tried in the past by many researchers. The main objective of their research were to understand and investigate the characteristics and effect of the constituent ingredients on the performance of bituminous mixture (Birhanu & Feyissa, 2001). From analysis of their data researchers pointed out that the improvement of asphalt concrete performance starts with modification of the mix design, better understanding of the characteristics of the mineral aggregates and the bitumen type.

The research herein with concentrates and builds on the Marshal Properties and moisture susceptibility of HMA mixtures prepared using different mineral fillers by type and content. This evaluation on the subject matter was conducted by comparing the traditional crushed stone mineral filler vs. bagasse ash and groundnut shell ash fillers. There are a few well-established literatures that indicate bagasse ash filler being under practice on HMA performance, but not for the groundnut shell ash as mineral filler. In this chapter, procedure in the bituminous mix design and review of researches conducted on the effect of mineral fillers on HMA performance will be discussed.

2.2 Flexible Pavement Layers

Flexible pavements are so named because the total pavement structure deflects, or flexes, under loading. They comprise several layers of carefully selected materials designed to gradually distribute loads from the pavement surface to the layers underneath. The design ensures the load transmitted to each successive layer does not exceed the layer's load bearing capacity.

Flexible pavement built up in several layers, consisting of sub-grade, sub-base layer and base course layer, asphalt binder course and asphalt wearing course. These layers together constitute the pavement. Each layer receives the loads from the above layer and spreads them out to the next layer (ERA Manual, 2013).

2.2.1 Sub grade

The surface upon which the pavement structure and shoulders are constructed. It is the top portion of the natural soil, either undisturbed/but re-compacted/ local material in cut sections, or soil excavated in cut or borrow areas and placed as compacted embankment (ERA Manual, 2013).

2.2.2 Sub-base

The layer of material of specified dimensions on top of the subgrade and below the road base. The secondary load-spreading layer underlying the base course. Usually consisting of a material of lower quality than that used in the base course and particularly of lower bearing strength. Materials may be unprocessed natural gravel, gravel-sand, or gravel-sand-clay, with controlled gradation and plasticity characteristics. The sub-base also serves as a separating layer preventing contamination of the base course by the subgrade material and may play a role in the internal drainage of the pavement (ERA Manual, 2013).

2.2.3 Base course

This is the main component of the pavement contributing to the spreading of the traffic loads. In many cases, it will consist of crushed stone or gravel, or of good quality gravelly soils or decomposed rock. Bituminous base courses may also be used /for higher classes of traffic/. Materials stabilized with cement or lime may also be contemplated(ERA Manual, 2013).

2.2.4 Binder course

Binder course is the lower course of an asphalt surfacing laid between the wearing course and either a granular base course or stabilized base course of an existing pavement or another HMA binder course in more than one layer. Its purpose is to distribute traffic loads so that stresses transmitted to the pavement foundation will not result in permanent deformation of that layer. Additionally, it facilitates the construction of the surface layer (Kar, 2012).

2.2.5 Wearing course

Wearing courses are the most critical layer in a pavement structure and must be of high quality and have predictable performance. It is the top layer and the layer that comes in contact with traffic that's why it contains superior quality materials. It may be composed of one or several different HMA sub layers. Generally, this surface prevents the penetration of surface water to the base course; provides a smooth, well-bonded surface free from loose particles resists the stresses caused by aircraft loads; and supplies a skid-resistant surface without causing undue wear on tires (ERA Manual, 2013).

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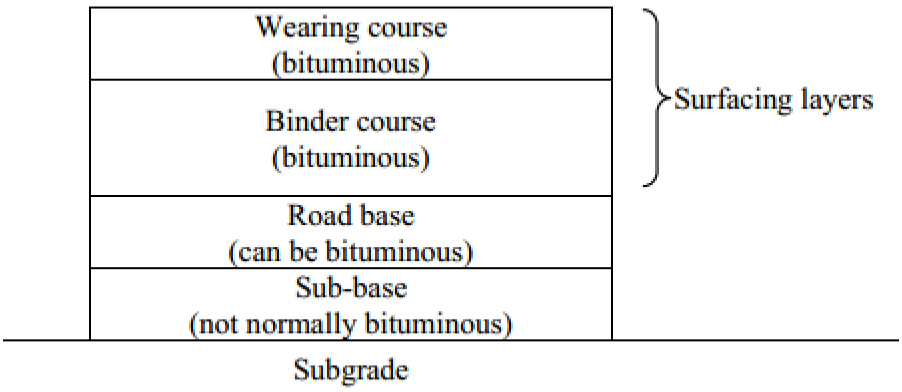

Figure 2. 1 Typical cross section of flexible pavement*(Source: ERA manual,2013)*

2.3 Types of Asphalt concrete

Asphalt concrete is a mixture to predetermined proportions of aggregate, filler and bituminous binder material plant mixed and usually placed by means of a paving machine. There are different types of asphalt mixtures commonly used in pavement construction these includes hot-mix, warm-mix and cold-mix. When used in the construction of highway pavements, it must resist deformation from imposed traffic loads, be skid resistant even when wet and not affected easily by weathering forces. The degree to which an asphalt mixture achieves these characteristics mainly is dependent on the design of the mix used in producing the material (Garber and Hoel, 2010).

- **Cold mix Asphalt concrete;** Cold mix asphalt is a blend of either emulsified or cutback asphalt binders and aggregate that are mixed and placed at much lower temperatures than conventional hot mix asphalt mixtures. Cold-laid asphalt mixes may be used for surface, base or sub-base courses if the pavement structure is properly designed. Cold-laid surface courses are suitable for light and medium traffic (Asphalt institute MS-2, 2014).

- **Warm mix Asphalt concrete;** Warm mix asphalt /WMA/ is a generic term for various products and technologies that are incorporated into plant-produced hot mix asphalt to reduce the plant mixing, roadway paving and compaction temperatures while maintaining workability. WMA can also be used as a compaction aid at hot mix temperatures. The goal with WMA is to produce mixtures with similar strength, durability and performance characteristics as HMA using substantially reduced production temperatures. Traditionally, HMA is produced in either batch or drum plants at a discharge temperature of between138° and 160°C. Mixes using WMA technologies are produced and placed at temperatures in a range of 100°C -140°C up to 38°C lower than typical hot mix. Research and field studies have shown that there can be a number of significant advantages to the use of WMA, including reduced fuel consumption, reduced emissions and increased compatibility (Asphalt institute MS-2, 2014).
- **Hot mix Asphalt concrete;** Hot mix asphalt is produced at a temperature between 150 and 190 °C, it is the highest quality among the different types. HMA mixtures consist of a combination of aggregate uniformly mixed and coated with asphalt binder. To dry the aggregate sand to obtain sufficient fluidity of asphalt binder for proper mixing and workability, both the aggregate and the asphalt binder must be heated before mixing. In this research HMA concrete has been utilized (Asphalt institute MS-2, 2014).

2.4 Hot Mix Asphalt/HMA/ Design

Mix design involves laboratory procedures developed to establish the necessary proportions of materials for use in the asphalt mixture. These procedures include determining an appropriate blend of aggregate sources to produce proper gradation of mineral aggregate and selecting the type and amount of asphalt cement to be used as the binder for that gradation. Well designed asphalt mixtures can be expected to serve successfully for many years under a variety of loading and environmental conditions.

The mix design is just the starting point to assure that an asphalt pavement layer will perform as required. Together with proper construction practice, mix design is an important step in achieving well-performing asphalt pavements. In many cases, the cause of poorly performing pavements has been attributed to a poor or inappropriate mix design, or is due to the production of a mixture different from what was designed in the laboratory. Correct mix design involves adhering to an established set of laboratory techniques and design criteria. It should be noted that the purpose of mix design is to determine the combination of asphalt cement and aggregate that will give long-lasting performance as part of the pavement structure (Asphalt Institute MS-2, 2014).

2.4.1 Required Properties of Hot mix asphalt

The design of asphalt paving mixes, as with other engineering materials designs, is largely a matter of selecting and proportioning materials to obtain the desired properties in the finished construction product. The overall objective for the design of asphalt paving mixes is gradation of aggregates and binder content that yields a mix having:

- sufficient asphalt to ensure a durable pavement;
- sufficient mix stability to satisfy the demands of traffic without distortion or displacement;
- sufficient air voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading and a slight amount of thermal binder expansion without flushing, bleeding and loss of stability;
- a maximum void content to limit the permeability of harmful air and moisture into the mix;
- sufficient workability to permit efficient placement of the mix without segregation and without sacrificing stability and performance; and
- aggregate texture and hardness to provide sufficient skid resistance in unfavorable weather conditions.

The final goal of mix design is to select a unique design binder content that will achieve a balance among all of the desired properties. Ultimate pavement performance is related to durability, impermeability, strength, stability, stiffness, flexibility, fatigue resistance and workability (Asphalt Institute MS-2, 2014).

Table 2. 1 Specification on mechanical properties of binder course(ERA manual,2013)

Total Traffic (106 ESA)	< 1.5		1.5 - 10.0		>10.0	
Traffic Class	T1, T2, T3		T4, T5, T6		T7, T8	
	Min	Max	Min	Max	Min	Max
No. of blows of Marshall Compaction	2*35		2*50		2*75	
Stability(KN)	3.5	-	6.0	-	7.0	-
Flow(mm)	2		2		2	4
Percent Air Voids	3	5	3	5	3	5
Percent Voids filled with Asphalt	70	80	65	78	65	75
Percent VMA(for 4% air voids and Nom. Max. Particle size of 19mm)	13	-	13	-	13	-

2.5 Materials for HMA

The different types of asphalt mixtures are primarily made up of asphalt binder and mineral aggregates. Additionally, based on the local materials available, traffic loading and climate, other ingredients /or additives/ may be required in the asphalt mixture, such as mineral fillers, fibers, liquid anti-strips, lime, recycled products and/or wastes(Asphalt Institute MS-2, 2014).

2.5.1 Aggregate

Aggregate is the major structural component in HMA which makes up 90-95% of the mixture by weight and 85% by volume (ERA manual, 2013). The American Society for Testing and Materials /ASTM/ defines aggregate as a granular material of mineral composition such as sand, gravel, shell, slag, or crushed stone, with a cementing medium to form mortar or concrete, or alone as in base course or railroad ballast. Aggregates for HMA are usually classified by size as coarse aggregates, fine aggregates, or mineral fillers. ASTM also defines coarse aggregates as particles retained on a 4.75mm sieve, fine aggregate as that passing through a 4.75mm sieve and mineral filler as material with at least 70 per cent passing a 0.075mm sieve (ASTM, 2003).

The most important properties of HMA like stability, durability, stiffness, fatigue resistance and stripping are related to the aggregate physical properties and gradation. Aggregates for HMA are generally required to be strong, sound, and properly graded; to have clean surface without deleterious materials; consist of angular particles with low porosity and appropriate absorption for asphalt cement. Therefore, the quality and physical properties of this material has a large influence on the mix performance so that care has to be given in the mix design of asphalt pavement(Nigatu, 2015).

Aggregate type has a significant effect on the fatigue resistance and permanent deformation of asphalt mixtures. Aggregates are deemed to give the mixture stability after various traffic loads, resistance to wear due to abrasive action of traffic, and still resistant to frost action. Thus, to obtain a mixture having good performance, evaluation of various mineral aggregate physical properties is essential (Roman, 2017).

The qualities required of aggregates are described in terms of shape, hardness, durability, cleanliness, bitumen affinity and porosity. The coarse aggregates used for making HMA should be produced by crushing sound, un weathered rock or natural gravel.

According to (ERA manual, 2013) has suggested 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.
- Have good affinity with bitumen - hydrophilic aggregates may be acceptable only where protection from water can be guaranteed or a suitable adhesion agent is used.

2.5.1.1 Aggregate Gradation

It has long been established that the gradation of the aggregate is one of the factors that must be carefully considered in the design of asphalt paving mixtures. The purpose for establishing and controlling aggregate gradation is to provide a sufficient volume of voids in the asphalt-aggregate mixture to accommodate the proper asphalt film thickness on each particle and provide the design air void system to allow for thermal expansion of the asphalt within the mix. Minimum voids in the mineral aggregate /VMA/ requirements have been established that vary with the nominal maximum aggregate size to help assure the correct volume of effective binder exists for each mix type. In HMA, gradation influences almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage (Asphalt Institute MS-2, 2014).

The formation of asphalt concrete starts from aggregates selection, and the basic requirement of its bearing capacity comes from traffic and environmental loads. It can be seen that different aggregate properties produce different road performances of asphalt concrete pavement. Meanwhile, the strength of asphalt concrete is mainly formed by aggregates, asphalt binder and their spatial distribution status in mixture. This leads to the volumetric properties extremely important. Due to the difficulty in using voids of each aggregate to design asphalt mixture directly, the related mass and density are easier to gain by appropriate tests. Therefore, the percentage mass is adopted to represent gradation instead of percentage volume in an asphalt mixture (Mingjing et al., 2018).

A research conducted by (Ruth et al., 2002) pointed out that the engineering properties of an asphalt concrete /AC/ mixture directly depend on the properties of the individual components and their interaction with one another. Because mineral aggregates make up to 96% of a mixture by weight or 85% by volume, the aggregate properties and gradation may significantly affect the volumetric properties and mechanical performance of a mixture. Aggregate gradation affects nearly all aspects of a mix design, from stability to modulus to volumetric properties.

Inappropriate selections of aggregate gradation, aggregate properties, and binder grade, type and content are major contributors to rutting and cracking of HMA pavements. The effect of gradation on HMA performance has long been a controversial issue. A research done by (Hand et al., 2001) revealed that strong opinions exist among industry experts as to which gradation type, ranging from fine to course to open-graded or stone matrix bituminous gradations, will provide the best performance.

HMA mixtures are divided into four main mixture categories: dense-graded; open-graded; gap graded and Stone-matrix asphalt as a function of the aggregate gradation used in the mix.

- **Open-graded mixes**: - are produced with relatively uniform-sized aggregate typified by an absence of intermediate-sized particles. Mixes typical of this structure are the permeable friction coarse and asphalt-treated permeable bases. Because of their open structure, precautions are taken to minimize asphalt draindown by using modified binders like “asphalt rubber,” or fibers. Stone-on-stone contact with a heavy asphalt cement particle coating typifies these mixes.

- **Dense-Graded Mixes**: - are well-graded HMA has good proportion of all constituents are also called Dense bituminous macadam. When properly designed and constructed, a dense-graded mix is relatively impermeable. Dense-graded mixes are generally referred to by their nominal maximum aggregate size and can further be classified as either fine graded or coarse-graded. Fine-graded mixes have finer and sand sized particles than coarse-graded mixes. It is suitable for all pavement layers and for all traffic conditions. It offers good compressive strength.
- **Gap-graded mixes**: - use an aggregate gradation with particles ranging from coarse to fine with some intermediate sizes missing or present in small amounts. The gradation curve may have a “flat” region denoting the absence of a particle size or a steep slope denoting small quantities of these intermediate aggregate sizes. These mixes are also typified by stone-on-stone contact and can be more permeable than dense-graded mixes or highly impermeable.

There are several terminologies commonly used in gradation design of asphalt mixture, such as sieve screening, fine gradation, coarse gradation, fine aggregate, coarse aggregate, mineral filler, mineral dust, control points and so on. The first challenge on working with asphalt mixture is to differentiate those terminologies. Sieve test is the most effective way to do analysis of aggregate gradation. From the test, the percentage retained and the percentage passing by mass can be calculated (Memphis, 2016).

From the above review, aggregate gradation can almost influence all the performances for asphalt pavement. Therefore, it is quite necessary to know the importance to keep the gradation stability during the asphalt mixture’s production, transportation, paving and compacting. However, each step of asphalt mixture construction easily leads to gradation variability, which will cause mixture uniformity and premature damage of pavement. (Peng and Sun, 2006) conducted a quantitative study on the relation between mixture uniformity and air voids, dynamic stability and mechanical strength. The results showed that the aggregate gradation has great influence on the uniformity of asphalt mixture, with the significance of the aggregate on the sieve of 4.75 mm greater than that on the size of 2.36 mm.

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

Sieve No.	Sieve size(mm)	Percentage by Weight passing	
		Min	Max
1''	25	100	100
3/4	19	90	100
1/2	12.5	71	88
3/8	9.5	56	80
No. 4	4.75	35	65
No. 8	2.36	23	49
No. 16	1.18	15	37
No. 30	0.6	10	28
No. 50	0.3	5	19
No. 100	0.15	4	13
No. 200	0.075	2	8
Bitumen content(%)		4	10

The mineral aggregates used in this research were crushed aggregate and subjected to various tests in order to assess their physical characteristic and suitability of the road construction. The aggregate were obtained from ERCC quarry and crusher site located in Unkulu of Ana Mana woreda special place Deneba .

2.5.2 Asphalt binder

Asphalt binder /bitumen/ is the thick, heavy residue which is produced artificially from crude oil within the petroleum refining process. It is a basic constituent of the upper layers in pavement construction. It can resist both deformation and changes in temperature. Its binding effect eliminates the loss of material from the surface of the pavement and prevents water penetrating the structure.

The physical properties of the asphalt binder vary considerably with temperature. At high temperature, asphalt binder will become fluid with a low consistency similar to that of oil. At room temperature, most asphalt binders should have the consistency of soft rubber. At sub-zero temperatures, asphalt binder can become very brittle. Many asphalt binders will contain small percentages of polymer to improve their physical properties; these materials are called polymer modified binders. Most of asphalt binder specification was designed to control changes in consistency with temperature (Transportation Research Board Committe, 2011).

Asphalt grade and characteristics are critical to the performance of the asphalt pavement. Three methods, based on penetration, viscosity and performance are used to classify asphalt cements into different standard grades. The penetration grading of asphalt cement and viscosity grading are specified in ASTM D946 and D3381 respectively.

For this experimental research work bitumen of penetration grade 60/70 was used and collected from Ethiopian Road Construction Corporation. The main reason of using this penetration grade was because of its common type of asphalt that is widely used in most road projects in our country and the temperature of the study area.

2.5.3 Mineral Filler Materials

The term mineral filler is typically referred to the mineral fine particle with physical size passing the number 200 standard mesh sieve /75 micron/. The use and the application of mineral filler in asphalt mixtures are intended to improve the properties of binder by reducing the binder's inherent temperature susceptibility (Zemicheal, 2007).

Mineral fillers play a dual role in asphalt mixtures, first ; they act as a part of the mineral aggregate by filling the voids between the coarser particles in the mixtures and thereby strengthen the asphalt mixture , second ; when mixed with asphalt , fillers form mastic, a high-consistency binder or matrix that cements lager binder particles together ; most likely a major portion of the filler remains suspended in the binder while a smaller portion becomes part of the load bearing framework (Harris and stuart, 2005). Mineral filler in hot mix asphalt is an important component of the mixture as the design and performance of hot mix asphalt /HMA/ concrete is greatly influenced by the nature and amount of the mineral filler in the mix.

2.5.3.1 Effect of Mineral Fillers on HMA

The mineral filler can greatly affect the properties of a mixture such as strength, plasticity, voids, resistance to the action of water, and the resistance to the forces of weathering. The proper use of filler can improve the asphalt paving mixture through increased density, stability, durability, and skid resistance (Yohannes , 2016). On the other hand, an excessive quantity of filler tends to increase brittleness and proclivity to cracking, and deficiency of filler tends to increase void content, lower stability, and soften the mix, which leads to shoving, and rutting of the pavement (Eltaher & Ratnasamy , 2016).

A study conducted on the effect of different filler types on performance properties of asphalt paving using six different types of filler to evaluate the resistance to plastic flow using Marshall Stiffness test and low temperature cracking and temperature susceptibly using indirect tensile strength test in addition to study retained strength test and resistance to permanent deformation by using indirect tensile creep test indicated that filler type has a great effect on the cohesion of the mix where such types shows high indirect tensile strength values with respect to other types of filler at different test temperature(Sadoon, 2010).

Newly constructed highway pavements show failure after a few years the opening of the road for traffic. Major types of failure include permanent deformation /rutting/ and cracking. Fillers are one of the contributors to these types of failures. Filler content and type have a significant effect on the mix making it act as stiffer, and thus affect the hot mix asphalt pavement performance including its fracture behavior (Asmael, 2015). Addition of waste concrete dust and brick dust filler produce a more viscous asphalt mix that increases Marshall Stability of the mix. Asphalt mixes prepared with brick dust filler show maximum stability of 11.3 kN at 5.5 % asphalt binder content. Concrete dust and brick dust can be used as filler as compared to crushed rock fines (Miah et al., 2015).

Performance of hot mix asphalt can be affected by many factors such as material property, traffic load, environmental condition, paving aging process, design and way of construction. Marshall Stability values of hot mix asphalt are improved with the addition of alternative fillers /lime, marble dust, stone dust/. The optimum asphalt content increases with increase the percent of filler content in the mix. While, percent air void decreases with increasing content of filler compacted mix. Compared value of asphalt mixes prepared with lime, stone dust, and marble dust fillers indicated that marble dust can achieved higher tensile strength value at low temperature, thus mixes prepared with marble dust resulted better performance in the cold region (Feyissa, 2001).

Using lime in place of conventional filler such as ordinary Portland cement and stone dust can be efficiently and effectively used in the asphalt mixes as a filler replacement from the viewpoint of stability, deformation, and voids characteristics with 4.8%optimum asphalt binder content. The replacement of the mineral filler with lime improves the stability of the asphalt mixes, while there is a slight increase in the flow of the mix with hydrated lime (Kalaitzaki et al., 2017).

Another study conducted on the effect of waste cement dust as mineral filler on the mechanical properties of hot mix asphalt by using 0%, 25%, 50%, 75% and 100% cement dust content by weight of the limestone mineral filler showed that an enhancement in Marshall and mechanical properties of asphalt concrete mixtures observed. Their Marshall testing results have also indicated that an increase in the stability, unit weight and a decrease in the flow, voids ratio and voids in mineral aggregates revealed when the percentage of cement dust content increases. When replacement of lime stone by cement increases the tensile strength and unconfined compression strength of the properties also increased. The optimum cement dust ratio was found to be 100% of the used mineral filler. Hence, cement dust can totally replace lime stone mineral filler in asphalt paving mixtures (Kandhal & Kim, 1992).

2.6 Sugarcane Bagasse ash

Sugarcane Bagasse (SCB) is a fibrous waste product of the sugar refining industry, along with ethanol vapor. Recently Bagasse Ash (BA), a readily available agricultural/industrial waste material has found useful application in engineering and other field of studies. Its analysis from sugar industry shows that it contains unburned carbon along with the other constituents present in Portland cement. BA can replace some of the raw materials; reduce the energy cost and increasing revenue from the cement industry (Mohammed, et al., 2009).

Sugar cane bagasse ash (SCBA) is generated as a combustion by-product from boilers of sugar and alcohol factories. Composed mainly of silica, this by-product can be used as a mineral admixture in mortar and concrete. Several studies have shown that the use of SCBA as partial Portland cement replacement can improve some properties of cementitious materials. However, it is not yet clear if these improvements are associated to physical or chemical effects. This work investigates the pozzolanic and filler effects of a residual SCBA in mortars. Initially, the influence of particle size of SCBA on the packing density, pozzolanic activity of SCBA and compressive strength of mortars was analyzed. In addition, the behavior of SCBA was compared to that of an insoluble material of the same packing density. The results indicate that SCBA may be classified as a pozzolanic material, but that its activity depends significantly on its particle size and fineness (Cordeiro, et al., 2008).

It is found that the cement could be advantageous if replaced with bagasse ash up to maximum limit of 10%. Replacement of cement by bagasse ash reduce industrial waste and to save cement. By saving cement reduced greenhouse gases emission and makes environmental green.OPC replacement by bagasse ash results in reduction of cost of production of concrete in the range of 5 to10%. Using bagasse as replacement of OPC in asphalt concrete, the emission of greenhouse gases can be reduced up to a greater extent (Singh and Kumar, 2015).

Filler is needed to stabilize the asphalt mixture. Asphalt mixture design is incomplete without filler. Filler is commonly selected for its ability to improve the adhesion between binders and aggregate. Various waste products can be used for several purposes, such as the replacement for a filler or binder material. These waste products can include industrial, agricultural and municipal solid waste. All these wastes should not be incinerated or discarded, but all of them can be utilized (Murana et al., 2013). This utilization of waste products can solve not only the environmental issue due to its disposal, but also can increase its economic value (Huwae and Tanijaya, 2013).

Bagasse-ash is a combustion residual of sugar-cane with only 1% weight-loss and contains 73% silica. Bagasse can be categorized as a fibrous waste-product with ethanol vapor. It contains unburned carbon along with the other constituent presented in Portland cement. The use of Bagasse-ash as a supplementary cementitious material to partially replaced Ordinary Portland Cement /OPC/ not only helps reducing the methane emissions from organic waste, but also can improve its compressive strength (Mohammed et al., 2009).

A research conducted by (Murana and Sani, 2015), shows that the mix containing 10% Bagasse-ash and 90% OPC at varying percentages of bitumen content have strength values which meet the standard specified in Asphalt Institute. The aggregate property of Bagasse-ash has also fulfilled the required properties of bitumen as binder. Therefore, it can be used for asphalt pavement.

Another study conducted by Osinubi and Thomas, 2007, shows that the tropical black cotton clay treated with a 10% of Bagasse-ash by weight of dry soil can increase soil strength properties. Therefore, Bagasse-ash with all its advantageous properties can be used as a substitute of fine aggregate.

In addition, the research of two Ethiopian scholars, (Hailu and Prof. Abebe Dinku, 2012), concluded that it is appropriate to replace 10% of cement with bagasse ash for expecting better concrete properties. On the other hand, (Srinivasan and Sathiya, 2010) concluded that it is appropriate to partially replacing cement with SCBA up to 25% and the strength of concrete increased as the percentage of replacement increased. In conclusion, considering the achievements of the above stated studies, it is appropriate to partially replace cement with Bagasse ash in production and works of construction materials such as concrete and hot mix asphalt concrete.

Table 2. 3 Chemical composition of SCBA(*Source:Destaye,2019)*

Chemical composition	Weight of Fraction(%)
SiO2	57.04
Al2O3	6.88
Fe2O3	4.56
CaO 1	1
MgO	1.96
Na2O	6.2
MnO	0.2
P2O5	1.18
TiO2	0.21
H2O	2.47
LOI	14.7

2.6.1 Uses of Sugarcane Bagasse Ash

Bagasse ash is agricultural waste product of sugarcane which can be used in construction sector either by replacement method or stabilization of construction materials to improve the engineering properties of material. Recent research works in the engineering construction technology materials focuses more on the search for cheaper and locally available materials, agricultural and industrial wastes, for use in construction industry. The use of different industrial and agricultural wastes has become a common practice in the construction industry. Fly ash, sugarcane bagasse ash, coconut husk ash and rice husk can be sited as an example. Those by-products are increasingly playing a part in road construction and concrete technology, hence minimizing the problem of resource depletion, environmental degradation and energy consumption. This research focuses on the potential utilization of bagasse ash in soil stabilization, specifically expansive clay.

Bagasse Ash as Soil stabilizing Material

These days sustainability plays major role in every aspect of human activities. Many technologies came to end because they were not in harmony with the idea of sustainable development. Sustainability is concerned about the world we will be leaving behind for future generations. It focuses on the social, environmental and economic issues of human activities. Therefore, it requires every activity to be environmentally friendly, economical and safe for the social. Bagasse ash contains large amount of silica which is the most important component of cement replacing materials. It is also found in large amount as a byproduct in sugar factories. Despite this abundance and silica content, relatively little has been done to examine the potential of this material for soil stabilization. Even though little, the conducted researches conform the suitability of this material for soil stabilization as an admixture with lime and cement. But still its suitability as a standalone material is still questionable.

Another study conducted by (Osinubi and Thomas, 2006) shows that the tropical black cotton clay treated with a 10% of Bagasse-ash by weight of dry soil can increase soil strength properties. Therefore, Bagasse-ash with all its advantageous properties can be used as a substitute of fine aggregate.

Bagasse ash as cement replacing material in concrete

It is found that the cement could be advantageous replaced with bagasse up to maximum limit of 10%. Replacement of cement by bagasse ash reduce industrial waste and to save cement. By saving cement reduced greenhouse gases emission and makes environmental green.OPC replacement by bagasse ash results in reduction of cost of production of concrete in the range of 5 to10%. Using bagasse as replacement of OPC in asphalt concrete, the emission of greenhouse gases can be reduced up to a greater extent(Singh and Kumar, 2015).

Subsequently, research by (Abdulkadir, et al., 2014) concluded that 10% replacement of SCBA has the highest PAI and also, based on the compressive strength results 10% and 20% replacement of SCBA with compressive strengths of 22.3N/mm2 and 20.1N/mm2 are recommended for concrete. On the other hand, (Srinivasan and Sathiya, 2010) concluded that it is appropriate to partially replacing cement with SCBA up to 25% and the strength of concrete increased as the percentage of replacement increased. (Kawade et al., 2013) characterized SCBA and partially replaced cement with bagasse and observed that the strength of concrete increased up to 15% SCBA replacement. In conclusion, considering the achievements of the above stated studies, it is appropriate to partially replace cement with Bagasse ash in production and works of construction materials such as concrete and hot mix asphalt concrete.

2.6.2 Sugar Cane bagasse ash availability in Ethiopia

Ethiopia has natural resources and out of the potential, 1.4 million hectares suitable for sugar cane plantation 485,115 hectares is already identified as suitable. The domestic demand for sugar is increasing at a faster rate and is difficult for the existing sugar mills to satisfy it and has also necessitated cutting down export. The increase in demand can be due to the combined effect of an increase in population and urbanization, expansion in micro and small-scale food processing sector such as pastries, candies, and expansion of tertiary and higher education sectors, etc. Thus the price of sugar in the domestic market is increasing and thereby justifying additional investment in the sector. Ethiopia's sugar industry sector includes the four sugar mills /Wonji, Shoa, Tendaho, Methara, and Fincha/ organized under three separate managements and the Ethiopian Sugar Industry Support Centre. The industry is mostly Government-owned, with the private sector making a modest entry (Ethiopian sugar corporation,2011).

In concern of the plenty of bagasse ash, huge sugar factories are under construction and some already started production with their partial or full production capacity in addition to the existing factories. When all the factories become fully operational, the bagasse ash from all these factories will be expected to be in thousands of tones as shown in table 2.4(Ethiopian sugar factories, 2015).

As per the information from Ethiopian Sugar Corporation, all of the factories that are operating currently are now using bagasse as fuel for the boiler. Not only the current factories but the future intended projects will also operate in the same manner as this method reduces energy consumption. When all the factories start to operate with their full capacity, the respective bagasse ash that will be produced by that time will reach up to two million tons per annum. Bagasse ash of this amount can substantially contribute to both technical and environmental advantage to the cement industry (Ethiopian Sugar Corporation department, 2016). Collaborating existing industries with the future ones, the total bagasse ash to be disposed of is estimated to be 1.9 million tons per year (Geremew and Gebreyohannes, 2017).

Table 2. 4 Annual sugar production capacity and expected bagasse ash amounts of sugar factories when fully operational capacity is attained

No.	Sugar Factories	Tone of cane per day(TCD)	Annual crushing capacity(Ton)	Bagasse (Ton)	Bagasse ash (Ton)
1	Arjo dediesa	8,000	1,920,000	556,800	69,600
2	Beles I	12,000	2,880,000	835,000	104,400
3	Beles II	12,000	2,880,000	835,000	104,400
4	Beles III	12,000	2,880,000	835,000	104,400
5	Fincha	12,000	2,880,000	835,000	104,400
6	Kesem	11,000	2,640,000	765,600	95,700
7	Kuraz I	12,000	2,880,000	835,000	104,400
8	Kuraz II	12,000	2,880,000	835,000	104,400
9	Kuraz III	12,000	2,880,000	835,000	104,400
10	Kuraz IV	24,000	5,760,000	1,670,400	208,800
11	Kuraz V	24,000	5,760,000	1,670,400	208,800
12	Metehara	5,000	1,200,000	348,000	43,500
13	Tendahu	26,000	6,240,000	1,809,600	226,200
14	Wolkayet	24,000	5,760,000	1,670,400	208,800
15	Wonji shoa	12,500	3,000,000	870,000	108,750
	TOTAL	**218,500**	**52,440,000**	**15,207,600**	**1,900,950**

2.7 Groundnut Shell ASH

Ground nut produce waste such as ground nut shell ash which are usually dumped in the open site by affecting of surrounding without any economic benefits. With the use of groundnut shell ash in concrete the cost will decrease and also it reduces the environmental pollution and saves the energy. GNSA has better pozzolanic property. It contains some chemical composition also. The pozzolanic activity of ash increases with an increase of time. The addition of GNSA in cement concrete may reduce drying shrinkage, water absorption, but increases the setting time. Increases of setting time are due to slow reactivity of GNSA (Venkata, et al., 2017).

Formerly the agricultural and industrial waste materials are creating waste management and surrounding employment problems. So that the utilization of agricultural and industrial wastes are gift of other traditional materials in construction field both practical and economic benefits(Naik, 2008). The waste materials have normally no commercial value and being locally available only for transportation charges is minimum (Chandraand Berntsson, 2002).

A study conducted by (Pandi, et al., 2018) showed that the compressive strength test results of concrete cube specimens at 20% replacement of ground nut shell ash were higher than those at 0% of GNSA. Furthermore incremental of GNSA percentage results in degreases the various strength properties of concrete specimens. It is pointed out that the rate of increase of strength of mixes with GNSA is higher at lateral days that may be due to pozzolanic properties of GNSA.

Table 2. 5 Chemical composition of GSA(*Source: Elias 2018)*

Chemical composition	Weight of Fraction(%)
SiO2	38.12
Al2O3	6.72
Fe2O3	4.83
CaO	14.88
MgO	2.46
Na2O	0.44
MnO	0.2
P2O5	1.21
K2O	9.14
H2O	1.21
LOI	4.0

2.7.1 Uses of Groundnut Shell Ash

In recent days, the natural pozzolanas materials use as partial replacement for cement has increased strength and durability. Literature and various research papers are available which have mentioned about the various advantages in the use of pozzolans in concrete production. At present, issues related to environmental conservation have gained importance; hence the utilization of these waste materials that are available in our environment is now necessary (Lakshmi and Sagar, 2017).

Groundnut shell is the form of fuel used in sweet manufacturing units and the oil mills. The groundnut shell after being used as fuel generates ash which can be used as a replacement material for cement, the disposal of which is the major hassle. Thereby results in the decrease in waste to be disposed of and also there is the effective usage of the waste that is generated (Lakshmi and Sagar, 2017).

GSA as Cement replacing material in concrete

With the use of groundnut shell ash in concrete the cost will decrease and also it reduces the environmental pollution and saves the energy. GNSA has better pozzolanic property. It contains some chemical composition also. The pozzolanic activity of ash increases with an increase of time. The addition of GNSA in cement concrete may reduce drying shrinkage, water absorption, but increases the setting time. Increases of setting time are due to slow reactivity of GNSA (Lakshmi and Sagar, 2017).

Another study conducted by (Adole, et al., 2011) showed that Groundnut Shell Ash /GSA/ or Groundnut Husk Ash /GHA/ is one of artificial pozzolanic or SCM material that can be incorporated in concrete as partial replacement as concluded by empirical report in their experimental tests. They have also tested in three chemical solutions, MgSO4, NaCl and H2SO4 and declared that concrete with GSA/GHA can resist magnesium sulfate /MgSO4/ and sodium chloride /NaCl/ which may found in soil. Groundnut shell ash has been used in concrete as a partial replacement material for cement with a measure of success achieved (Alabadan *et al.*, 2005).

GSA as soil stabilizing material

Groundnut shell is an agricultural waste obtained from milling of groundnut. Nigeria contributes about 7 percent of world groundnut production which makes Nigeria the 3rd largest producer of groundnut in the world. In 2002, about 2,699,000 Mt of groundnut were produced in about 2,783,000 Hectares of Land. Meanwhile, the ash from groundnut shell has been categorized under pozzolana and the utilization of this pozzolana as a replacement for traditional stabilizers will go a long way in actualizing the dreams of most developing countries of scouting for cheap and readily available construction materials(Alabadan et.al, 2006).

2.7.2 Groundnut shell ash availability in Ethiopia

In Ethiopia, groundnut is the second important lowland oilseed of warm climate next to sesame (Dawit and Samuel, nd). The lowland areas of Ethiopia have considerable potential for increased oil crop production including groundnut. After its first introduction to Eritrea in the 1920 and then to Harer (EARO, 2000), groundnut is grown in many lowland areas of Ethiopia. It is mainly grown in eastern Harerghe, with immense potential in Gamogofa, Illubabor, West Gojam, North Shoa, North and South Wello, East and West Wellega, and Western Tigray (CSA, 2010). According to the CSA report on area and production of crops, more than 352,077private peasant holding households have grown groundnut in close to 80,000 hectares of land in the 2013/14 cropping season leading to a total production of well over 0.11 million tons (CSA, 2014). According to the same report, Oromia region constitutes the largest proportion of groundnut production areas accounting for 66% /52, 921.26 ha;, out of which more than one half /28,909.44 ha/ is found in East Harerghe. Benishangul Gumz is the second largest contributor in terms of ground nut production areas /18,592.72 ha/ followed by Harari /2874.09/, Amhara /2,380.15 ha/ and SNNP /376.66 ha/.

Groundnut production in Ethiopia, although still limited to some lowlands of the country, is playing an increasing role in terms of serving as an alternative oil crop to an increasing number of small holder farmers. However, it has been indicated that the sector is limited by wide range of problems related to marketing, production and distribution. Ethiopian Institute of Agricultural Research /EIAR/ has conducted a value chain analysis on the channels of groundnut in Ethiopia. This report, which benefits significantly from the marketing chain analysis, along with other previous and ongoing studies will form a basis for developing future research agenda that contributes to improved production and marketing of groundnut in Ethiopia(Nega, et al., 2015).

Table 2.6 Trends in area, production and productivity of groundnut in Ethiopia(*Source: CSA(2004-2014)*

Year	**Area(ha)**	**Production(tons)**	**Yield(ton/ha)**
2013/14	79947	112089	1.40
2012/13	90156	124419	1.38
2011/12	64477	103479	1.60
2010/11	49603	71607	1.44
2009/10	41579	46425	1.12
2008/09	41761	46887	1.12
2007/08	40198	44685	1.11
2006/07	37126	51080	1.38
2005/06	35462	34150	0.96
2004/05	27084	29053	1.07
Growth	**12.8%**	**16.2%**	**3.0%**

2.8 Moisture susceptibility of HMA

Resistance to moisture induced damages is one of the desirable properties of bituminous mixtures. A major durability problem is associated with moisture damage, commonly referred to as “stripping.” This typically is the result of water in combination with repeated traffic loadings, causing a scouring effect as the water is pushed into and pulled out of the voids in the pavement. Stripping involves water or water vapor getting between the asphalt film and the aggregates, thereby breaking the adhesive bond between the aggregate and the asphalt binder film. This will “strip” the asphalt from the aggregate(Asphalt institute MS-2, 2014).

The resistance to moisture damage under the presence of moisture in the mixture is a complex matter and the degree mainly depends on the properties of each ingredient materials in the mixture, type and use of mix, environment, traffic, construction practice, and the use of anti-strip additives. Among these factors, aggregate response to asphalt cement underwater is primarily responsible for this phenomenon, although some asphalt cement are more subjected to stripping than others (Zemichael, 2007).

2.9 Summary of Literature Review

The importance of mineral fillers in the bituminous mixtures have been overlooked where their effect was considered to be only filling the voids in the mixture and fulfilling the gradation criteria. However, recent researches demonstrate that they are more than just filling the voids in the aggregate particles. In this literature review, it is exhibited that different mineral fillers and quantity influence the performance of HMA mixtures. Some filler have a considerable effect on the properties of asphalt cement mortar as compared to the neat asphalt cement and some filler types are also found to make HMA mixtures more susceptible to moisture-induced damages.

While considering the effect of filler types in the bituminous mixtures, various desirable characteristics such as: increased stability, resistant to moisture effect and rutting were obtained by many researchers.

CHAPTER THREE

MATERIAL AND RESEARCH METHODOLOGY

3.1 Introduction

This study involved investigating the Marshal properties and tensile properties /moisture susceptibility/ of bituminous mixtures prepared in the laboratory using different types of non-conventional mineral fillers /all P-200 sieves/ namely, bagasse ash and groundnut shell ash by partially replacing conventional filler/ crushed stone dust /.

This study involves collecting of materials for the preparation of bituminous mixtures. The materials used in the mixture includes: coarse and fine aggregates, different types of mineral fillers, and asphalt binder.

The materials mentioned above were subjected to various laboratory test in order to determine their physical properties and decide whether they meet common specification and to assure the quality assurance or not. The quality assurance test conducted on the aggregate was determination of the aggregate physical properties such as Toughness, Gradation, Abrasion, Durability, Specific gravity and water absorption. For asphalt binder penetration test, ductility, softening point, flash and fire point, and specific gravity and for the filler material the study investigated specific gravity and PI. All tests on aggregate; asphalt binder, mineral fillers, sugarcane bagasse ash, groundnut shell ash fillers, and compacted specimens were conducted according to respective ERA, AASHTO, ASTM, and BS testing standards.

3.2 Study Area

The laboratory test was conducted in Jimma town which is located at about 354 Km in Southwest of Addis Ababa. According to WGS 84 coordinate reference system which is the latest revision of the World Geodetic System, Jimma is geographically located between 7° 38’52” - 7° 43’ 14” N latitude, and 36° 48’ 00” - 36° 53’ 24” E longitude. Jimma town is found in an area of average altitude of about 1780m above mean sea level. It lies in the climatic zone locally known as Woyna-Dega.

However, the filler materials bagasse & groundnut shell were delivered from different sources. Bagasse was delivered from Wonji Shoa Sugar Factory which is located between 8° 20' 00'' - 8° 28' 00'' N latitude, and 38° 12' 00''- 39° 16' 01'' E longitude in East shoa, Oromia region near Adama city at 110km from Addis Ababa at an altitude of 1540 m.a.s.l. Whereas, groundnut shell /husk/ was delivered from Shebe which is located between 7° 28' 00"-7° 33' 00" N latitude and 36° 25" 00"- 36° 28" 00"E longitude in Jimma zone, South East Oromia region,. It is found at a distance of 402km from Addis Ababa. Altitude of the place is 1370m above mean sea level. Its climatic condition is known for being temperate /Woyna-Dega/.

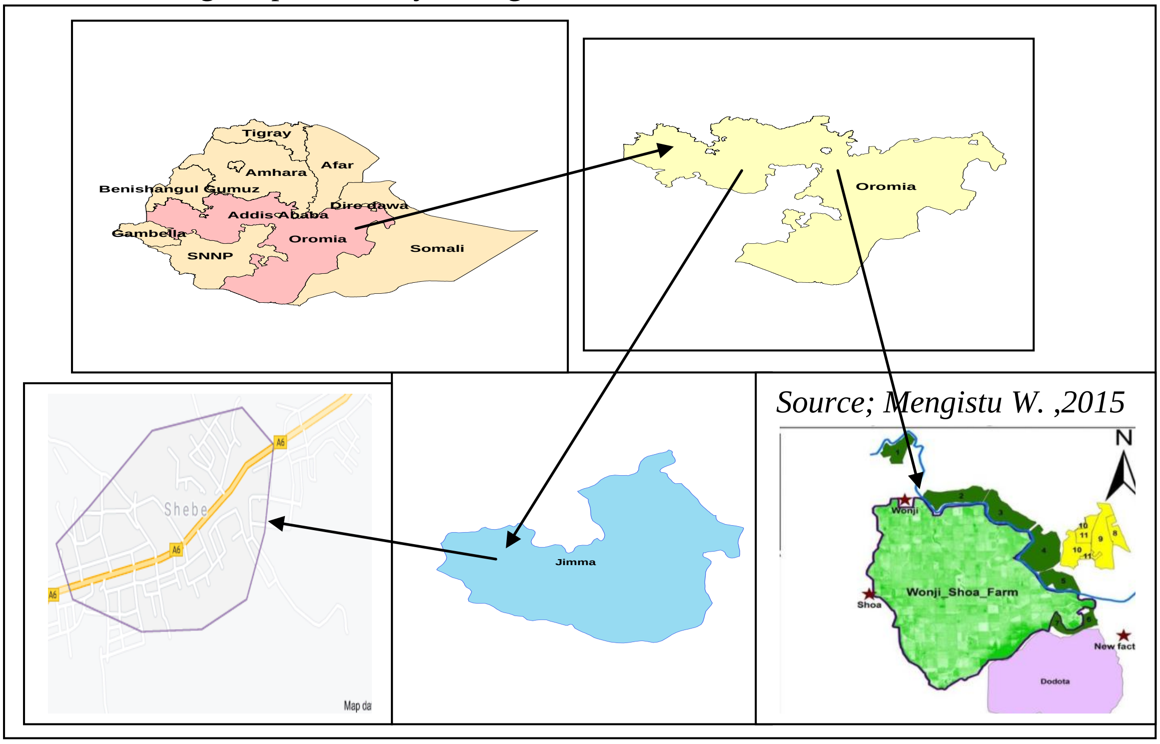

Figure 3. 1 Study area

3.3 Research Design

This research was conducted by using both experimental and analytical methods. Qualitative and quantitative study was employed in this study area. Qualitative study gives impression of the findings where a quantitative study was used to describe the numerical aspects of the research finding.

3.4 Study Variables

The study variables include both dependent and independent variables.

3.4.1 Dependent Variable

The dependent variables are more related with of general objective of the study. So, Hot-Mix Asphalt Concrete is a dependent variable.

3.4.2 Independent Variables

- Physical properties of vital materials in production of HMA such as aggregate, asphalt binder/bitumen, filler content, SCBA & GSA and

- Marshal properties of the mix.
- Tensile properties of the mix
- Weigh percentage of SCBA and GSA
- Chemical properties of SCBA and GSA

3.5 Sampling Techniques and Size

3.5.1 Sampling Techniques

This study followed a purposive sampling selection process in terms of which a representative sample of all materials for the mix design /Bitumen/Asphalt binder, Coarse Aggregate, Fine Aggregate, and Fillers/ were surveyed and had free distribution. Since the samples were just a small portion of the total material, for each tests quartering and weighting was used as sampling technique.

After retrieving samples, laboratory testing was undertaken to assess the material suitability. Initially materials physical property tests were conducted in laboratory, followed by Marshall stability test and IDT test. All the tests had been performed in accordance to ASTM Standards and compared to ERA manual.

3.5.2 Sample size

All samples such as asphalt binder, coarse and fine aggregates and additives such as bagasse and groundnut shell were taken from a different stockpile. For each samples, sample splitter or quartering and weighting was used as sampling techniques to reduce samples delivered from stockpile .

3.6 Sources of data

For the commencement of this research work different types of data were collected. These include primary source data and secondary source data. The primary data that were used in this study had included the physical properties and characteristics of aggregate, bitumen, filler /CSD, GSA and SCBA/. Those data were collected through laboratory tests using standard test methods and then the results of the tests were recorded in the standard format. The secondary data were collected from literatures, existing relevant documents and manuals.

3.7 Data Processing and Analysis

In this research different laboratory tests were conducted to determine the physical properties and characteristic of fillers, aggregates and asphalt bitumen which were used in the preparation of the mix using Marshall mix design. Having ensured the quality of the materials, different numbers of specimens were prepared to determine optimum bitumen content, optimum filler contents and optimum replacement percentage of GSA and SCBA as a filler.

The data were analyzed and processed using graphs and tables, and the test result comparison was performed with a standard specification of ERA pavement design manual which is an important aspect of the analysis.

3.8 Materials selection

Several materials were required for producing hot mix asphalt specimens. Since the main objective of the study was to investigate a comparative study on the effect of bagasse ash and groundnut shell ash as filler with respect to overall parameters of asphalt pavement mix, it was important to evaluate not only bagasse ash and groundnut shell ash, but also various aggregate and binder sources.

The raw material used in this study such as crushed stone dust, 60/70 penetration grade asphalt cement, coarse aggregate and fine aggregate were taken from ERCC quarry where the crusher site is located in Deneba, Jimma Zone. Whereas bagasse and groundnut shell were collected from Wonji Shoa Sugar Factory and Shebe, Jimma zone respectively.

3.9 Material preparation and Tests

3.9.1. Mineral Aggregate

Bulk samples taken from each source of nominal size aggregate were reduced in the laboratory by riffling or quartering to give enough material to complete the mix design programme. If additional filler is to be added during production then sufficient material should be obtained from the relevant source for use in the mix design process. By volume aggregate generally accounts for 90 to 95 percent of HMA. Aggregate is also used for base and sub-base courses for both flexible and rigid pavements (ERA manual, 2013).

Representative samples of each aggregate source and filler were subjected to dry sieve analysis and other relevant tests. It is important that the sieve sizes used for the sieve analysis of the aggregates were the same as those specified in the final mix gradation.

3.9.1.1 Gradation and Sieve Analysis

Aggregate gradation is the distribution of particle sizes expressed as a percent of the total weight. The gradation as a percent of the total volume is of most importance, but expressing gradation as a percent by weight is much easier and is standard practice.

Gradation is perhaps the most important property of an aggregate. It affects almost all the important properties of a HMA, including stiffness stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage. Therefore, gradation is a primary consideration in asphalt mix design, and the specifications used by most countries place limits on the aggregate gradations that can be used in HMA.

The gradation of an aggregate is determined by a sieve analysis. Standard procedures for a dry sieve analysis are given in ASTM Cl36, and for a washed-sieve analysis for determining the amount of material passing the No. 200 /0.075mm/ sieve, the procedures are in ASTM C117. The washed sieve analysis is a more accurate measure of the true gradation, but the dry method is faster and is often used to estimate the actual gradation.

The aggregate gradation is normally 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 each sieve by one of several mathematical procedures. One method is to subtract 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(Asphalt institute MS-2, 2014).

3.9.1.2. Los Angeles Abrasion

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.

Figure 3. 2 LAA test*(photo credit; Dejene D. date Sept 21,2020)*

The L.A. abrasion test measures the degradation of a coarse aggregate sample that is placed in a rotating drum with steel spheres as shown in Figure 3.1. As the drum rotates the aggregate degrades by abrasion and impact with other aggregate particles and the steel spheres /called the “charge”/. Once the test is complete, the calculated mass of aggregate that has broken apart to smaller sizes is expressed as a percentage of the total mass of aggregate. Therefore, lower L.A. abrasion loss values indicate aggregate that is tougher and more resistant to abrasion.

3.9.1.3. 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. With aggregate of aggregate impact value higher than 30 the result may be anomalous. Also, aggregate sizes larger than 12 mm AASHTO are not appropriate to the aggregate impact test. The standard aggregate impact test shall be made on aggregate passing a 12.5-mm AASHTO test sieve and retained on a 10.0 mm AASHTO test sieve.

a) b)

Figure 3. 3 AIV test a) compacting aggregate with rammer b) compacting by sudden load*(photo credit;Yan A. date Sept 21,2020)*

3.9.1.4. Aggregate Crushing Value

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 shall be made on aggregate passing 12.5 mm AASHTO test sieve and retained 9.5 mm AASHTO.

3.9.1.5. Particle Shape and Surface Texture

Rounded particles create less particle-to-particle interlock than angular particles and thus provide 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 /although particle smoothness will not appreciably affect strength/.These particles tend to impede compaction or break during compaction and thus, may decrease strength.

These particles have a lower surface-to-volume ratio than rough-surfaced particles and thus may be easier to coat with binder. However, in HMA asphalt tends to bond more effectively with rough-surfaced particles. Thus, rough-surface particles are desirable for HMA. The flat and elongated particle test is used to determine the dimensional ratios for aggregate particles of specific sieve sizes. This characterization is used in the super pave specification to identify aggregate that may have a tendency to impede compaction or have difficulty meeting VMA specifications due to aggregate degradation.

3.9.1.6. Surface Area

One important property that can be computed from the aggregate gradation is the surface area. The aggregate surface area is important since it affects 'the amount of asphalt needed to coat the aggregate. Dense-graded asphalt mixtures are usually designed to contain a desired amount of air voids; hence, the aggregate surface area is not a design factor. It is possible to increase the surface area of an aggregate and at the same time reduce the optimum asphalt content.

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Table 3. 1Surface area factors

Sieve size	Surface area factors
Percent passing max. sieve size	2
Percent passing No.4	2
Percent passing No.8	4
Percent passing No.16	8
Percent passing No.30	14
Percent passing No.50	30
Percent passing No.100	60
Percent passing No.200	160

3.9.2. Asphalt Binder Selection and Test

For demanding, high-performance applications, small amounts of polymers are sometimes blended into the asphalt binder, producing a polymer-modified binder. In general asphalts can be classified into three general types:

- Asphalt emulsion
- Asphalt cement
- Cut back asphalt

Cutbacks and emulsions are used almost entirely for cold mixing and spraying and will not use for hot mix asphalt mixture. Because of its chemical complexities, asphalt specifications have been developed around physical property tests, such as penetration, viscosity and ductility. These tests are performed at standard test temperatures, and the results are used to determine if the material meets the specification criteria.

Asphalt binders have been mixed with crushed aggregate to form paving materials for over 100 years. They are a very useful and valuable material for constructing flexible pavement worldwide. However, asphalt binders have very unusual engineering properties that must be carefully controlled in order to ensure good performance. One of the most important characteristics of asphalt binders that must be addressed in test methods and specifications is that their precise properties almost always depend on their temperature.

Asphalt binders tend to be very stiff and brittle at low temperatures, thick fluids at high temperatures, and leathery/rubbery semi-solids at intermediate temperatures. Such extreme changes in properties can cause performance problems in pavements. At high temperatures, a pavement with a binder that is too soft will be prone to rutting and shoving.

On the other hand, a pavement that contains a binder that is too stiff at low temperatures will be prone to low-temperature cracking. There is an extreme change in modulus that occurs in asphalt binders over the range of temperatures. Specifications for asphalt binders must control properties at high, low, and intermediate temperatures. Furthermore, test methods used to specify asphalt binders usually must be conducted with very careful temperature control; otherwise, the results will not be reliable.

Asphalt binder of penetration grade 60/70 was used in this research work for preparation of mixtures due to its medium air blowing and penetration. Bitumen 60/70 is suitable for road construction and for the asphalt pavements with superior properties and acceptable in a regions with mild temperature like Ethiopia. Grade of bitumen used in pavement is selected on the basis of climatic conditions and their performance in past.

3.9.2.1. Asphalt binder tests

The physical properties of the asphalt binder were determined according to the procedure specified by ASTM standards. A series of tests including penetration, specific gravity, softening point and ductility were conducted for the basic characterization properties of penetration grade asphalt.

A) Specific gravity

Specific gravity is the ratio of the weight of any volume of a material to the weight of an equal volume of water both at specified temperature. There are two reasons that needed to know about the specific gravity of asphalt cement. One's asphalt expands when heated and contracts when cooled. This means that the volume of a given amounts of asphalt cement will be grater at higher temperatures than at lower ones. Specific gravity measurements provide a yardstick for making temperature volume correction. Second specific gravity of asphalt is essential in the determination of the effective asphalt content and the percentage of air voids in compacted mix specimens and compacted pavement.

B) Flashpoint

The flashpoint of asphalt cement is the lowest temperature at which volatile gases separate from a sample to "flash" in the presence of an open flame. Flashpoint must not be fire point, the lowest temperature at which the asphalt cement will burn. The asphalt flashpoint is determined to identify the maximum temperature at which asphalt can be handled and stored without danger of flashing. The basic procedure for determining flashpoint is to gradually heat a sample of asphalt cement in brass cup while periodically moving a small flame over the sample. The temperature at which an instantaneous flashing of vapors occurs across the surface is the flashpoint.

Figure 3. 4 Flash and fire point test*(photo credit; Bilisuma L. date Sept 22,2020)*

C) Ductility

Ductility is a measure of how far a sample of asphalt cement can stretch before it breaks into two parts. It is used in the penetration and viscosity classification systems. It is measured by an "extension" test in which a briquette of asphalt cement is extended or stretched, at a specific rate and temperature. Extension is continued until the thread of asphalt cement joining the two halves of the sample breaks. The length in centimeters of the specimen at the moment it breaks is the ductility.

D) Penetration

The penetration test is an empirical measure of the hardness of asphalt at room temperature. 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. A standard needle is then brought to near the surface of the asphalt under a load of 100 gm. for exactly five seconds. The distance that the needle penetrates into the asphalt cement is recorded in units of 0.1 mm. The distance the needle travel is called "penetration" of the sample.

E) Softening point

The softening point of asphalt binder is the temperature at which the substance attains a particular degree of softening. According to AASHTO T 53, the same samples were poured into two small brass rings and allowed to cool. A heated knife blade was used to trim the surface of the samples to the level of the brass rings. The prepared samples were then conditioned in a temperature controller at 5°C for at least 30 minutes before the test. A steel ball bearing /weighing 3.5 g/ were centered on each specimen and placed in a transparent glass jar. An electric heater and thermometer were fitted into the beaker filled with clean, distilled water. The temperature at which each asphalt binder specimen touches the base plate was recorded to the nearest degree. The average of the three readings was taken and rounded to the nearest whole degree.

3.9.3 Mineral Filler

Mineral fillers can be screened and grinded rock fines, Portland cement, or hydrated lime to assist the adhesion of the bitumen to aggregate and fill up the void. It should be an inert material, which passes 75-micron sieve. Mineral fillers are by-products of stone crushing procedures, manifesting the feasibility of including them in the design of hot mix asphalt (Eltaher, 2016).

In this study, crushed stone dust, bagasse ash and groundnut shell ash all passing100% through sieve No.200 were used as filler material and their physical properties, which were believed to be major suspects of affecting the bituminous mixture property such as gradation parameters specific gravity and plasticity index, were determined.

3.10 Asphalt Mix Design

A properly designed asphalt mixture provides a balance of engineering properties and economics that ensures a durable pavement that satisfies both its users and owners. Care should be exercised to consider the intended function of the pavement both overall and in terms of the specific location within the pavement structure where the mixture will be applied. Thus, for a surface layer it may be wise to use a mixture whose properties differ from those of a bottom or intermediate layers, each of which may also differ from the others.

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. However, in this research marshal mix design method was utilized.

3.10.1 Objective of Mix Design

The design of asphalt mix is largely a matter of selecting and proportioning materials to obtain the desired properties in the finished construction. The overall objective for the design of asphalt paving mixes is selecting the gradation of aggregates and proportioning of asphalt that yields a mix having the desirable properties. such as

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

The selected mix design is usually the one that best meets all of the established criteria. It should be accomplished with well trained personnel using the proper materials and calibrated equipment and following the specified procedures. For this study the Marshall Mix Design method for HMA mixtures was used to identify the optimum asphalt binder contents for all mixtures.

3.10.2 Marshall Mix Design

The earliest version of Marshall mix design method was developed at the Mississippi Highway Department by Bruce Marshall. The Marshall method is applicable only to hot mix asphalt using penetration, viscosity or PG graded asphalt binder or cement and containing aggregate with maximum size of 25.0 mm /1 in./ or less. The method is used for both laboratory design and field control.

The purpose of marshal mix design method is to determine the optimum bitumen content for a particular blend of aggregate. And also provide information about the properties of the resulting pavement mix, including density and void content, which are used during pavement constriction.

The Marshall method uses standard test specimen minimum 63.5 mm /2.5 in/ high and 100 mm /4 in./ internal diameter. A series of specimens, each containing the same aggregate blend but varying in asphalt content from 4 % to 6 % with an increment of 0.5 % were prepared using a specific procedure to heat, mix and compact the asphalt aggregate mixture. The procedure for the Marshall method starts with the preparation of test specimens, and steps preliminary to specimen preparation are:

- All material proposed for use have to meet the physical requirement of the specification.
- Determine the bulk specific gravity of all aggregate used in the blend and the specific gravity of asphalt cement for performing density and void analyses.
- Aggregate blend combination meets the graduation requirements of the specification.

The Marshall test procedures have been standardized by ASTM and published as ASTM D 1559.

3.10.3 Preparation of test specimens

In determining the design asphalt content for a particular blend or gradation of aggregate by the Marshall method, a series of test specimens is prepared for a range of different asphalt contents so the test data curve show well defined relationships. The steps recommended for preparing Marshall Test specimens are:

3.10.3.1 Preparation of aggregate

Since gradation was a primary consideration in asphalt mix design aggregate grading was obtained by combining several fractions prior to mixing. Calculations have been done to obtain the right fraction to get the right grain size distribution for hot mix. These fractions were then spitted down to the required quantities to avoid segregation problems. The different fractions were then mixed to produce the final correct aggregate grading in the correct amount required for the specimens that was be made. The amount of aggregate required for each sample shall be that which was sufficient to make compacted specimens standard height/minimum63.5mm/. That was normally approximately 1.2kg. Then aggregates were heated in a suitable container to maximum 28°C above the mixing temperature of 140^{O}C - 170^{O}C for 24 hours in order to keep them dry well.

a) b)

Figure 3. 5 Aggregate preparation for mix a) aggregate gradation b) aggregate blending *(photo credit; Dejene D. date Sept 24,2020)*

3.10.3.2 Mixing

Before mixing, the half-liter containers of bitumen were heated in an oven to the ideal mixing temperature range of 140^{O}C - 170^{O}C. Having heated the bitumen, mixing was done in a mechanical mixer with a bowl capacity of approximately 4 liters. The mixing bowl, mechanical stirrers and any other implements to be used in the mixing procedure were pre-heated to a mixing temperature. Having heated the materials needed for mixing, the heated aggregate sample was placed in the mixing bowl and thoroughly mixed using a trowel. A crater was formed in the centre of the mixed aggregate into which the required weight of bitumen was poured and finally mixed together using a mixer.

a) b)

Figure 3. 6 Preparation of Asphalt concrete mix a) heating bitumen b) HMA mixing *(photo credit; Dejene D. Oct 16,2020)*

3.10.3.3 Compaction

Prior to compaction the base plate, mould, filling collar were pre-heated and a paper disc to be inserted at the bottom/top of the mould were preassembled so that the sample could be compacted immediately after mixing was completed.

The mould was then filled with the mixed material and the contents spaded vigorously with a heated spatula or trowel, 15 times around the perimeter and 10 times over the interior. The surface of the material was then smoothed to a slightly rounded shape onto which another paper disc was placed. The temperature of the mix prior to compaction was checked whether it was within the determined limits /110^{O}C - 115^{O}C/. The mould, base plate and filling collar were transferred to the Marshall compaction apparatus and the sample was compacted by Marshall hammer to a specified number of 75 blows. After compaction, the mould assembly was removed and dismantled so that the mould can be inverted. The equipment was reassembled and the same number of blows was applied to the inverted sample. Having compacted the mixture, the mould assemblies like the base plate, filling collar and paper discs were removed. The mould and the specimen were allowed to cool in air for 24 hours to a temperature at which there was no deformation of the specimen during extraction from the mould using an extrusion jack. The compacted briquette was labeled and allowed to cool to room temperature ready for testing the following day. The specimens were then weighed dry in the air, weighed in water, and saturated surface dry weight of the specimen were recorded then the briquettes were inundated for 30 minutes in the water bath at 60^{O}C.The whole procedure was then repeated on the remaining prepared samples. The briquettes were then tested using a universal testing to determine their volumetric composition and strength characteristics from which optimum binder content and optimum filler content was obtained.


a) b)

c) d)

Figure 3. 7 Marshall specimen test procedure a) compacting AC mix date b) weighing AC c) soaking AC in a water bath at 60^{O}C d) recording marshal stability & flow *(photo credit; Asebew A. Oct 18(a),19(b),25(c&d), 2020)*

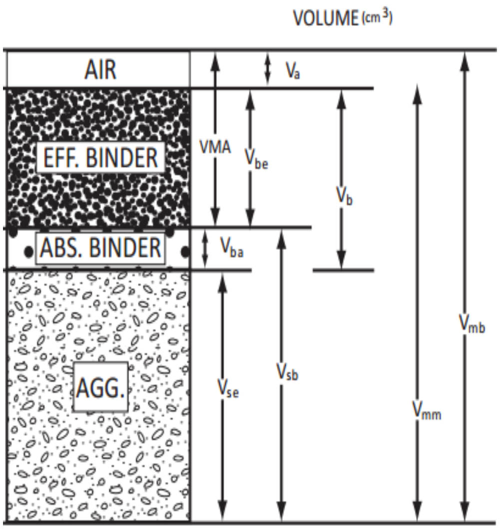
To determine the optimum bitumen content and optimum filler content a total of 45 specimens were prepared as shown below in Fig 3.7 as a sample. Marshall Test was done for each gradation prepared with 5%, 5.5% and 6.5 % CSD by weight of total aggregates and five different percentages of bitumen contents /4%,4.5%,5%,5.5% and 6% by weight of total mix/ with 3 trial specimen for each test which resulted in a total number of 45 specimen to determine OBC and OFC.

Figure 3. 8 Marshall specimens*(photo credit; Eyuael Oct 29,2020)*

3.11 Volumetric properties of HMA

Mix design is required to optimize the properties of a mix with the given raw materials available. The sample preparation, as well as the measurements of stability, flow, void content etc. must be performed with high accuracy to ensure reliable results. The most important volumetric properties of bituminous mixtures that are to be considered include

- Theoretical maximum specific gravity /Gmm/
- Bulk specific gravity/Gmb/
- Percent air voids in compacted mix /Va/
- Percent volume of bitumen(Vb)
- Percent voids in mineral aggregate /VMA/
- Percent voids filled with asphalt/VFB/
- Bitumen absorption/Pba/ and
- Effective asphalt content/Pbe/



Vmb = Bulk volume of compacted mix

Vmm = Void less volume of HMA mix

VFB = Volume of voids filled with bitumen

Va = Volume of air voids

Vb = Volume of bitumen

Vba = Volume of absorbed bitumen

Vsb = Volume mineral aggregate

Vse = Volume of mineral aggregate

VMA = Volume of voids in mineral aggregate

Figure 3. 9 Representation of volume in a compacted HMA specimen*(Source: Asphalt institute, 2014)*

3.11.1 Bulk specific gravity/Gmb/

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. The bulk specific gravity of an asphalt concrete mixture can be determined using either laboratory compacted specimens or cores or slabs cut from a pavement. The standard procedure for determining the bulk specific gravity of compacted asphalt concrete involves weighing the specimen in air and in water. The following formula is used for calculating bulk specific gravity of a saturated surface-dry specimen:

$$Gmb=\frac{A}{(B-C)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{EQ. } 3.1$$

Where:

Gmb= Bulk specific gravity of compacted specimen

A = Mass of the dry specimen in air in g

B = Mass of the saturated surface-dry specimen in air in g

C = Mass of the specimen in water in g

3.11.2 Theoretical maximum specific gravity /Gmm/

Theoretical maximum specific gravity /Gmm/ is the ratio of the mass of a given volume of void less /V_a =0/ HMA at a stated temperature /usually 25^{O}c/ to a mass of an equal volume of gas-free distilled water at the same temperature. The maximum specific gravity /Gmm/ at different asphalt contents was measured to calculate air voids. The theoretical maximum specific gravity is computed as: -

$$Gmm=\frac{A}{(A+B-C)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.\dots\dots\dots\dots.\dots \text{Eq. } 3.2$$

Where:

Gmm =Maximum theoretical specific gravity is calculated as per ASTM D2041.

A= Mass of the dry sample in air in g

B = Mass of jar filled with water in g

C = Mass of jar filled with water + sample in g

3.11.3 Percent air voids in compacted mix /Va/

The air voids, Va, in a compacted mix is the volume of air between the coated aggregate particles. It is calculated using:

$$Va = 100 * \left(\frac{Gmm-Gmb}{Gmm}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. \text{Eq. } 3.3$$

Where:

Va = Air voids in a compacted mixture

Gmm= maximum specific gravity of paving mixture

Gmb= bulk specific gravity of the compacted mixture

3.11.4 Percent voids in mineral aggregate /VMA/

VMA, defined as the inter-granular void space between the aggregate's particles in a compacted paving mixture. It includes the volume of air between the coated aggregate particles and the volume of effective bitumen. It is expressed as per cent by weight of total mix using:

$$\text{VMA}= 100 - \frac{(\text{Gmb}*\text{Ps})}{\text{Gsb}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots.. \text{Eq. } 3.4$$

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 the total mixture

3.11.5 Percent voids filled with bitumen /VFB/

The voids filled with bitumen, VFB, is the percentage of VMA that is filled with bitumen. It is calculated using:

$$\text{VFB}= 100 * \left(\frac{\text{VMA}-\text{VIM}}{\text{VMA}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots.. \text{Eq. } 3.5$$

Where:

Va = Air voids in a compacted mixture

VMA= voids in the mineral aggregate

3.11.6 Bitumen absorption/Pba/

Bitumen absorption is expressed as a percentage by weight of aggregate and is calculated using:

$$Pba = 100 * \frac{(Gse-Gsb)}{Gse*Gsb} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. Eq. 3.6$$

Where:

Pba = absorbed bitumen, percent by weight of aggregate

Gse = effective specific gravity of aggregate

Gsb = bulk specific gravity of total aggregate

Gb = specific gravity of bitumen

3.11.7 Effective asphalt content /Pbe/

Effective asphalt content, Pbe, is the volume of asphalt binder which is *not* absorbed into the aggregate. It is calculated using:

$$Pbe = Pbe - \frac{(Pba*Ps)}{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. Eq. 3.7$$

Where:

Pbe = effective bitumen content, percent by total weight of mix

Pb = bitumen content, percent by total weight of mix

Pba = absorbed bitumen, percent by weight of aggregate

Ps = aggregate content, percent by total weight of mix

3.12 Determination of design bitumen content

There are two most commonly used methods to determine the design bitumen content. These are:

- Method 1: Asphalt Institute method and
- Method 2: NAPA /National Asphalt pavement Association/

The design bitumen content of the mix was selected by considering all of the volumetric property data discussed previously. As an initial starting point the bitumen content giving4% air voids using three different filler contents/5%,5.5%&6%/ were chosen as the optimum bitumen content for each filler content. All of the calculated and measured mix properties at these bitumen contents were then determined by interpolation from the graphs shown in Figure 4.4-4.6. The individual properties were then compared to the mix design criteria as specified in NAPA and cross checked with ERA pavement design manual 2013. Finally, from these OBCs the one that resulted with a highest stability was selected as the design bitumen content.

3.13 Determination of optimum replacement ratio of GSA and SCBA

Before starting the replacement procedure certain steps were followed to prepare the additive materials used to replace crushed stone dust in this study namely GSA and SCBA. These are:

1. The raw materials such as groundnut shell and sugarcane bagasse were collected from Shebe and Wonji Sugar Factory respectively.
2. The materials were then dried on open air.
3. The dried groundnut shell and sugarcane bagasse were then burned at a temperature between 500^{O}C - 700^{O}C using a furnace.
4. The burned groundnut shell ash and sugarcane bagasse ash were allowed to cool in an open air.
5. After cooling, both ashes were sieved separately using mechanical sieve shaker and the ash that passed No.200 sieve /0.075mm/ 100% and retained on pan was used to replace crushed stone dust.

a)

b)

c) d)

Figure 3. 10 Material preparation of GSA and SCBA a) drying groundnut husk b) burning GS & bagasse in a furnace c) drying bagasse d) sieving SCBA & GSA *(photo credit; Dejene D. Oct 09(a),17(b&d),11(c),2020)*

Prior to the determination of optimum replacement ratio of GSA and SCBA as filler ,three Marshall specimens were prepared using design bitumen content and optimum conventional filler content as a control mix by following the same Marshall mix design procedures utilized previously. Having determined Marshall properties of a control mix, the additives used in this study namely GSA and SCBA were used to replace the crushed stone dust filler at different percentage of 5%, 10%, 15%, 100% and 5%, 10%, 15%, 20%, 25%, 100% by weight respectively using similar Marshall procedure as previous. So, based on the above basis a total number of 33 specimens including control mix were prepared to determine the optimum replacement percent of GSA and SCBA using Marshall test.

3.14 Indirect Tensile strength test

The indirect tensile test was developed to determine the tensile properties of cylindrical concrete and asphalt concrete specimens through the application of a compression load along a diametrical plane through two opposite loading heads. This type of loading produces a relatively uniform stress acting perpendicular to the applied load plane, causing the specimen to fail by splitting along the loaded plane(Ahmed, et al , 2006).

In this study, the tensile strength of the asphalt mixtures was evaluated by loading a specimen along a diametral plane to determine moisture susceptibility of HMA mixtures prepared by partially replacing CSD with different percentage of SCBA and GSA meeting all marshal properties . This loading was applied to the specimen by forcing the bearing plates together using universal testing machine. A relatively uniform tensile stress develops perpendicular to the direction of the applied load and causes the specimen to fail by splitting along the vertical diameter. The tensile strength ratio /TSR/ is conducted in agreement with AASHTO T283, in this test method the resistance of compressed mixtures of asphalt concrete to moisture damage was measured. The test set up is shown in Figure 3.10. The maximum force required for failing the specimen was recorded, and, the tensile strength of the mixtures was calculated using Equation 3.8.

$$ITS=\frac{2000*P}{\pi*t*D} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . Eq. 3.8$$

Where:

ITS = Indirect tensile strength, Kpa

P= Maximum load, N

t= specimen thickness immediately before test, mm

D= specimen diameter, mm

a) b)

Figure 3. 11 IDT test set up a) recording ITS data b) adjusting thickness and diameter*(photo credit; Dejene D. Nov 19, 2020)*

Moisture susceptibility of a bituminous mix was determined by tensile strength ratio /TSR/ using the indirect tensile strength obtained by Eq. 3.8. Tensile strength ratio /TSR/ is the relation of the strength values before and after water storage. The tensile strength ratios were calculated using the following equation:

$$TSR = \frac{ITS(\text{conditioned})}{ITS(\text{unconditioned})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{Eq. } 3.9$$

Where:

TSR= Tensile strength ratio

ITS (conditioned)= Avg. Indirect tensile strength of wet group, kPa

ITS (unconditioned)= Avg. Indirect tensile strength of dry group, kPa

In this research, a total number 42 specimens were prepared and compacted using a Marshall Compactor in lab with a similar procedure utilized previously in marshal test. Those specimens/42/ were divided into three groups. The first group contained of 6 specimens containing 0% additives and was prepared using CSD filler at design bitumen content and optimum filler content obtained previously, which served as control. The second group was prepared with 5% and 10% of GSA additive as partial replacement of CSD containing 6 specimens each. The third group was prepared with 5%, 10%, 15% and 20% of SCBA additive as partial replacement of CSD containing 6 specimens each. The mixes were compacted using a Marshall Compactor. Two cases were tested in this study, first one symbolizes the control models /unconditioned case/ which were tested at 25°C with minimum of 3 trial specimen each. The second was the conditioned case, which was inundated in water at 60°C for 24 hours, and were tested at 25°C to measure the moisture susceptibility of the mixtures.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 General

In this study, one hundred twenty/120/ sets of bituminous mixtures using different types and amount of mineral fillers and bitumen content were evaluated using the Marshal Mix design method. These mixtures were prepared using crushed stone dust, sugarcane bagasse ash and groundnut shell ash fillers with varying the content by the total mixture and their effects on Marshal Properties were assessed. Indirect tensile strength test was then carried out to evaluate the moisture susceptibility of various specimens prepared with different replacement percentage of GSA and SCBA at optimum asphalt content and optimum filler content.

4.2 Material property test result

4.2.1 Physical properties of mineral aggregate

Aggregates for HMA are generally required to be tough, hard, strong, durable/sound/, properly graded; to consists of cubical particles with low porosity; and to have clean, rough hydrophobic surfaces. Since aggregate properties play an essential role in overcoming permanent deformation, a number of laboratory tests has been conducted towards determining their properties. 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.

Table 4. 1 Physical properties of aggregate

Test	Test Method	Test Result				Specification
		25-13mm	13-6mm	6-3mm	3-0mm	
Bulk Spec. gravity (Dry)	AASHTO T 84-85	2.637	2.613	2.60	2.5999	
Bulk Spec. gravity(SSD)		2.669	2.657	2.684	2.675	
Apparent Spec. gravity		2.724	2.734	2.86	2.851	
Water Absorption, %	BS 812 Part 2	1.213	1.695	1.777		<2

Flakiness Index	BS 812 Part 105	22				<45
Aggregate Crushing Value(ACV), %	BS 812 Part 3	12				<25
Aggregate Impact Value(AIV), %	BS 812 Part 3	12.59				
Los Angeles Abrasion(LAA)	ASTM C 131 and C535	12.875				< 30
Sand Equivalent	AASHTO T176-86				75.47	> 40
Surface area (m²/Kg) At 5%CSD At 5%CSD At 5%CSD		 4.1107 4.3106 4.5107				 - - -

4.2.2 Physical properties of mineral fillers

The mineral fillers used in the research namely crushed stone dust, bagasse ash and groundnut shell ash were subjected to various tests in order to assess their physical characteristics and suitability in the road construction. These properties consist of the gradation parameters, plasticity index and apparent specific gravity. Apparent specific gravity test was conducted according to ASTM D-854 by using Water Pycnometer method.

Table 4. 2 Physical properties of mineral fillers CSD, GSA and SCBA

Test Description		Material Type			Specification ASTM D242-854	Status
	Sieve No.	CSD	GSA	SCBA		
Sieve(% Passing)	No.30	100	100	100	100	Ok!
	No.50	100	100	100	95-100	Ok!
	No.200	100	100	100	70-100	Ok!
Plasticity Index		NP	NP	NP	< 4	Ok!
Specific Gravity(Dry)		2.63	2.004	1.98	-	Ok!

4.2.3 Asphalt binder test results

It has been well established that the properties of asphalt cement binder affect pavement performance. Since the properties of asphalt cement binder change during HMA production and continue to change subsequently in service its properties have to be studied.

In this study a 60/70 penetration paving grade bitumen was utilized for the preparation of asphaltic mixtures. The properties of the 60/70 penetration grade binder specification requirement like penetration, flash point, ductility, softening point and specific gravity tests were performed and test results are given in Table 4.3.

Table 4. 3 Asphalt binder Physical properties

Test Description	**Test Method**	**ERA Specification**	**Results**	**Status**
Penetration@25^{O}C	ASTM D5	60-70	65.2	Ok!
Ductility@25^{O}C	ASTM D113	> 100cm	120.33	Ok!
Softening point ^{O}C	ASTM D36	49-56	52.7	Ok!
Flash point ^{O}C	ASTM D92	> 232	279	Ok!
Fire point ^{O}C	ASTM D92	-	314	Ok!
Specific Gravity@25^{O}C	ASTM D70	1.01-1.06	1.015	Ok!

4.3 Aggregate gradation for HMA mixture

The coarse and fine aggregate particles were separated into different sieve size and proportioned to obtain the desired gradation for bituminous mixtures of ASTM 3515 for 19mm nominal maximum aggregate size. Incorporating different amount of mineral fillers, the aggregate gradation is expressed as the percentage by weight of the 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 as shown in Table 4.6.

Table 4. 4 Asphalt paving mixture specification ASTM D3515

Mix Designation and Nominal Maximum Size of Aggregate						
Sieve Size		1½" (37.5 mm)	1" (25.0 mm)	¾" (19 mm)	½" (12.5 mm)	⅜" (9.5 mm)
2"	50 mm	100	....	....	....	....
1½"	37.5 mm	90 to 100	100	....	....	....
1"	25.0 mm	....	90 to 100	100	....	....
¾"	19 mm	56 to 80	....	90 to 100	100	....
½"	12.5 mm	....	56 to 80	....	90 to 100	100
⅜"	9.5 mm	....	....	56 to 80	....	90 to 100
No. 4	4.75 mm	23 to 53	29 to 59	35 to 65	44 to 74	55 to 85
No. 8	2.36 mm	15 to 41	19 to 45	23 to 49	28 to 58	32 to 67
No. 16	1.18 mm	....	....	....	....	....
No. 30	0.6 mm	....	....	....	....	....
No. 50	0.3 mm	4 to 16	5 to17	5 to19	5 to 21	7 to 23
No. 100	0.15 mm	....	....	....	....	....
No. 200	0.075 mm	0 to 5	1 to 7	2 to 8	2 to10	2 to10
Bitumen, Weight% of Total Mixture		3 to 8	3 to 7	4 to10	4 to11	5 to12

Source: Asphalt institute MS-2 Asphalt mix designs 7th edition

4.3.1 Aggregate blending

The most common method of determining the proportions of aggregate to use to meet specification requirements is the trial-and-error method. In this study, different aggregate types were utilized namely coarse aggregate /13- 25mm/, intermediate aggregate IA /6- 13mm and 3- 6mm/, fine aggregate /0- 3mm/ and filler, which were combined in order to determine the proper gradation within the allowable limits according to ASTM specifications using the mathematical trial method.

The mathematical trial method suggests different trial proportions for aggregate types from whole gradation. The percentage of each size of aggregates is to be computed and compared to specification limits. If the calculated gradation is within the allowable limits, no further adjustments need to be made; if not, an adjustment in the proportions must be made, and the calculations must be repeated until it falls between specification limits. Table 4.5 shows the aggregate type and their blending proportions to produce the desired gradation for different filler content.

Table 4. 5 Aggregate type and their blending proportions

Filler (%)	Aggregate Type in size					Total
	Coarse Aggregate, CA(25-13mm)	Intermediate Aggregate, IA1(13-6mm)	Intermediate Aggregate, IA2(6-3mm)	Fine Aggregate, FA(3-0mm)	Filler (CSD)	
5	24.3	30.5	16.2	27.36	1.64	100
5.5	24.23	30.45	16.19	26.95	2.21	100
6	24.23	30.45	16.19	25.8	3.33	100

4.3.1 Desired gradation curves

Gradation of an aggregate can be graphically represented by a gradation curve for which the ordinate is the total percent by weight passing a given size on an arithmetic scale, while the abscissa is the particle size plotted to a logarithmic scale. So, in order to comply with the desired gradation standard specified in ASTM 3515 the gradation curves for the aggregates used in the preparation of HMA mixture in this study have to fall in between the upper and lower limit curves as depicted in Figure 4.1. Figure4.2-4.4 shows aggregate gradation curve utilized in this research which satisfied the specification guideline.

Table 4. 6 Aggregate gradation for HMA mixture at 5%,5.5% and 6.0% CSD

Sieve size(mm)	Gradation for the three different fillers			ASTM D3515 specification		
	Percentage passing			UPPER	MIDDLE	LOWER
	5%	5.50%	6%			
25	100	100	100	100	100	100
19	93.03	93.08	93.13	100	95	90
12.5	77.76	77.86	77.96	88	79.5	71
9.5	65.31	65.46	65.56	80	68	56
4.75	47.07	47.27	47.47	65	50	35
2.36	30.55	30.80	31.05	49	36	23
1.18	25.80	26.10	26.40	37	26	15
0.6	17.18	17.53	17.88	28	19	10
0.3	8.57	8.96	9.36	19	12	5
0.15	6.45	6.89	7.34	13	8.5	4
0.075	5	5.5	6	8	5	2

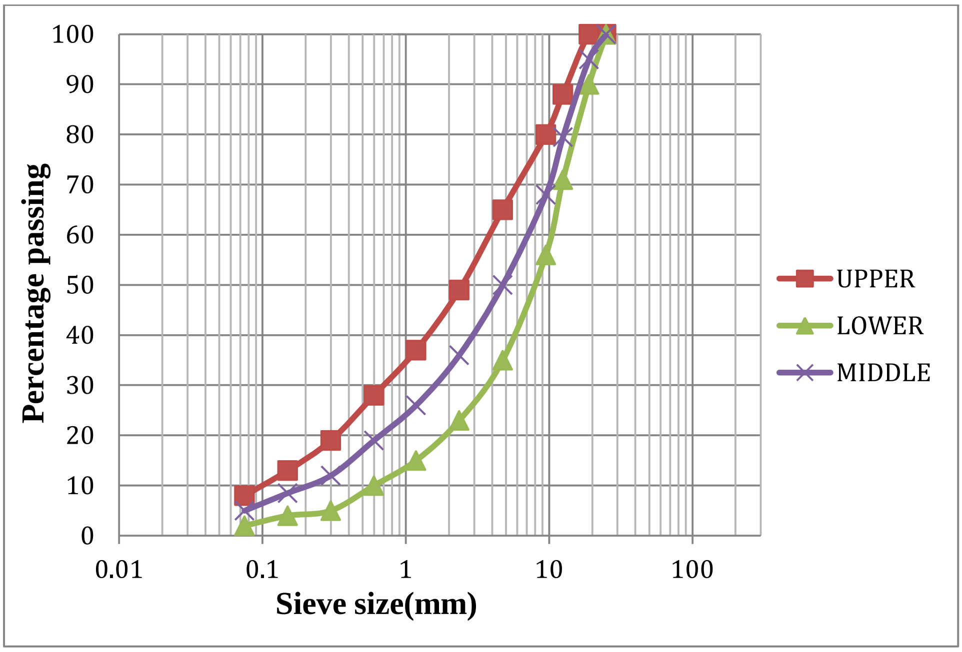


Figure 4. 1 Aggregate gradation curve of ASTM D3515

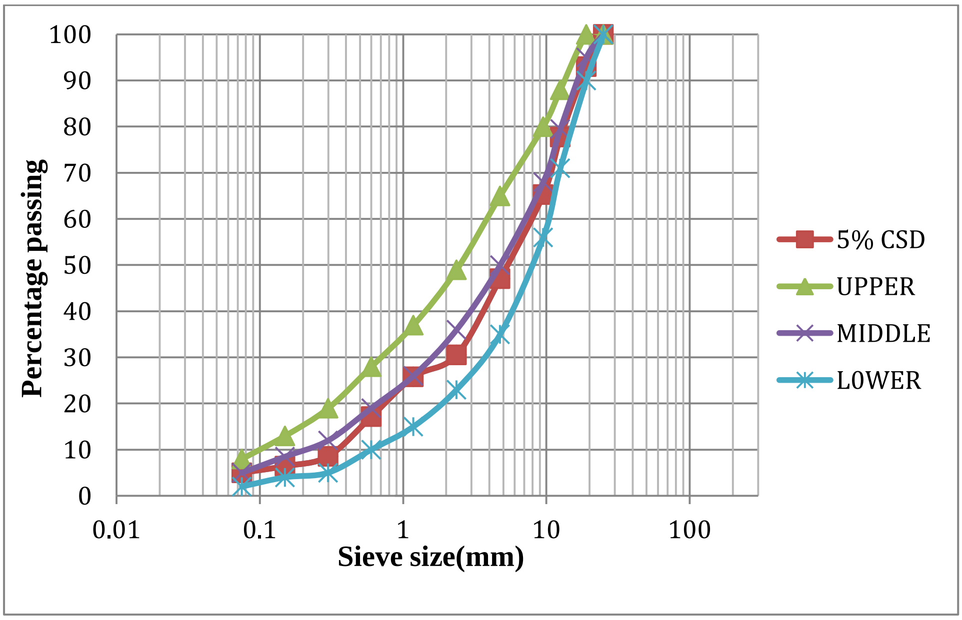


Figure 4. 2 Aggregate gradation curve for asphalt binder course with 5% CSD filler

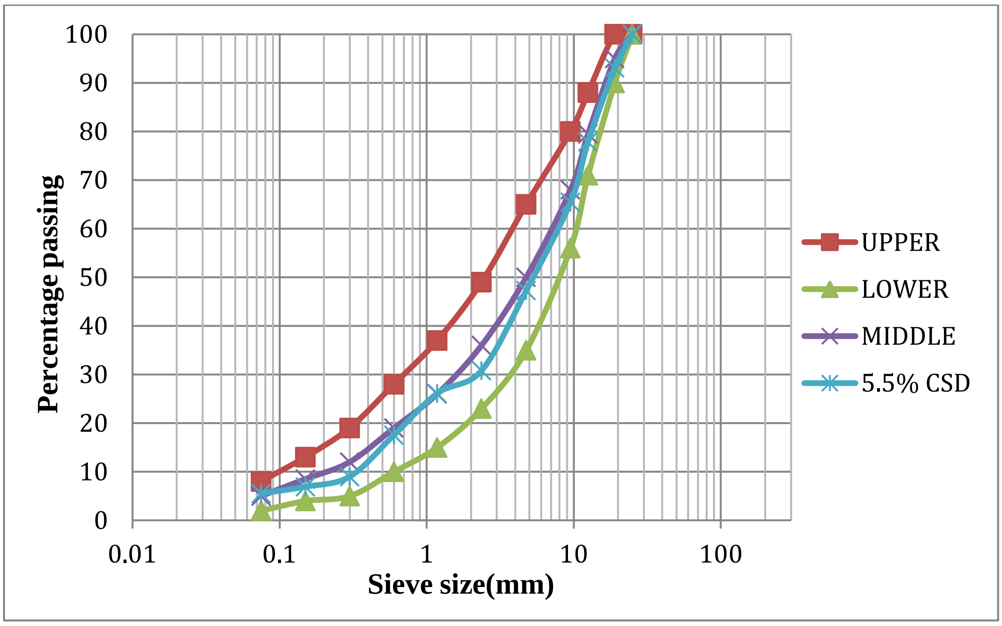


Figure 4. 3 Aggregate gradation curve for asphalt binder course with 5.5% CSD filler

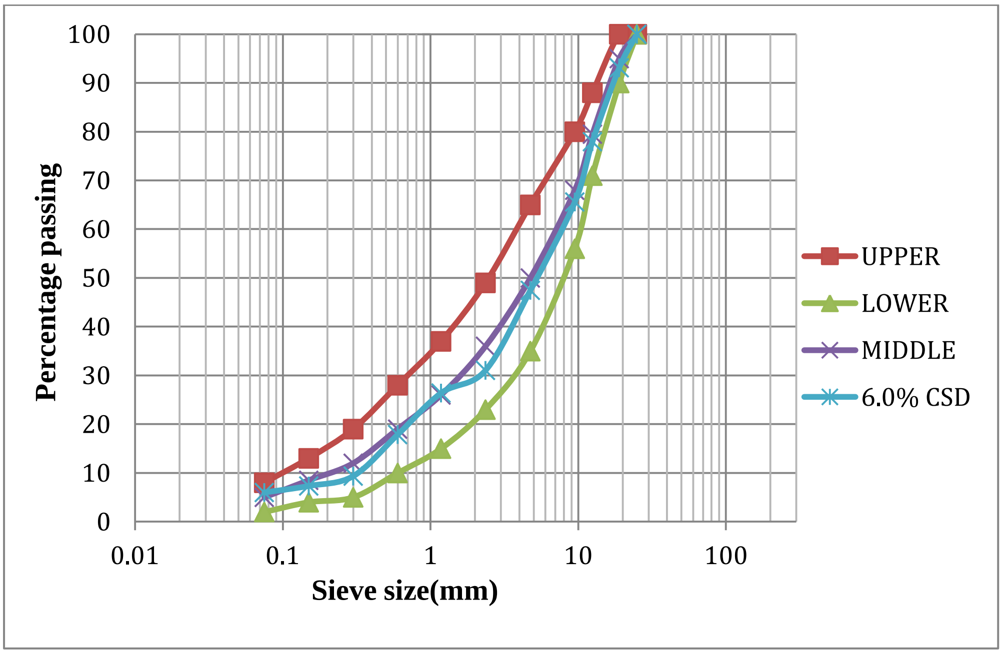


Figure 4. 4 Aggregate gradation curve for asphalt binder course with 6% CSD filler

4.4 Analysis of HMA mixtures

4.4.1 Marshall test results and Analysis

In order to achieve the objective of this research different laboratory works had been conducted and analyzed. Out of which, Marshall test was used to examine volumetric and marshal properties of asphalt mixture at different percentages of bitumen content /4.0%, 4.5%, 5.0%, 5.5% and 6.0%/ and varying CSD filler content percentages of 5%,5.5% and 6% by weight of aggregate to obtain the optimum bitumen content as well as design filler content following ERA pavement manual and NAPA. Prior to achieving OBC and OFC, characterization of asphalt mixture in Marshall mix design including measurement of air voids, voids in mineral aggregate, voids filled with asphalt cement, bulk specific gravity of compacted mixtures, theoretical maximum specific gravity, Marshall stability and flow had been examined by preparing and testing a total of 45 specimens. Table 4.7-4.9 indicates the properties of the mixture at various asphalt content for mixes with different conventional filler content /CSD/.Further details are presented in Appendix D.

Table 4. 7 Summary of volumetric and Marshall data of mix with 5% CSD filler and varying bitumen contents

AC content	Sample no.	Bulk density	VIM (%)	VMA (%)	VFA (%)	STABLITY (kN)	FLOW (mm)
4	1	2.268	8.272	16.627	50.251	7.87	2.53
	2	2.278	7.899	16.288	51.504	7.64	2.69
	3	2.266	8.358	16.705	49.969	7.97	2.56
	Average	2.271	8.176	16.540	50.567	7.827	2.593
4.5	1	2.294	6.259	16.132	61.203	8.37	2.761
	2	2.285	6.608	16.445	59.815	8.44	2.98
	3	2.293	6.310	16.178	60.996	8.21	2.83
	Average	2.291	6.392	16.252	60.666	8.34	2.857
5	1	2.322	4.622	15.531	70.241	8.28	3.64
	2	2.333	4.173	15.133	72.427	8.64	2.79
	3	2.307	5.269	16.104	67.279	8.41	2.88
	Average	2.321	4.688	15.589	69.929	8.443	3.103
5.5	1	2.329	4.013	15.752	74.522	8.89	3.16
	2	2.338	3.628	15.414	76.463	8.36	3.37
	3	2.338	3.641	15.425	76.396	9.05	3.941
	Average	2.335	3.761	15.530	75.785	8.767	3.490
6	1	2.346	2.545	15.582	83.668	8.08	3.62
	2	2.325	3.408	16.329	79.132	8.37	3.83
	3	2.330	3.201	16.150	80.181	8.2	3.91
	Average	2.333	3.051	16.022	80.957	8.217	3.787

Table 4.7 shows marshal test result of a mix with 5% conventional filler /CSD/ and the corresponding values of volumetric and marshal properties such as stability, flow value, air void, voids in mineral Aggregate, voids filled with asphalt and unit weight at different bitumen content. In addition to this, Figure 4.4 shows the relationships between different volumetric and marshal properties at different asphalt content and 5% crushed stone dust filler.

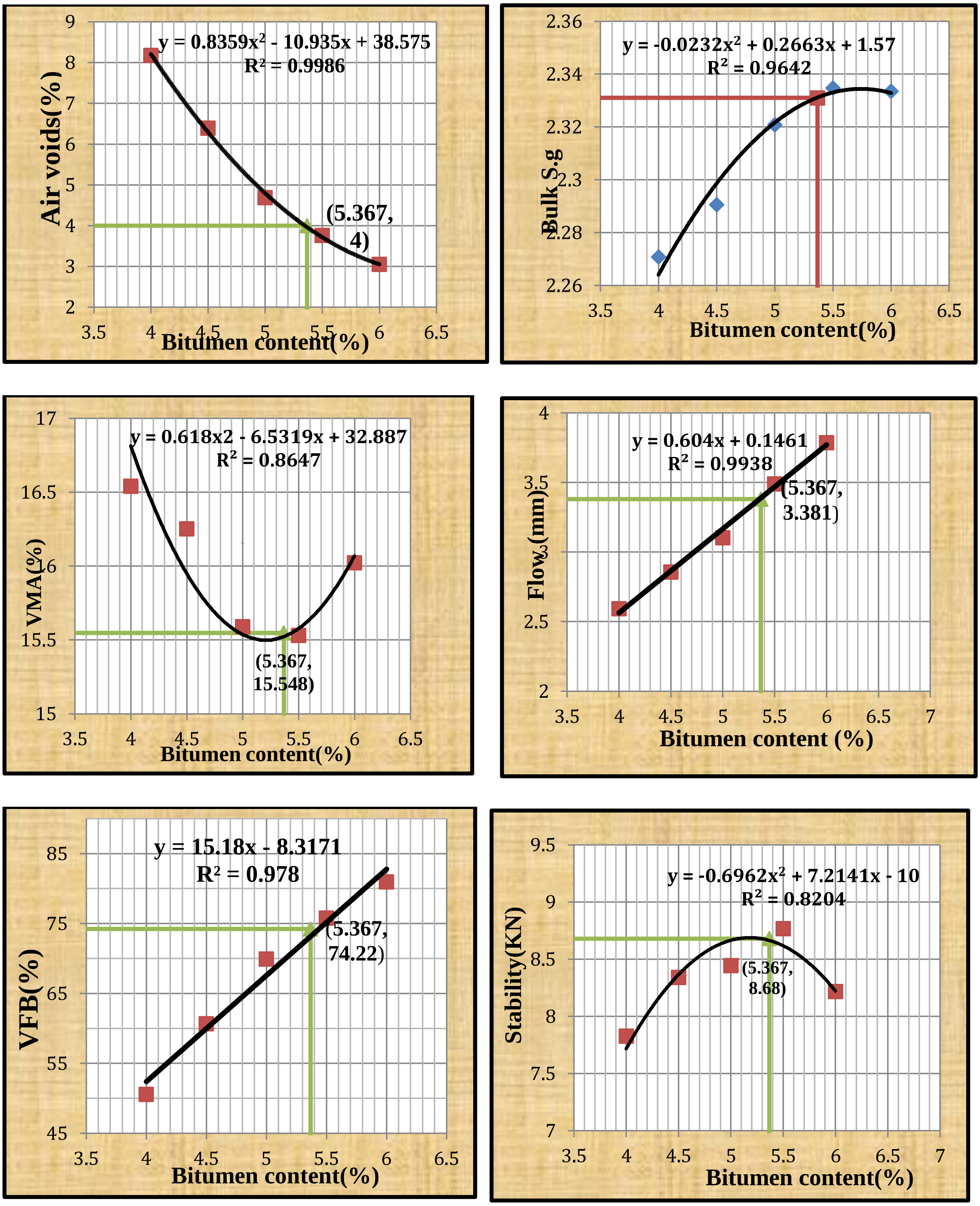


Figure 4. 5 Graphical representation of mix test properties at different BC and 5% CSD filler

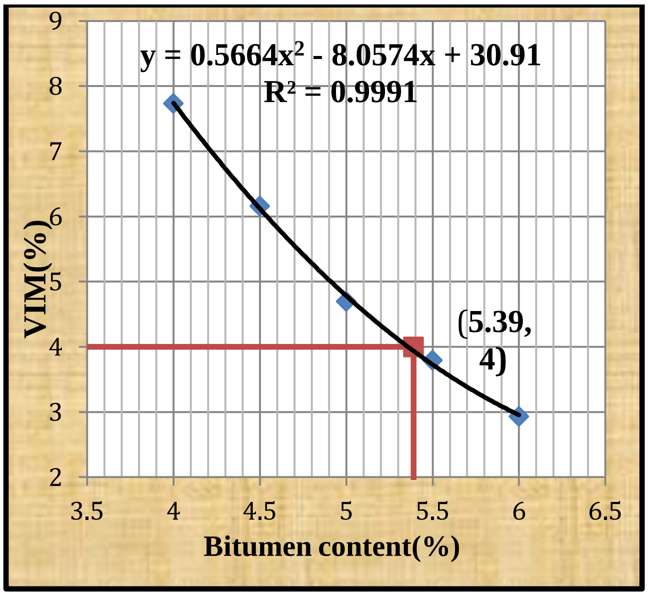
Figure 4.5 indicates the relationships between binder content and volumetric as well as marshal properties of a mix prepared with 5% conventional filler /CSD/. As it can be seen from the figure as asphalt content increases the mix showed a trend of increase in stability and unit weight up to maximum value and then decrease as asphalt content increase. On the other hand, the mix showed a trend of increase in voids filled with asphalt /VFA/ and flow as the asphalt content increase. However, the percent of voids in the mineral aggregate /VMA/ decreases to a minimum and then increase with increasing bitumen content in the mix where as the percent of air voids, VIM, in the mix steadily decreases with increasing bitumen content. According to NAPA method of determining OBC, it is specified that optimum binder content of the mix is obtained at 4% air voids. Depending up on this method and figure 4.5, it was found that the OBC of the mix with 5% CSD filler is 5.367% by weight of the total mix.

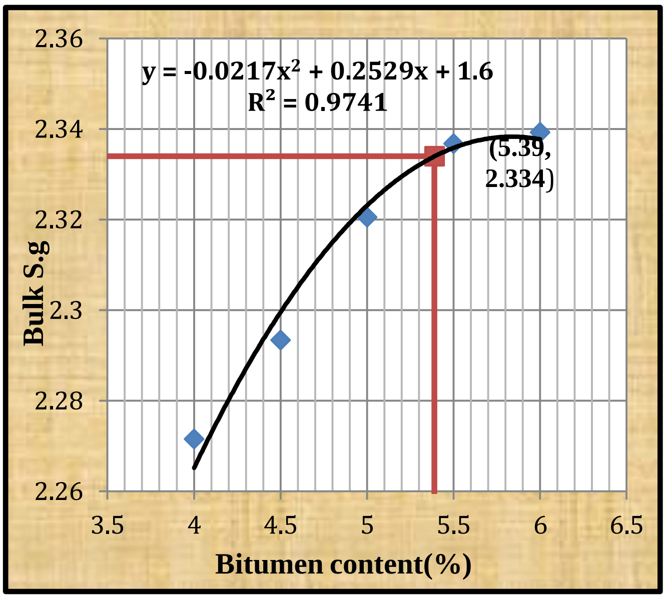
Table 4. 8 Summary of volumetric and Marshall data of mix with 5.5% CSD filler and varying bitumen contents

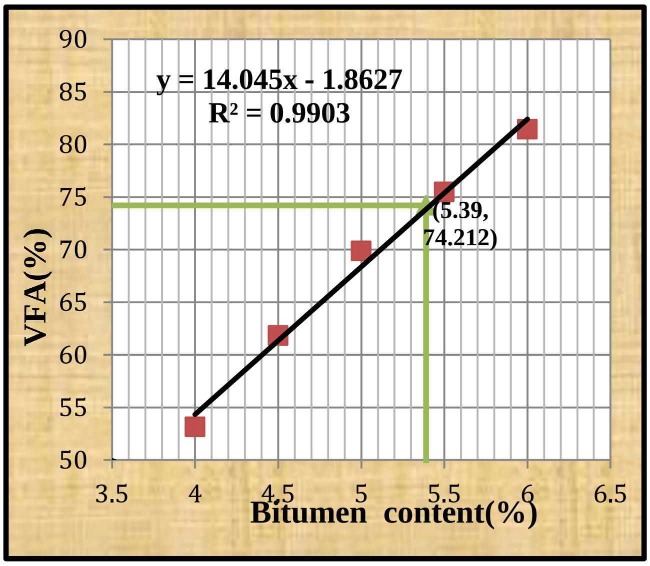
BC	Sample no.	Bulk density	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4	1	2.27	7.806	16.576	52.909	8.02	2.51
	2	2.268	7.89	16.653	52.619	8.23	2.62
	3	2.277	7.51	16.309	53.951	8.59	2.79
	Average	2.272	7.735	16.513	53.155	8.28	2.64
4.5	1	2.293	6.176	16.161	61.783	8.64	2.79
	2	2.294	6.154	16.142	61.873	8.92	2.83
	3	2.294	6.155	16.142	61.871	8.75	2.89
	Average	2.293	6.162	16.149	61.842	8.77	2.837
5	1	2.329	4.37	15.308	71.453	9.85	3.18
	2	2.32	4.736	15.632	69.703	8.91	3.24
	3	2.313	4.993	15.859	68.519	9.56	3.09
	Average	2.321	4.7	15.6	69.875	9.44	3.17
5.5	1	2.333	3.972	15.611	74.557	9.51	3.69
	2	2.35	3.27	14.995	78.191	9.82	3.09
	3	2.328	4.146	15.764	73.701	10.2	3.29
	Average	2.337	3.796	15.457	75.483	9.843	3.357
6	1	2.338	2.983	15.857	81.186	8.65	3.85
	2	2.344	2.744	15.65	82.464	8.83	3.74
	3	2.336	3.075	15.936	80.705	8.54	3.37
	Average	2.339	2.934	15.815	81.446	8.673	3.653

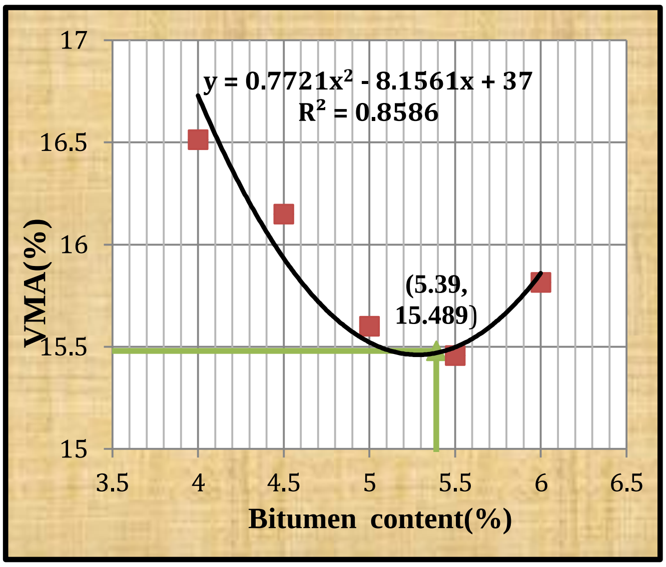
Table 4.8 shows marshal test result and volumetric data of a mix with 5.5% conventional filler /CSD/ and the corresponding values of volumetric and marshal properties such as

stability, flow value, air void, voids in mineral aggregate, voids filled with asphalt and unit weight at different asphalt content. Additionally, Figure 4.6 shows the relationships between different volumetric and marshal properties at different asphalt content and 5.5% crushed stone dust filler.









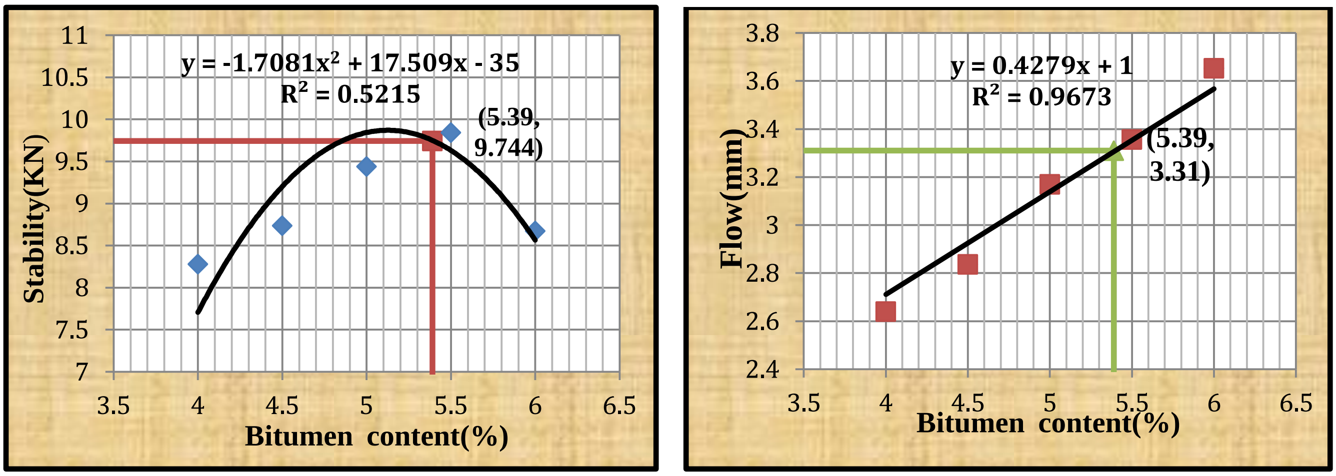


Figure 4. 6 Graphical representation of mix test properties at different BC and 5% CSD filler

Figure 4.6 indicates the relationships between binder content and volumetric as well as marshal properties of a mix prepared with 5% conventional filler /CSD/. As it can be seen from the depicted figure, as asphalt content increases the mix showed a trend of increase in stability and unit weight up to maximum value and then decrease as asphalt content increase. On the other hand, the mix showed a trend of increase in voids filled with asphalt /VFA/ and flow value as the asphalt content increase. However, the percent of voids in the mineral aggregate /VMA/ decreases to a minimum and then increase with increasing bitumen content in the mix where as the percent of air voids, VIM, in the mix steadily decreases with increasing bitumen content. According to NAPA method of determining OBC, it is specified that optimum binder content of the mix is obtained at 4% air voids. Depending up on this method and figure 4.6, it was found that the OBC of the mix with 5.5% CSD filler is 5.39% by weight of the total mix.

Table 4. 9 Summary of volumetric and Marshall data of mix with 6.0% CSD filler and varying bitumen contents

BC	Sample no.	Bulk density(gm/cm3)	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4	1	2.274	7.496	16.432	54.381	8.29	2.83
	2	2.262	7.982	16.871	52.688	8.53	3.04
	3	2.284	7.064	16.042	55.964	8.13	2.97
	Average	2.273	7.514	16.45	54.322	8.317	2.95
4.5	1	2.318	5.106	15.24	66.495	9.09	3.23
	2	2.301	5.797	15.857	63.444	8.33	3.17
	3	2.295	6.07	16.101	62.299	8.63	3.079
	Average	2.305	5.658	15.734	64.041	8.683	3.16
5	1	2.337	4.222	15.003	71.856	9.98	3.23
	2	2.334	4.328	15.097	71.331	9.82	3.37
	3	2.33	4.489	15.24	70.542	9.53	3.29
	Average	2.334	4.347	15.127	71.266	9.777	3.3
5.5	1	2.342	3.773	15.262	75.281	10.16	3.48
	2	2.343	3.745	15.238	75.422	10.09	3.38
	3	2.351	3.424	14.955	77.102	10.24	3.43
	Average	2.345	3.647	15.152	75.928	10.163	3.43
6	1	2.314	4.059	16.72	75.727	9.07	4.02
	2	2.351	2.547	15.409	83.468	9.1	3.84
	3	2.339	3.041	15.837	80.799	8.97	3.87
	Average	2.334	3.216	15.989	79.888	9.047	3.91

Table 4.9 shows marshal test result and volumetric data of a mix with 6.0% conventional filler /CSD/ and the corresponding values of volumetric and marshal properties such as stability, flow value, air void, voids in mineral aggregate, voids filled with asphalt and unit weight at different asphalt content. Additionally, Figure 4.6 shows the relationships between different volumetric and marshal properties at different asphalt content and 5.5% crushed stone dust filler.

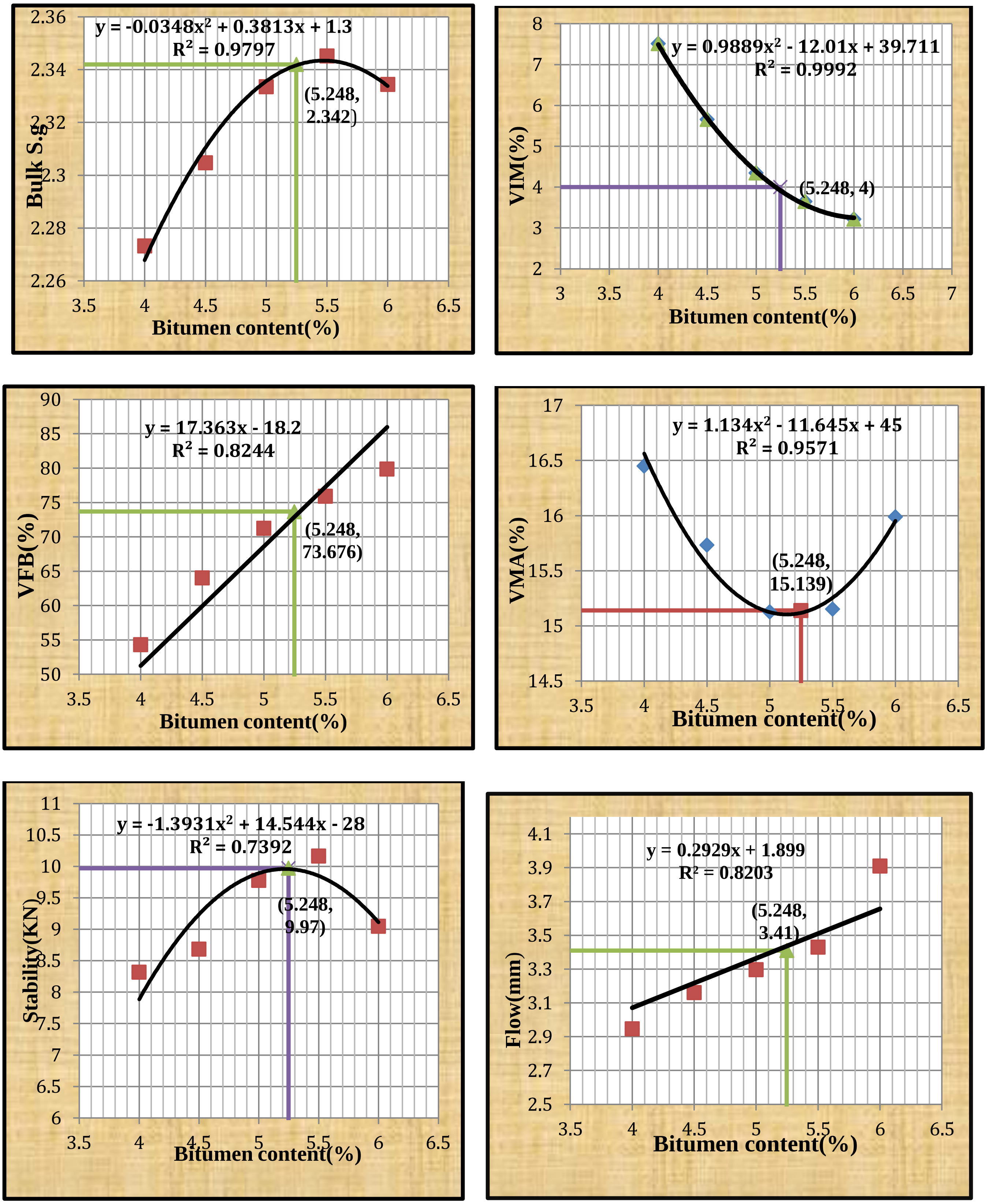


Figure 4. 7 Graphical representation of mix test properties at different BC and 6.0% CSD filler

Figure 4.7 indicates the relationships between asphalt content and volumetric as well as marshal properties of a mix prepared with 6.0% conventional filler /CSD/. As it can be seen from the figure as asphalt content increases the mix showed a trend of increase in stability and unit weight up to maximum value and then decrease as asphalt content increase. On the other hand, the mix showed a trend of increase in voids filled with asphalt /VFA/ and flow as the asphalt content increase. However, the percent of voids in the mineral aggregate /VMA/ decreases to a minimum and then increase with increasing bitumen content in the mix where as the percent of air voids, VIM, in the mix steadily decreases with increasing bitumen content. According to NAPA method of determining OBC, it is specified that optimum binder content of the mix is obtained at 4% air voids. Depending up on this method and figure 4.7, it was found that the OBC of the mix with 6.0% CSD filler is 5.248% by weight of the total mix.

4.4.2 Design Bitumen Content Determination and Marshall results of HMA mix properties at varying contents of CSD filler

Marshal test was used primarily to obtain the optimum bitumen content and check performance of the mixtures by examining the specimens of HMA mixture with different percentage of bitumen content at 4%,5%,5.5%, and 6%. The optimum asphalt content was determined by the method stated previously, that was National Asphalt Pavement Association/NAPA/.It states that the optimum asphalt content is determined by the percent of asphalt content that corresponds to the median air void /4%/. Having sought OBC of the mix prepared with different filler content accordingly, other volumetric and marshal values such as marshal stability, flow, VFA, VMA and unit weight of the mix were determined by interpolation as shown in figure 4.5-4.7.Then each of those values were compared with the specification and all results are within the specification limit of both ERA Pavement Design Manual, 2013 and Asphalt Institute, 2014.From the above discussion it was determined that the optimum asphalt content at 4 % air void for a mix prepared with 5%, 5.5 %, 6 % CSD filler is 5.367%, 5.39, 5.248% respectively.

Table 4. 10 Summary of volumetric and Marshal data at 5% CSD filler and 5.367 % OBC

Mix property		ERA spec. limit		Asphalt Institute Spec. limit		STATUS
		LOWER	UPPER	LOWER	UPPER	
BC%	5.367	4	10	4	10	OK!
Air Void%	4	3	5	3	5	OK!
VFB%	74.22	65	75	65	75	OK!
VMA%	15.548	min. 13	-	min. 13	-	OK!
STABLITY(KN)	8.68	min. 7	-	min. 8	-	OK!
FLOW(mm)	3.381	2	4	2	4	OK!
BSG(gm/cm3)	2.331	2	4.5	2	4.5	OK!

Table 4.10 shows the marshal and volumetric results of mix obtained by interpolation from the graphs shown in Figure 4.5 at optimum bitumen content corresponding to the standard specification criteria. Based on this, the marshal results for volumetric and marshal properties of the mix such as Stability, flow value, VMA, bulk specific gravity and VFA at 5% CSD filler, and 5.367 % OBC full fill or satisfy ERA pavement Design Manual, 2013 and Asphalt Institute, 2014 Specification. This shows that mixes at 5% CSD filler and 5.367 % OBC met the criteria.

Table 4. 11Summary of volumetric and Marshal data at 5.5% CSD filler and 5.39 % OBC

Mix property		ERA spec. limit		Asphalt Institute Spec. limit		STATUS
		LOWER	UPPER	LOWER	UPPER	
BC%	5.39	4	10	4	10	OK!
Air Void%	4	3	5	3	5	OK!
VFB%	74.212	65	75	65	75	OK!
VMA%	15.48	min. 13	-	min. 13	-	OK!
STABLITY(KN)	9.744	min. 7	-	min. 8	-	OK!
FLOW(mm)	3.31	2	4	2	4	OK!
BSG(gm/cm3)	2.334	2	4.5	2	4.5	OK!

Table 4.11 shows the marshal and volumetric results of mix obtained by interpolation from the graphs shown in Figure 4.6 at optimum bitumen content corresponding to the standard specification criteria. Based on this, the marshal results for volumetric and marshal properties of the mix such as Stability, flow value, VMA, bulk specific gravity

and VFA at 5.5% CSD filler, and 5.39 % OBC full fill or satisfy ERA pavement Design Manual, 2013 and Asphalt Institute, 2014 Specification. This shows that mixes at 5.5% CSD filler and 5.39 % OBC met the criteria.

Table 4. 12Summary of volumetric and Marshal data at 6% CSD filler and 5.248 % OBC

Mix property		ERA spec. limit		Asphalt Institute Spec. limit		STATUS
		LOWER	UPPER	LOWER	UPPER	
BC%	5.248	4	10	4	10	OK!
Air Void%	4	3	5	3	5	OK!
VFB%	73.676	65	75	65	75	OK!
VMA	15.139	min. 13	-	min. 13	-	OK!
STABLITY(KN)	9.97	min. 7	-	min. 8	-	OK!
FLOW(mm)	3.41	2	4	2	4	OK!
BSG(gm/cm3)	2.342	2	4.5	2	4.5	OK!

Table 4.12 shows the marshal and volumetric results of mix obtained by interpolation from the graphs shown in Figure 4.7 at optimum bitumen content corresponding to the standard specification criteria. Based on this, the marshal results for volumetric and marshal properties of the mix such as Stability, flow value, VMA, bulk specific gravity and VFA at 6.0% CSD filler, and 5.248 % OBC full fill or satisfy ERA pavement Design Manual, 2013 and Asphalt Institute, 2014 Specification. This shows that mixes at 6.0% CSD filler and 5.248 % OBC met the criteria..

In this research the amount of conventional filler /CSD/ percentage utilized were 5%,5.5 %,6.0% and a total of 45 specimens of HMA mixtures were prepared at each percentage of CSD with five different bitumen contents /4%-6%/ at 0.5% increments. Table 4.13 shows that the summary of marshal properties of the mix prepared with different percentage of conventional filler content/CSD/ at their respective optimum bitumen content obtained by interpolation and comparison to the established specification according to ERA manual and Asphalt institute.

Table 4. 13 Summary of interpolated Marshal property result at three CSD filler percent with respect to their OBC

Properties	Crushed Stone Dust Filler			Specification	
	5.00%	5.50%	6.00%	ERA Spec.	Asphalt inst.
Bitumen, %	5.367	5.387	5.248	4-10%	4-10%
Air Voids, %	4	4	4	3-5%	3-5%
VMA, %	15.548	15.48	15.139	min. 13	min. 13
VFB,%	74.22	74.212	73.676	65-75%	65-75%
Stability, KN	8.68	9.744	9.97	min. 7	min. 8
Flow, mm	3.381	3.31	3.41	2-4mm	2-4mm
BSG, (gm/cm)	2.331	2.34	2.342	2-4.5	2-4.5

Table 4.13 shows that the marshal property and their interpolated result with respect to their optimum bitumen content/5.367%,5.39% and5.248%/ obtained previously and three different percentage of CSD filler content/5%, 5.5%, and 6%/. All marshal property results of the mix with three different filler content at their OBC are within the specification.

As shown in table 4.13 all volumetric and marshal values obtained at three different percentages of crushed stone dust filler with respect to their OBC were within the specification range. In this study, a mixture resulting with highest stability and lower bitumen content from alternative filler content were selected as design mix. Depending up on this, a mix with a highest stability was obtained at 6.0% filler content. So that,6.0% conventional filler content /CSD/ and the corresponding 5.248% optimum bitumen content was selected as a final mix design/control mix/ used for the replacement of conventional filler/CSD/ by Non –Conventional filler /SCBA and GSA/. Additionally, this result was used to evaluate and compare the effect of SCBA and GSA in a mix and determine their optimum replacement percentage.

4.5 The effect of SCBA and GSA on Marshall properties of HMA

In this study, thirty three/33/sets of bituminous mixtures were used to evaluate and compare the effect of replacing varying percentages of the conventional filler /CSD/ with SCBA and GSA on Marshal Stability, Flow and different volumetric properties of HMA mixture. The effect of SCBA and GSA on the Marshal properties of HMA were determined and compared using mixes prepared with optimum filler content /6.0%/ and design bitumen content/5.248%/ obtained previously as a control mix design, and by partially replacing crushed stone dust with sugarcane bagasse ash/SCBA/ at six different percentages that was 0%/control mix/,5%,10%,15%,20%,25 and 100% and four different percentage of GSA that was 0%control mix,5%,10%,15% and 100% by weight of conventional filler content/CSD/ with a minimum of three trial specimens each.

The test results of all Marshall Properties of mixes prepared using the design asphalt content of 5.248% and different replacement percentage of CSD filler content by SCBA and GSA are summarized in Table 4.14 and Table 4.15 respectively.

Table 4. 14 Summary of volumetric and Marshall data of mix at design bitumen content of 5.248% and different proportion of SCBA and CSD filler

Replacement % of CSD by SCBA	Sample no.	Bulk density	VIM(%)	VMA(%)	VFA(%)	stability(KN)	Flow (mm)
0%SCBA+ 100%CSD (Control)	1	2.318	4.345	15.924	72.711	9.41	3.23
	2	2.32	4.252	15.842	73.157	9.17	2.98
	3	2.319	4.282	15.867	73.016	9.54	3.11
	Average	2.319	4.293	15.878	72.961	9.37	3.11
5%ASCB+ 95%CSD	1	2.314	4.386	16.063	72.697	9.74	3.12
	2	2.311	4.499	16.162	72.165	8.87	3.23
	3	2.31	4.541	16.2	71.967	10.02	3.43
	Average	2.312	4.475	16.142	72.275	9.54	3.26
10%SCBA+ 90%CSD	1	2.312	4.231	16.136	73.776	10.09	2.73
	2	2.312	4.224	16.13	73.811	9.91	3.41
	3	2.312	4.218	16.124	73.84	9.63	3.21
	Average	2.312	4.225	16.13	73.809	9.88	3.12
15%SCBA+ 85%CSD	1	2.314	4.0	16.068	74.88	10.07	3.89
	2	2.314	4.04	16.07	74.88	10.21	3
	3	2.316	3.96	16.003	75.25	10.18	3.48
	Average	2.314	4.0	16.047	75.00	10.15	3.46
20%SCBA+ 80%CSD	1	2.321	4.149	15.821	73.772	9.24	2.74
	2	2.316	4.345	15.993	72.83	9.41	2.98
	3	2.311	4.543	16.166	71.9	9.62	3.17
	Average	2.316	4.346	15.993	72.827	9.42	2.96
25%SCBA+ 80%CSD	1	2.316	4.222	15.989	73.595	8.32	4.15
	2	2.313	4.33	16.083	73.08	8.88	4.06
	3	2.322	3.989	15.784	74.729	8.65	4.21
	Average	2.317	4.181	15.952	73.794	8.62	4.14
100%SCBA	1	2.311	4.088	16.15	74.685	8.58	4.46
	2	2.32	3.752	15.856	76.338	8.02	4.17
	3	2.296	4.728	16.709	71.703	8.44	5.04
	Average	2.309	4.189	16.24	74.203	8.35	4.56

Table 4. 15 Summary of volumetric and Marshall data of mix at design bitumen content of 5.248% and different proportion of GSA and CSD filler

Replacement % of CSD by GSA	Sample no.	Bulk density	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
0%GSA+ 100%CSD (Control)	1	2.318	4.345	15.924	72.711	9.41	3.23
	2	2.32	4.252	15.842	73.157	9.17	2.98
	3	2.319	4.282	15.867	73.016	9.54	3.11
	Average	2.319	4.293	15.878	72.961	9.37	3.11
5%GSA+ 95%CSD	1	2.313	4.514	16.107	71.972	9.64	3.24
	2	2.318	4.3	15.918	72.987	9.27	3.19
	3	2.319	4.241	15.866	73.272	9.34	3.31
	Average	2.317	4.352	15.964	72.74	9.42	3.25
10% GSA+ 90%CSD	1	2.324	4.006	15.695	74.475	9.31	3.38
	2	2.324	3.99	15.686	74.525	10.15	3.47
	3	2.324	4.021	15.708	74.4	9.81	3.45
	Average	2.324	4.00	15.696	74.467	9.76	3.433
15 GSA+ 85%CSD	1	2.317	4.25	15.944	73.343	9.16	4.28
	2	2.312	4.471	16.138	72.294	10.19	4.71
	3	2.322	4.06	15.777	74.268	9.78	4.49
	Average	2.317	4.26	15.953	73.294	9.71	4.49
100% GSA+ 0%CSD	1	2.31	4.34	16.196	73.206	8.98	4.96
	2	2.315	4.153	16.033	74.095	9.26	4.57
	3	2.32	3.943	15.849	75.121	9.64	5.04
	Average	2.315	4.145	16.026	74.134	9.29	4.86

Tables 4.14 and table 4.15 shows a laboratory test results of the asphalt mixtures prepared using SCBA and GSA filler at different replacement percentage of CSD and their corresponding volumetric and marshal property values of at a design bitumen of 5.248% respectively. In the following section, the relationship and effects of varying amounts of SCBA and GSA on asphalt mixture properties are discussed.

Table 4. 16 Summary of Marshal Properties of mixes at the different proportion of CSD and SCBA

Replacement % of CSD with SCBA	BSG	VIM(%)	VMA(%)	VFB(%)	Stability (KN)	Flow (mm)
0%	2.319	4.29	15.878	72.961	9.373	3.107
5%	2.312	4.47	16.142	72.275	9.543	3.26
10%	2.312	4.23	16.13	73.809	9.877	3.117
15%	2.314	4.01	16.047	75.007	10.153	3.457
20%	2.316	4.35	15.993	72.827	9.423	2.963
25%	2.317	4.18	15.952	73.794	8.617	4.14
100%	2.309	4.19	16.24	74.203	8.347	4.557

Table 4. 17 Summary of Marshal Properties of mixes at the different proportion of CSD and GSA

Replacement % of CSD with GSA	BSG	VIM(%)	VMA(%)	VFB(%)	Stability(KN)	Flow(mm)
0	2.319	4.293	15.878	72.961	9.373	3.107
5	2.317	4.352	15.964	72.74	9.417	3.247
10	2.324	4.008	15.696	74.467	9.757	3.433
15	2.317	4.26	15.953	73.294	9.71	4.493
100	2.315	4.145	16.026	74.134	9.293	4.857

4.5.1 Effect of SCBA and GSA on Marshall flow

As it is clearly shown in Figure 4.8, the Marshal flow values obtained from the laboratory prepared mixes by partially replacing CSD filler with GSA and SCBA filler types, meet the Marshal criteria /2.0mm – 4.0mm/ except for mixture prepared using 15%,100% GSA and 25% ,100% SCBA which exceeds the maximum specification limit.

Results indicated that the flow value of mixtures containing 5% and 10%GSA filler replacement were greater than control mixture, and the values show an increasing trend by increase in GSA percentages. On the other hand, addition of SCBA filler partially to the mixture, led to increase the flow values except for 20%SCBA replacement which decreased and it had increasing and decreasing trend by addition of higher replacement percentage of SCBA on crushed stone dust filler. So, it could be concluded from the results that by addition of GSA at 5%,10% replacement proportion and SCBA at5%.10%,15% replacement proportion the flow value increased but decreased at 20%SCBA replacement percent. As shown on Fig.8, samples modified with GSA have higher flow values than samples comprising SCBA at equivalent replacement percent satisfying the minimum requirement for flow stated on ERA pavement manual and Asphalt institute manual.

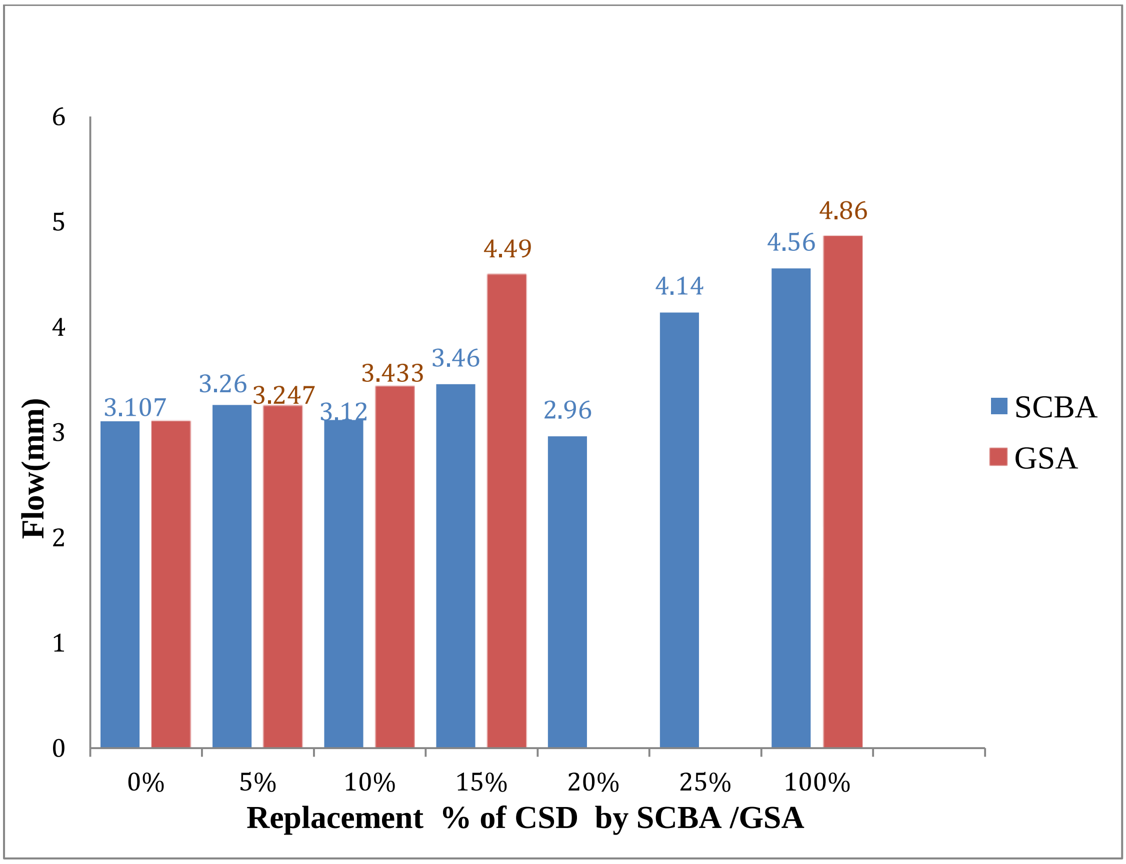


Figure 4. 8 Relationship between flow and replacement proportion of SCBA & GSA at a design bitumen content of 5.248%

4.5.2 Effect of SCBA and GSA on VFA

Effect of filler types on the voids filled with asphalt property of the mixture is indicated on Figure 4.9. The values of voids filled with asphalt are greater than70% for all types of fillers with respect to their replacement proportion, where the Marshal Criteria for VFA is 65% - 75%. This criterion is important for the durability of mixes and is related to the effective asphalt content in the mix. If the percentage of voids filled with asphalt is lower than the limit indicated, there will be less asphalt film around the aggregate particles. Lower asphalt films are more subjected to moisture and weather effects where they can be detached from the aggregate particles and subsequently lower performance. On the other hand, if the limit is exceeded, more voids are filled with asphalt than required for durability.

As shown in Figure 4.9, mixes prepared with 5% GSA and 5%, 20% SCBA replacement results a minimum value of voids filled with asphalt binder and mixes prepared with other replacement percentage of both additives yields a maximum value of voids filled with asphalt binder compared to the control mix prepared using CSD filler. However, in this study all the VFA results for all replacement percentage meet the established criteria stated in ERA pavement manual and Asphalt institute manual MS-2.

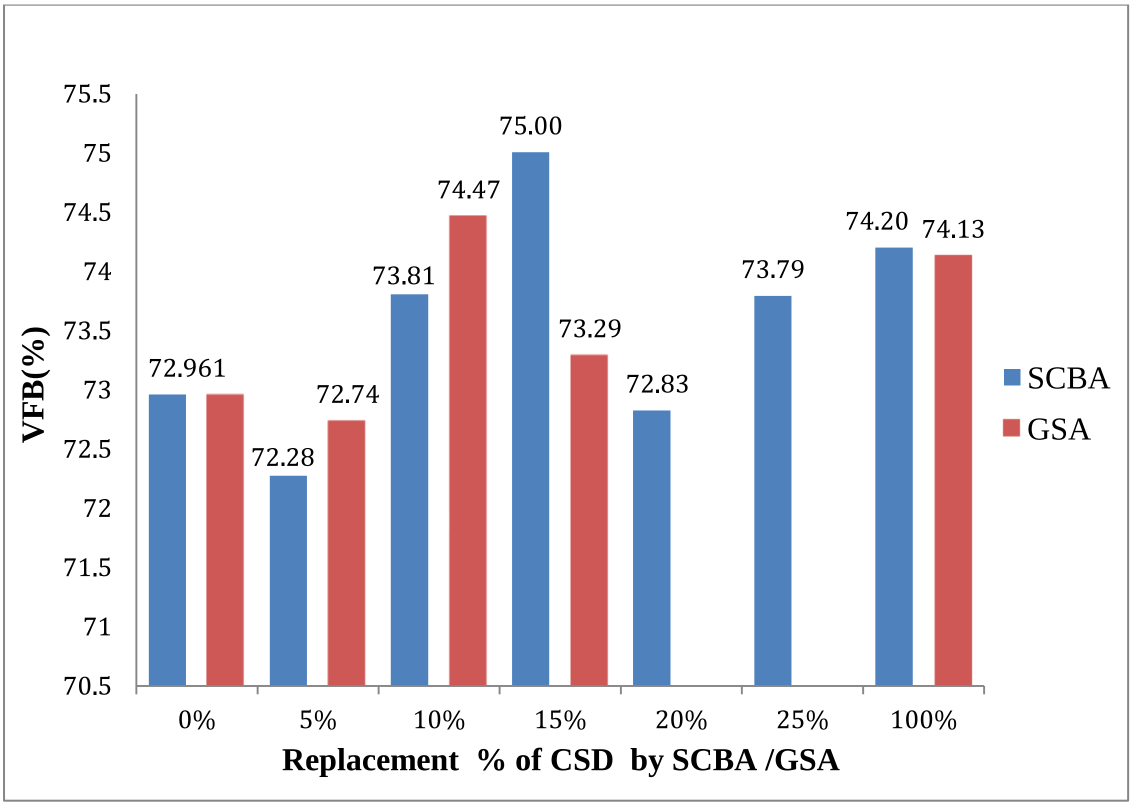


Figure 4. 9 Relationship between VFB and replacement proportion of SCBA & GSA at a design bitumen content of 5.248%

4.5.3 Effect of SCBA and GSA on VMA

The effect of partially replacing CSD with SCBA and GSA fillers on voids in mineral aggregate was also evaluated and the results are shown in Figure 4.10. As can be seen from Figure 4.10, mixtures prepared using both SCBA and GSA filler types partially replacing CSD filler showed that as the replacement percentage in the mixes increase, the voids in mineral aggregate increase except for 10% GSA replacement compared to VMA of the control mix. Higher voids in mineral aggregate were obtained from mixes prepared with SCBA for all CSD filler replacement percentage as compared to mixes prepared by replacing CSD filler with GSA at different percent.

Minimum VMA is necessary in mixtures to accommodate enough asphalt content, so that aggregate particles can be coated with adequate asphalt film thickness. This consequently results in a durable asphalt paving mixtures.

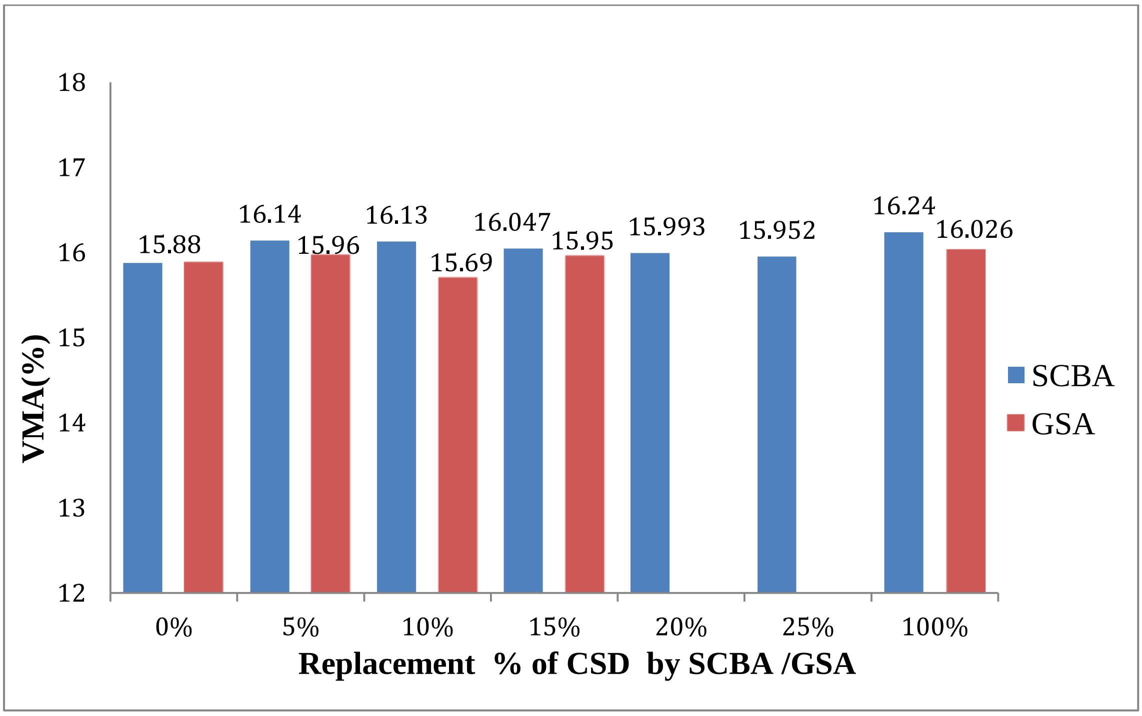


Figure 4. 10 Relationship between VMA and replacement proportion of SCBA & GSA at a design bitumen content of 5.248%

4.5.4 Effect of SCBA and GSA on Marshall stability

The results of Marshall stability for different mixtures were indicated on Figure 4.11. As depicted in Figure 4.11, Marshall stability of a mixtures containing 5% SCBA, 10% SCBA, 15% SCBA and 20% SCBA increases however, it decreases for mixtures prepared with 25%SCBA and 100%SCBA filler compared to control mix stability. Marshall stability of mixtures has increasing trend as the percentage of SCBA increase except for higher replacement percentages i.e. 25%SCBA and 100%SCBA.Replacing 15% of conventional filler by SCBA, cause to increase Marshall stability almost 7.7%. Also, as can be seen from Figure 4.11,Marshall stability of asphalt mixtures increases by addition of GSA while partially replacing CSD filler at different percent. Marshall stability of mixtures has increasing trend as the percentage of GSA increase compared to control mix stability. As the percentage of GSA increases the Marshall stability increases, which means that the GSA has positive effect on stability of mixture. As it can be seen from Figure 4.11 a mixture with maximum stability using GSA was achieved at 10%GSA replacement which increased the stability almost 4%. Results indicated that replacing of conventional filler with GSA and SCBA stiffens the binder and led to increase the cohesion of bitumen and it has a positive influence on adhesion of bitumen to aggregates in mixture.

This indicates that both fillers, SCBA and GSA are finer than crushed stone dust which is used as conventional mineral filler in this research. Moreover, anything that increases the viscosity of the asphalt cement increases the Marshal stability. Higher marshal stability was obtained from mixes prepared with SCBA for all CSD filler replacement percentage as compared to mixes prepared by replacing CSD filler with GSA at equivalent replacement percent

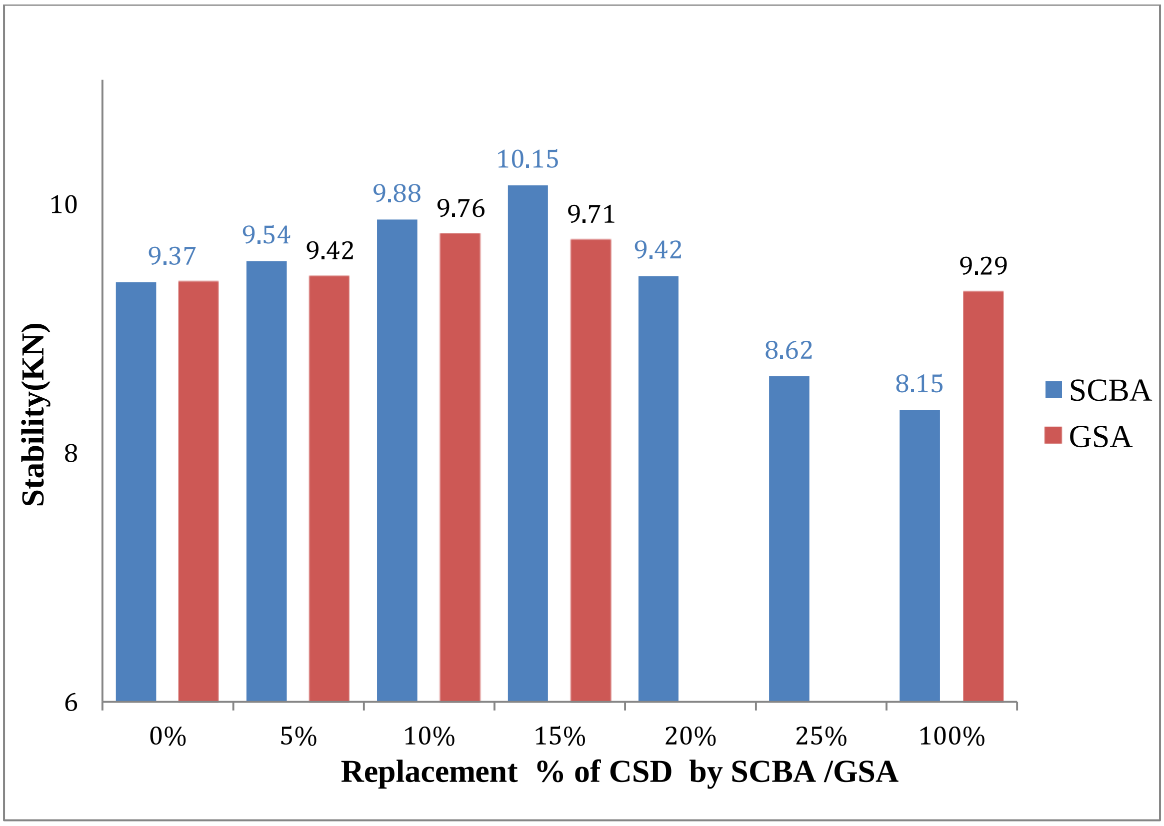


Figure 4. 11 Relationship between stability and replacement proportion of SCBA & GSA at a design bitumen content of 5.248%

4.5.4 Effect of SCBA and GSA on VIM

The durability of asphalt pavement is a function of the air void content of the in-place HMA pavement. The lower air voids provide, the less permeable the mix becomes. Figure 4.12 indicates the relationship between percent air voids in total mix and different replacement percentage of SCBA and GSA. As can be seen from Figure 4.12 the results of air voids for all replacement percentages of SCBA and GSA is within the range of 3-5% as specified on ERA pavement manual 2013 and Asphalt institute 2014. Asphalt mixes prepared with 10% GSA and 15% SCBA had the lowest percentage of air voids

/4.0%/ at 5.248% design asphalt binder content relative to the value obtained for mixes prepared with the rest of replacement percent and control mix.

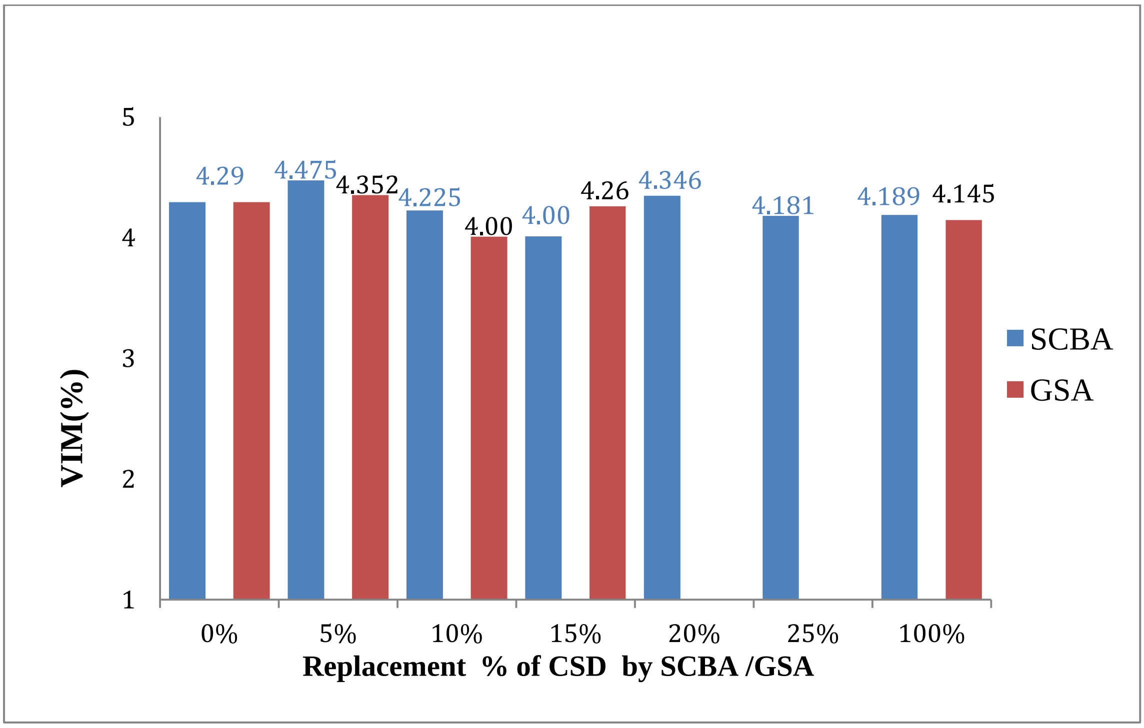


Figure 4. 12 Relationship between VIM and replacement proportion of SCBA & GSA at a design bitumen content of 5.248%

4.5.5 Effect of SCBA and GSA on BSG

The effect of both non-conventional filler types namely /SCBA and GSA/ and their replacement percentage on the unit weight of compacted mixes is shown on Figure 4.13. Mixes prepared with SCBA filler showed a trend of increase in unit weight as the replacement percentage increases, while for mixes made with GSA increases up to maximum and then decreases as the replacement percentage increases. It is shown that at all CSD filler replacement percentages, mixes made with GSA possessed higher unit weight as compared to mixes made with SCBA. However, when the unit weight of mixes prepared by partially replacing CSD with SCBA and GSA is compared to the control mix, the control mix have greater unit weight except for mixes prepared with 10% GSA replacing CSD. The results obtained show a wide variability in unit weight for respective filler type and content, and hence it would be difficult to give an explanation on filler type effects.

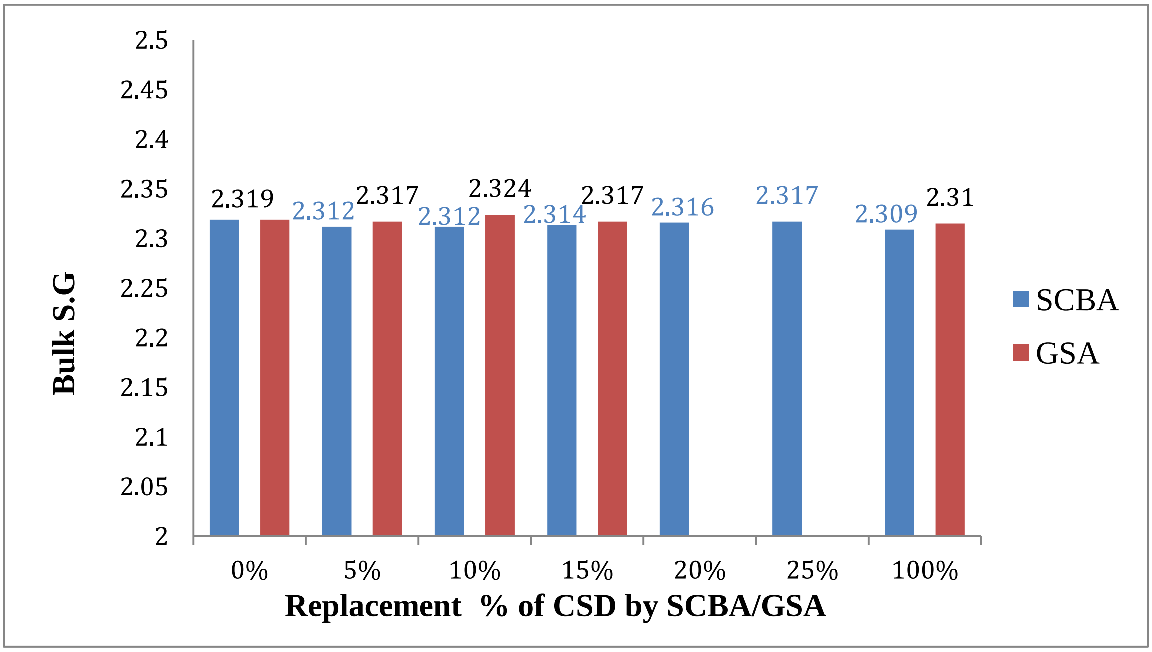


Figure 4. 13 Relationship between VMA and replacement proportion of SCBA & GSA at a design bitumen content of 5.248%

4.6 Indirect Tensile Strength test results and analysis

To evaluate the influence of the two filler on tensile strength and water resistance of samples, the ITS test was implemented. Mixtures with greater amounts of ITS and TSR have better resistance against water. The ITS results of control and samples with different fillers/SCBA and GSA/ and percentage are indicated in Figure 4.14.

4.6.1 The effect of SCBA and GSA on moisture susceptibility of HMA

The results of ITS and TSR for different mixtures were tabulated and indicated on Table 4.18 and Figure 4.14-4.15,respectively. As depicted in Figure 4.14, results indicated that the ITS value of mixtures containing SCBA and GSA filler were greater than control mixture. In addition, the ITS values increases by increase in SCBA and GSA replacement percentages and it had increasing trend by addition of higher percentage of SCBA and GSA filler. The more the cohesive of binder to aggregate, the greater the ITS value. So, it could be concluded from the results that by addition of both SCBA and GSA filler the cohesion and adhesion of asphalt binder to aggregate increase. As shown on Figure 4.14, mixtures prepared with SCBA have higher ITS values than samples comprising GSA filler.

Table 4. 18 Summary of indirect tensile strength test result

Filler Type	Additive Replacement Percent	Average ITS(kPa)		TSR(%)	Specification >=70%
		conditioned	unconditioned		
CSD	Control(0%)	560.8769863	646.59208	86.7435598	OK!
GSA	5%GSA+95%CSD	571.7374996	651.05562	87.8169973	OK!
	10%GSA+90%CSD	580.7192257	655.31428	88.6169037	OK!
SCBA	5%SCBA+95%CSD	574.8140667	652.24530	88.1285093	OK!
	10%SCBA+90%CSD	583.0256349	655.83013	88.8988786	OK!
	15%SCBA+85%CSD	592.5280576	663.7669	89.2674897	OK!
	20%SCBA+80%CSD	571.4505501	652.5223401	87.57563	OK!

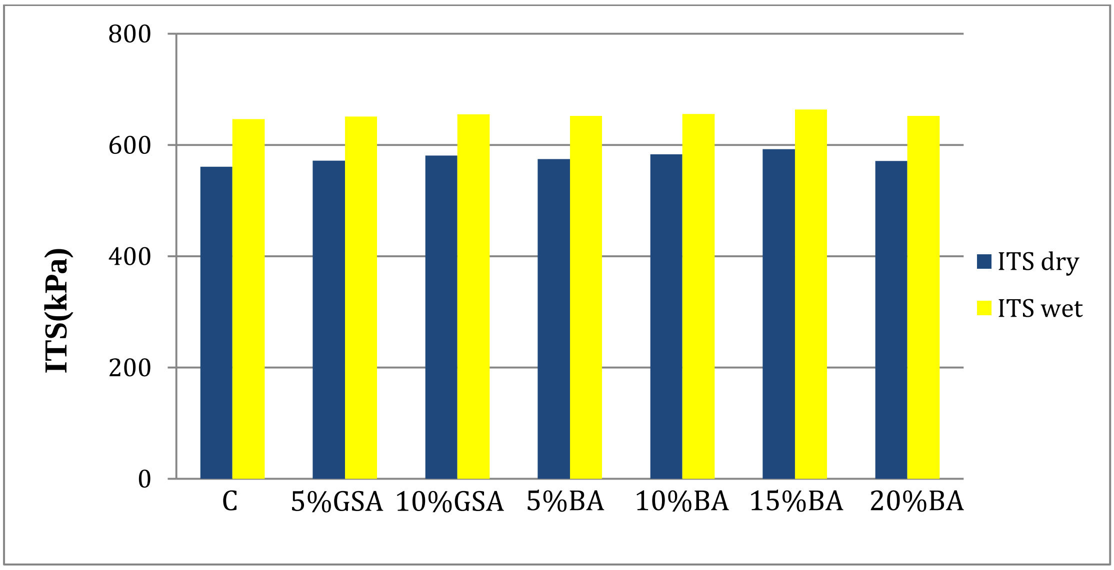


Figure 4. 14 ITS values of mixtures at a design bitumen content of 5.248% and additives

TSR values of different mixtures were depicted on Figure 4.15 showing that the increase in the amount of SCBA and GSA content leads to higher hydrophobic nature of mix, and consequently, when conditioning it in water for 24 hours at 60˚C the SCBA and GSA resists the washing effect of water and eventually resulting in higher tensile strength.

As can be seen from the results, all the mixtures met the minimum requirement of specification which is considered as 70%. Based on the results, mixtures containing

SCBA have better performance against moisture conditioning than GSA replaced mixtures and control mix.

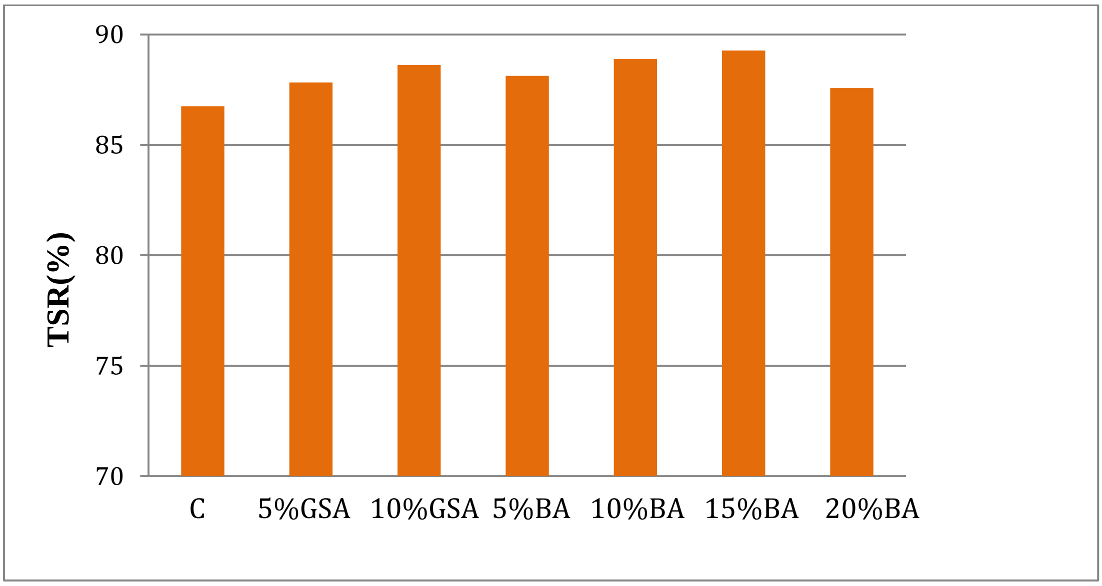


Figure 4. 15 TSR values of mixtures at a design bitumen content of 5.248% and varying amount of additives

4.7 Summary of the effect of SCBA and GSA on properties of HMA

Table 4. 19 Summary on effects of SCBA and GSA on marshal and tensile property of HMA

Addit i-ve type	Additive Replace-ment percentage with CSD	Conventio-nal filler (CSD)%	Volumetric and Marshall results						Moisture susceptibil-ity result
			BSG (gm/cm3)	VIM (%)	VMA (%)	VFB (%)	Stability(KN)	Flow (mm)	TSR(%)
			ERA manual Specification						
				3-5	Min13	65-75	Min7	2- 4	>=70
GSA	0%	100%	2.319	4.29	15.878	72.961	9.37	3.11	86.744
	5%	95%	2.317	4.352	15.964	72.74	9.42	3.25	87.817
	10%	90%	2.324	4.008	15.696	74.467	9.76	3.43	88.617
	15%	85%	2.317	4.26	15.953	73.294	9.71	4.49	-
	100%	0%	2.315	4.145	16.026	74.134	9.29	4.86	-
SCBA	0%	100%	2.319	4.29	15.878	72.961	9.37	3.11	86.744
	5%	95%	2.312	4.475	16.142	72.275	9.54	3.26	88.1285
	10%	90%	2.312	4.225	16.13	73.809	9.88	3.12	88.898
	15%	85%	2.314	4.01	16.047	75.00	10.15	3.46	89.2675
	20%	80%	2.316	4.346	15.993	72.827	9.42	2.96	87.5756
	25%	75%	2.317	4.181	15.952	73.794	8.62	4.14	-
	100%	0%	2.309	4.189	16.24	74.203	8.35	4.56	-

Table 4.19 shows that the effect of both non-conventional filler types namely /SCBA and GSA/ and their replacement percentage on the volumetric, marshal and tensile property of mixes. As can be seen from table 4.19, the replacement percentage of CSD with GSA stopped at 15% whereas for SCBA the replacement percentage stopped at 25% this was because of mixes prepared with both additives at those replacement percentage didn't satisfy all marshal criteria. As shown in Table 4.19, flow value for mixes prepared by partially replacing CSD filler with GSA as well as SCBA at 10% and 25% is 4.49mm and 4.14mm respectively which is beyond the minimum requirement/2 - 4mm/ specified by ERA pavement manual. As tabulated in Table 4.19, indirect tensile strength test/moisture susceptibility test/ was conducted on mixes prepared with 0%(control),5%,10% GSA and 5%,10%,15%,20% SCBA because at these replacement percentages all marshal criteria specified by ERA pavement manual and Asphalt institute were satisfied. As can be seen from table 4.19, mixes prepared with SCBA filler possessed better performance compared to the control mix as well as mixes prepared with GSA in terms of marshal stability and moisture susceptibility.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The main objectives of this research work is to investigate the effect sugarcane bagasse ash and groundnut shell ash on hot mix asphalt as filler material, where the results can be concluded as the following.

- The possible use of industrial by-product and agriculture waste /such as SCBA and GSA/ in pavement construction as Partial replacement of CSD will considerably reduce the cost of construction and reduce or eliminate the environmental hazards caused by such wastes due to inappropriate disposal; hence this can help in the actualization of the phrase “waste to wealth”.
- The desirable properties of constituent materials that were used in this study to prepare hot mix asphalt such as aggregates, bitumen and mineral fillers satisfy all the required value specified by the relevant standards and ERA pavement manual. Therefore, they can be used in the design of asphalt pavement.
- The recommended properties of mineral filler in terms of pozzolanic characteristics was met by SCBA and GSA since the combined percentage of Silica, Aluminum and Iron oxides meets the specification in ASTM standard C618 for class C pozzolana /$Si02 + Al203 + Fe203 >= 50\%$/.
- According to Marshall test results, partially replacing crushed stone dust by sugarcane bagasse ash and groundnut shell ash at 15% and 10% respectively resulted in Maximum bulk density, Maximum stability in addition to Va %content/4%/ within the allowed range of control specification.
- Therefore, the Optimum GSA and SCBA content to be partially replaced with crushed stone dust/CSD/ in asphalt concrete mix should be 10% and 15% respectively.
- Based on the results of ITS test, substitution of CSD filler with SCBA and GSA at different percentages satisfying all marshal criteria led to increase the ITS values compared to control mix. The improvement in adhesion and also cohesion of bitumen to aggregate might be the reason for this result. Specimens with SCBA have greater ITS values in comparison with specimens with GSA.

- Depending on moisture susceptibility test results, using both SCBA and GSA filler enhanced the moisture susceptibility of specimens compared to CSD. However, GSA filler increased the water sensitivity of specimens compared to SCBA.

5.2 RECOMMENDATION

- Further studies are needed using various gradation and different percentages of SCBA and GSA content.
- Groundnut shell ash and sugarcane bagasse ash as investigated in this research work can be used as a crushed stone dust replacing material with economical, technical and environmental benefits. Therefore, concerned bodies like sugar industries, farmers cultivating groundnut and government entities should be made aware about this potential conventional filler/CSD/ replacing material and promote its standardized production and usage
- Sugar factories and agricultural sectors working on oil seeds in collaboration with higher education organizations in the country should work together and establish a research team to further study the use of groundnut shell ash and sugarcane bagasse ash as a conventional filler replacing material.

Further studies are required on the following items:

- Studies should be made using controlled burning of the bagasse and groundnut husk/shell/ at different temperature
- As presented earlier in this research, groundnut is widely cultivated in different regions of Ethiopia. So, the groundnut shell ash from different sources should be studied.
- Sugarcane bagasse ash from different sources like, Arjo dediesa, Metahara, Finchaa and the coming new sugar factories should be studied.
- Studies should be made to check the chemical composition of sugarcane bagasse ash and groundnut shell ash using more advanced methods.

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APPENDEX A

Physical properties, Aggregate, Bitumen and Mineral filler quality tests

Table A1 Physical properties of Aggregate

Test	Test Method	Test Result				Specification
		25-13mm	13-6mm	6-3mm	3-0mm	
Bulk Spec. gravity (Dry)	AASHTO T 85-84	2.637	2.613	2.60	2.5999	
Bulk Spec. gravity(SSD)		2.669	2.657	2.684	2.675	
Apparent Spec. gravity		2.724	2.734	2.86	2.851	
Water Absorption, %	BS 812 Part 2	1.213	1.695	1.777		<2
Flakiness Index	BS 812 Part 108	22				<45
Aggregate Crushing Value(ACV), %	BS 812 Part 3	12				<25
AggregateImpact Value(AIV), %	BS 812 Part 3	12.59				
Los Angeles Abrasion(LAA)	AASHTO T 96	12.875				< 30
Sand Equivalent	ASTM D 2194				75.47	
Surfacearea(m2/ kg • 5% • 5.5% • 6.0%		4.1107 4.3106 4.5107				- - -

Table A2 Los Angeles Abrasion Test Result of Aggregate

Sieve size		Mass of indicated size(g)			
		Grading with their respective no. of Steel Balls			
Passing (mm)	Retained on (mm)	A 12 Balls	B 11 Balls	C 8 Balls	D 6 Balls
37.5	25	1250 ± 25			
25	19	1250 ± 25			
19	12.5	1250 ± 10	2500 ± 10		
12.5	9.5	1250 ± 10	2500 ± 10		
9.5	6.3			2500 ± 10	
6.3	4.75			2500 ± 10	
4.75	2.36				5000 ± 10
TOTAL		5000 ± 10	5000 ± 10	5000 ± 10	5000 ± 10
TEST RESULT(AASHTO T 96)					
Grading		A	B	C	D
No. of revolution		500 rev.	500 rev.	500 rev.	500 rev.
Mass of sample before test M1 (g)		500	500	500	500
Mass retained on sieve size 1.7mm		4362	4358	4349	4255

M2 (g)				
Mass passing on sieve size 1.7mm M3(g)=(M1-M2)	638	642	651	644
LAA value=(M3/M1)*100	1276	12.84	13.02	12.88

Table A3 Aggregate Crushing Value Test Result of Aggregate

TEST METHOD BS:812 PART 110(1990)			
Trial No**.**	**1**	**2**	**3**
Mass of sample(14mm pass and 10mm retain) M1	2297	2292	2295
Mass of sample passing on 2.36mm sieve M2	281	278	283
Mass of sample retained on 2.36mm sieve M3	2016	2013	2012
Aggregate crushing value (ACV)	12.23334	12.1291	12.331
Average ACV	**12**		

Table A4 Aggregate Impact Test Result

TEST METHOD BS:812 PART 110(1990)			
Trial No**.**	**1**	**2**	**3**
A) Weight of mold,g	2750.4	2750.4	2750
B) Weight of mold + sample(9.5mm retain),g	3341.9	3344.2	3338.8
C) Weight of aggregate,g	591.5	593.8	588.8
D) Mass of agg. Passing 2.36mm,g	517.3	518.6	514.7
E) Mass of agg. Retained on 2.36mm,g	74.2	75.2	74.1
E) Aggregate impact value (AIV)	12.5444	12.664	12.5849
Average AIV to the nearest integer	**12.59783129**		

Table 5A Sand Equivalent Test Result of Aggregate

Test Method: AASHTO T 176-86			
Test No.	1	2	3
A. Sand reading, mm	97	96	95
B. Clay reading, mm	128	126	127.6
Sand Equivalent(A/B)*100	75.78125	76.1904	74.4514
Average	**75.47437895**		

Table A6 Specific gravity and Absorption of Coarse aggregate (CA) (13-25mm)

Trial	1	2	3
Weight of sample, g	2000	2000	2000
Weight of sample+ vessel+ water(A),g	1725.7	1724.7	1723.9
Weight of vessel+ water(B),g	460.7	460.9	460.8
Weight of SSD sample(C), g	2020.4	2022.1	2021.3
Weight of oven dry sample(D),g	1996.1	1997.6	1997.4
Bulk Specific gravity(oven dry)= D/(C-(A-B))	2.642441	2.634314	2.634397
Bulk spec. gravity(SSD)=C/(C-(A-B))	2.674609	2.666623	2.665919
Apparent Specific gravity= D/(D-(A-B))*100	2.730269	2.722268	2.720142
Average Bulk Specific gravity(oven dry)	**2.637051**		
Average Bulk Specific gravity(SSD)	**2.66905**		
Average Apparent Specific gravity	**2.724226**		
Water Absorption, percentage dry weight= (C-D)/D*100	1.217374	1.226472	1.196556
Average	**1.213467**		

Table A7 Specific gravity and Absorption of Intermediate aggregate (IA1) (6-13mm)

Trial	1	2	3
Weight of sample, g	2000	2000	2000
Weight of sample+ vessel+ water(A),g	1722.5	1723.6	1721.9
Weight of vessel+ water(B),g	460.3	458.5	459.2
Weight of SSD sample(C), g	2025.4	2027.2	2024.1
Weight of oven dry sample(D),g	1991.5	1992.6	1991.3
Bulk Specific gravity(Dry)= D/(C-(A-B))	2.609408	2.614618	2.615314
Bulk spec. gravity(SSD)=C/(C-(A-B))	2.653826	2.660018	2.658392
Apparent Specific gravity= D/(D-(A-B))*100	2.730701	2.738969	2.73305
Average Bulk Specific gravity(oven dry)	**2.613113**		
Average Bulk Specific gravity(SSD)	**2.657412**		
Average Apparent Specific gravity	**2.73424**		
Water Absorption, percentage dry weight= (C-D)/D*100	0.017022	0.017364	0.016472
Average	**0.016953**		

Table A8 Specific gravity and Absorption of Intermediate aggregate (IA2) (3-6mm)

Trial	1	2	3
Weight of sample(gm)	250	250	250
A. Mass of pycnometer + water (gm)	680.4	680.4	680.4
B. Mass of pycnometer + water + sample(gm)	839.2	840.5	839.9
C. Weight of SSD sample(gm)	253.4	254.1	253.6
D. Mass of oven dry sample(gm)	245.2	244.7	244.9
Observed T^O of water, Ti	24^Oc	24^Oc	24^Oc
k=			
T^O when Mpsw was taken, Tx	24^Oc	24^Oc	24^Oc
K for Tx	1.0003	1.0003	1.0003
Specific gravity(SSD), Gs = C*k/(C-(A-B))	2.679451	2.686852	2.686852
Specific gravity(dry), Gs = D*k/(C-(A-B))	2.592744	2.603972	2.603331
Apparent Specific gravity= D*k/(D-(A-B))*100	2.838814	2.893303	2.868542
Water Absorption, % dry weight= (C-D)/D*100	1.774878	1.780548	1.780548
Average Specific gravity(SSD),	**2.684385**		
Average Apparent Specific gravity	**2.866886**		
Average Gs(dry) at 20^Oc	**2.600016**		

Table A9 Specific gravity and Absorption of Fine aggregate (FA) (0-3mm)

Trial	1	2	3
Weight of sample(gm)	250	250	250
A. Mass of pycnometer + water (gm)	680.8	680.8	680.8
B. Mass of pycnometer + water + sample(gm)	840.9	841.7	840.8
C. Weight of SSD sample(gm)	255.6	255.4	255.1
D. Mass of oven dry sample(gm)	247.7	246.9	246.3
Observed T^O of water, Ti	24^Oc	24^Oc	24^Oc
k=			
T^O when Mpsw was taken, Tx	24^Oc	24^Oc	24^Oc
K for Tx	1.0003	1.0003	1.0003
Specific gravity(SSD), Gs = C*k/(C-(A-B))	2.677243	2.675148	2.675148
Specific gravity(Dry), Gs = D*k/(C-(A-B))	2.594495	2.613482	2.590682
Apparent Specific gravity= D*k/(D-(A-B))*100	2.828474	2.871792	2.854854
Average Gs(SSD) at 20^Oc	**2.675846**		
Average Gs(apparent) at 20^Oc	**2.851706**		
Average Gs(dry) at 20^Oc	**2.599553**		

Table A10 Specific gravity of CSD filler

Material type	Crushed stone dust		
	1	2	3
A. Mass of oven dry sample(gm)	25	25	25
B. Mass of pycnometer + water (gm)	127.34	127.66	127.52
C. Mass of pycnometer + water + sample(gm)	142.76	143.2	142.99
Observed T^O of water, Ti	24^Oc	24^Oc	24^Oc
k=			
T^O when Mpsw was taken, Tx	24^Oc	24^Oc	24^Oc
K for Tx	1.0003	1.0003	1.0003
Specific gravity 20^Oc, Gs = A*K/(A+B-C)	2.610386	2.643499	2.624082
Average Gs at 20^Oc	**2.625989**		

Table A11 Specific gravity of GSA filler

Material type	Groundnut shell ash	
Trial	1	2
A. Mass of oven dry sample(gm)	25	25
B. Mass of pycnometer + water (gm)	126.44	127.52
C. Mass of pycnometer + water + sample(gm)	138.9	140.2
Observed T^O of water, Ti	24^Oc	24^Oc
k=		
T^O when Mpsw was taken, Tx	24^Oc	24^Oc
K for Tx	1.0003	1.0003
Specific gravity 20^Oc, Gs = A*K/(A+B-C)	1.9942	2.0135
Average Gs at 20^Oc	**2.003852**	

Table A12 Specific gravity of SCBA filler

Material type	Bagasse ash	
Trial	1	2
A. Mass of oven dry sample(gm)	25	25
B. Mass of pycnometer + water (gm)	124.37	127.22
C. Mass of pycnometer + water + sample(gm)	136.96	139.31
Observed T^O of water, Ti	24^Oc	24^Oc
k=		
T^O when Mpsw was taken, Tx	24^Oc	24^Oc
K for Tx	1.0003	1.0003
Specific gravity 20^Oc, Gs = A*K/(A+B-C)	2.015109	1.937064
Average Gs at 20^Oc	**1.976087**	

Table A13 Bitumen quality Test Results

Test type	Test Method	Trial No.	Test Temperature (°C)	Testing time (sec)	Test load (gm)	Reading data(mm/10)			Average (mm/10)
Penetration	ASTM D5	1	25	5	100	66	65	64	65
		2	25	5	100	65	65	66	65.333
		3	25	5	100	66	64	66	65.333
	Average Penetration								65.222
Ductility	Test Method	Trial No.	Test Temperature (°C)	Speed (cm/min)	Ductility(cm)				Average
	ASTM D113	1	25	5	117				120.33
		2	25	5	121				
		3	25	5	123				
Softening point	Test Method	Trial No.	Temp. when starting to heat (°C)	Record of liquid temp. in a beaker: 5min	6min	7min	Softening point(°C)		Average
	ASTM D36	1	7°C	5 min			52.4		
		2	7°C	5 min			54.1		
		3	7°C	5 min			51.6		52.7
Flash point	Test Method	Trial No.	Flash point Temp. (°C)		Fire point Temperature (°C)				Average Temp. (°C)
	ASTM D92	1	278						279
		2	280						
Fire point		1			312				314
		2			316				

Table A14 Effective bitumen content

Filler content	5%			5.5%			6%		
Bitumen content	Gse	Pba	Pbe	Gse	Pba	Pbe	Gse	Pba	Pbe
4	2.630	0.266	3.745	2.618	0.0814	3.922	2.613	0.015	3.98
4.5	2.621	0.137	4.369	2.617	0.0762	4.427	2.6165	0.066	4.437
5	2.628	0.245	4.768	2.6275	0.237	4.775	2.635	0.334	4.68
5.5	2.6396	0.406	5.12	2.643	0.46	5.02	2.65	0.551	4.98
6	2.638	0.382	5.64	2.642	0.438	5.59	2.644	0.475	5.55

Table A15 Bitumen Specific gravity

Trial	1	2
A. weight of pycnometer, g	42.58	41.56
B. weight of pycnometer filled with sample, g.	59.89	58.94
C. weight of pycnometer filled with water, g@ 25^{O}c	66.39	65.36
D. weight of pycnometer + sample + water, g@ 25^{O}c	66.65	65.62
E. weight of water replaced by sample, g ((C-A)+B)-D)	17.13	17.12
F. specific gravity, (B-A)/E	1.01517805	1.01518692
G. average specific gravity(g/cm^{3})	1.01518248	
H. Density, @25^{O}c WT=0.9971 (WT*G)	1.01223845	
I. Density, @15.6^{O}c WT=0.9990(WT*G)	1.0141673	

APPENDIX B

Particle size distribution and Gradation of Aggregate

Table B1 Particle size distribution of Aggregate

Material type: Coarse Aggregate(CA) **25-13mm**							
Dry sample weight (g)		4675		4892			
Weight after wash (g)		4663		4882			
Sieve size(mm)	Mass of Retained sample(g)	Cumulative passing (g)	Cumulative passing (%)	Mass of Retained sample(g)	Cumulative passing (g)	Cumulative passing (%)	Average cumulative passing(%)
25	0	4675	100	0	4892	100	100
19	1205.7	3469.3	71.33	1403.1	3488.9	71.4	71.325
12.5	3066.3	403.0	11.5	2926.9	562.1	11.5	11.495
9.5	190.7	212.2	1.66	481.4	80.7	1.6	1.655
4.75	323.5	111.3	0.5	56.7	23.9	0. 5	0.495
2.36	259.9	98.7	0.3	9.8	14.2	0.3	0.295
1.18	136. 7	12	0.26	4.2	10	0.2	0.23
0.6		12	0.26		10	0.2	0.23
0.3		12	0.26		10	0.2	0.23
0.15		12	0.26		10	0.2	0.23
0.075		12	0.26		10	0.2	0.23
pan	0			0			
Wash loose	12			10			
Total	4675			4892			

Material type: Intermediate Aggregate(IA-I) **13-6mm**							
Dry sample weight (g)		4255		4212			
Weight after wash (g)		4244		4203			
Sieve size(mm)	Mass of Retained sample(g)	Cumulat passing (g)	Cumulati passing (%)	Mass of Retained sample(g)	Cumulative passing (g)	Cumulative passing (%)	Average cumulative passing(%)
25	0	4255	100	0	4212	100	100
19	0	4255	100	0	4212	100	100
12.5	100.8	4154.2	97.63	100.1	4111.9	97.6	97.6
9.5	1383.3	2770.9	65.12	1369.3	2742.5	65.1	65.1
4.75	2315.1	455.7	10.71	2291.75	450.8	10.7	10.70
2.36	339.97	115.7	2.72	336.54	114.2	2.7	2.7
1.18	95.3	20.4	0.48	94.35	19.9	0.47	0.48
0.6	8.1	12.34	0.29	8.0	11.9	0.28	0.29
0.3	1.34	11	0.259	2.90	9	0.21	0.24
0.15		11	0.259		9	0.21	0.24
0.075		11	0.259		9	0.21	0.24
pan	0			0			
Wash loose	11			9			
Total	4255			4212			

Material type: Intermediate Aggregate(IA-II) **6-3mm**							
Dry sample weight (g)		3136		3321			
Weight after wash (g)		3120		3302			
Sieve size(mm)	Mass of Retained sample(g)	Cumulative passing (g)	Cumulative passing (%)	Mass of Retained sample(g)	Cumulative passing (g)	Cumulative passing (%)	Average cumulative passing(%)
25	0	3136	100	0	3321	100	100
19	0	3136	100	0	3321	100	100
12.5	0	3136	100	0	3321	100	100
9.5	28.224	3107.776	99.1	29.59475	3291.4052	99.10886	99.10443
4.75	246.176	2861.6	91.25	260.6985	3030.7067	91.25886	91.25443
2.36	2343.846	517.7536	16.51	2482.115	548.59134	16.51886	16.51443
1.18	145.824	371.9296	11.86	154.4265	394.16484	11.86886	11.86443
0.6	227.0464	144.8832	4.62	240.4404	153.72444	4.62886	4.62443
0.3	76.2048	68.6784	2.19	80.7003	73.024141	2.19886	2.19443
0.15	34.1824	34.496	1.1	36.1989	36.825241	1.10886	1.10443
0.075	18.496	16	0.51	17.825241	19	0.572	0.541
pan	0			0			
Wash loose	16			19			
Total	3136			3321			

Material type: Fine Aggregate(FA) **0-3mm**							
Dry sample weight g)		1985		1962			
Weight after wash (g)		1760		1742			
Sieve size(mm)	Mass of Retained sample(g)	Cumulati passing (g)	Cumulative passing (%)	Mass of Retained sample(g)	Cumulative passing (g)	Cumulative passing (%)	Average cumulative passing(%)
25	0	1985	100	0	1962	100	100
19	0	1985	100	0	1962	100	100
12.5	0	1985	100	0	1962	100	100
9.5	0	1985	100	0	1962	100	100
4.75	6.9475	1978.053	99.65	7.00214256	1954.9979	99.643112	99.647
2.36	139.347	1838.706	92.63	137.7324	1817.2655	92.623112	92.627
1.18	240.979	1597.727	80.49	238.1868	1579.0787	80.483112	80.487
0.6	534.759	1062.968	53.55	528.5628	1050.5159	53.543112	53.547
0.3	595.103	467.8645	23.57	588.2076	462.30826	23.563112	23.566
0.15	140.935	326.9295	16.47	139.302	323.00626	16.463112	16.4665
0.075	98.2575	228.672	11.52	97.119	225.88726	11.513112	11.5165
pan	3.672	225	10.3	5.88725744	220	10.293112	10.2965
Wash loose	225			220			
Total	1985			1962			

Table B2 Aggregate Gradation and Blending Proportion

Aggregate Blending proportion for 5% filler Utilized in HMA preparation

		Agg. Type											
		CA(13-25)mm	100	71.32	11.49	1.65	0.49	0.29	0.23	0.23	0.23	0.23	0.23
		IA1(6_13)mm	100	100	97.61	65.1	10.71	2.71	0.47	0.29	0.24	0.24	0.24
		IA2(3_6)mm	100	100	100	99.1	91.25	16.51	11.86	4.62	2.19	1.1	0.54
		FA(0_3)mm	100	100	100	100	99.65	92.62	80.49	53.54	23.6	16.5	11.52
		Filler	100	100	100	100	100	100	100	100	100	100	100
		Sieve size	25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
		Agg. Type											
Blending %	24.3	CA(13-25)mm	24.3	17.33	2.792	0.401	0.119	0.07	0.056	0.056	0.06	0.06	0.056
	30.5	IA1(6_13)mm	30.5	30.5	29.77	19.86	3.267	0.827	0.143	0.088	0.07	0.07	0.073
	16.2	IA2(3_6)mm	16.2	16.2	16.2	16.05	14.78	2.675	1.921	0.748	0.35	0.18	0.087
	27.4	FA(0_3)mm	27.4	27.36	27.36	27.36	27.26	25.34	22.02	14.65	6.45	4.5	3.152
	1.64	Filler	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
Total	100	Blend	100	93.03	77.76	65.31	47.07	30.55	25.78	17.18	8.57	6.45	5
		Upper	100	100	88	80	65	49	37	28	19	13	8
		Middle	100	95	79.5	68	50	36	26	19	12	8.5	5
		Lower	100	90	71	56	35	23	15	10	5	4	2

Aggregate Blending proportion for 5.5% filler Utilized in HMA preparation

		Agg. Type											
		CA(13-25)mm	100	71.3	11.49	1.65	0.49	0.29	0.23	0.23	0.23	0.23	0.23
		IA1(6_13)mm	100	100	97.61	65.1	10.7	2.71	0.47	0.29	0.24	0.24	0.24
		IA2(3_6)mm	100	100	100	99.3	91.5	16.5	11.9	4.62	2.19	1.1	0.54
		FA(0_3)mm	100	100	100	100	99.7	92.7	80.8	53.5	23.3	16.3	11.4
		Filler	100	100	100	100	100	100	100	100	100	100	100
		Sieve size	25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.08
		Agg. Type											
Blending %	24.23	CA(13-25)mm	24.23	17.3	2.784	0.4	0.12	0.07	0.06	0.06	0.06	0.06	0.06
	30.45	IA1(6_13)mm	30.45	30.45	29.72	19.8	3.26	0.83	0.14	0.09	0.07	0.07	0.07
	16.19	IA2(3_6)mm	16.19	16.19	16.19	16.19	14.8	2.67	1.92	0.75	0.35	0.18	0.09
	26.95	FA(0_3)mm	26.95	26.95	26.95	26.95	26.95	25	21.8	14.4	6.27	4.38	3.08
	2.21	Filler	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21
Total	100	Blend	100	93.1	77.86	65.5	47.3	30.8	26.1	17.5	8.96	6.9	5.5
		Upper	100	100	88	80	65	49	37	28	19	13	8
		Middle	100	95	79.5	68	50	36	26	19	12	8.5	5
		Lower	100	90	71	56	35	23	15	10	5	4	2

Aggregate Blending proportion for 6.0% filler Utilized in HMA preparation

		Agg. Type											
		CA(13-25)mm	**100**	**71.63**	**11.59**	**1.65**	**0.49**	**0.29**	**0.23**	**0.23**	**0.23**	**0.23**	**0.23**
		IA1(6_13)mm	**100**	**100**	**97.97**	**65.6**	**10.77**	**2.71**	**0.47**	**0.29**	**0.24**	**0.24**	**0.24**
		IA2(3_6)mm	**100**	**100**	**100**	**99.1**	**92.72**	**16.5**	**11.76**	**4.62**	**2.19**	**1.1**	**0.54**
		FA(0_3)mm	**100**	**100**	**100**	**100**	**99.68**	**93.6**	**80.29**	**53.1**	**21.5**	**14.36**	**9.52**
		Filler	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
		Sieve size	**25**	**19**	**12.5**	**9.5**	**4.75**	**2.36**	**1.18**	**0.6**	**0.3**	**0.15**	**0.075**
		Agg. Type											
Blending %	**24.23**	**CA(13-25)mm**	**24.23**	**17.36**	**2.808**	**0.399**	**0.1187**	**0.07**	**0.0557**	**0.056**	**0.056**	**0.0557**	**0.0557**
	30.45	**IA1(6_13)mm**	**30.45**	**30.45**	**29.8**	**19.98**	**3.279**	**0.83**	**0.143**	**0.09**	**0.07**	**0.073**	**0.073**
	16.19	**IA2(3_6)mm**	**16.19**	**16.19**	**16.19**	**16.04**	**15.01**	**2.67**	**1.904**	**0.75**	**0.36**	**0.178**	**0.0874**
	25.8	**FA(0_3)mm**	**25.8**	**25.8**	**25.8**	**25.8**	**25.717**	**24.15**	**20.715**	**13.71**	**5.539**	**3.7049**	**2.4562**
	3.33	**Filler**	**3.33**	**3.33**	**3.33**	**3.33**	**3.33**	**3.33**	**3.33**	**3.33**	**3.33**	**3.33**	**3.33**
Total	**100**	**Blend**	**100**	**93.13**	**77.96**	**65.55**	**47.46**	**31.05**	**26.15**	**17.93**	**9.35**	**7.34**	**6**
		Upper	**100**	**100**	**88**	**80**	**65**	**49**	**37**	**28**	**19**	**13**	**8**
		Middle	**100**	**95**	**79.5**	**68**	**50**	**36**	**26**	**19**	**12**	**8.5**	**5**
		Lower	**100**	**90**	**71**	**56**	**35**	**23**	**15**	**10**	**5**	**4**	**2**

APPENDIX C

Maximum Theoretical Specific Gravity of non compacted Mixture

Table C1 Theoretical Maximum Specific Gravity of HMA mixture at 5% CSD filler

AC	4%		4.50%		5%		5.50%		6%	
Trial	1	2	1	2	1	2	1	2	1	2
Mass of dry sample in air(A)	1225.1	1225.6	1233.2	1232.9	1233.7	1234.7	1241	1243	1248.9	1251.2
Mass of jar filled with water(B)	2294.1	2294.1	2294	2294.1	2294.1	2294.1	2294	2294	2294.1	2294.1
Mass of jar filled with water + sample@25ºc(C)	3023.9	3023.8	3022.1	3023.8	3021	3022.1	3024	3025	3024.2	3025.4
Gmm=A/(A+B-C)	2.4735	2.4715	2.443	2.4501	2.4343	2.4367	2.426	2.426	2.4073	2.4066
Average Gmm	2.473		2.447		2.435		2.426		2.407	

Table C2 Theoretical Maximum Specific Gravity of HMA mixture at 5.5% CSD filler

AC	4%		4.50%		5%		5.50%		6%	
Trial	1	2	1	2	1	2	1	2	1	2
Mass of dry sample in air(A)	1227.2	1228.1	1233.6	1236.9	1234.7	1238.7	1244.9	1243.7	1254.2	1251.6
Mass of jar filled with water(B)	2294.1	2294.1	2294.1	2294.1	2294.1	2294.1	2294.1	2294.1	2294.1	2294.1
Mass of jar filled with water + sample@25ºc(C)	3023.2	3023.1	3023.2	3024.8	3023.8	3022.1	3026.6	3025.7	3027.6	3027.1
Gmm=A/(A+B-C)	2.4638	2.46063	2.4452	2.4435	2.44495	2.42549	2.4295	2.4286	2.4087	2.41342
Average Gmm	2.4622		2.4443		2.43522		2.4291		2.4111	

Table C3 Theoretical Maximum Specific Gravity of HMA mixture at 6% CSD filler

AC	4%		4.50%		5%		5.50%		6%	
Trial	1	2	1	2	1	2	1	2	1	2
Mass of dry sample in air(A)	1233	1234	1238	1238	1238.7	1240.7	1242.9	1244.7	1253.4	1256.8
Mass of jar filled with water(B)	2294	2294	2294	2294	2294.1	2294.1	2294.1	2294.1	2294.1	2294.1
Mass of jar filled with water + sample@25ºc(C)	3025	3026	3025	3026	3026.1	3027.3	3026.6	3027.2	3029.6	3028.1
Gmm=A/(A+B-C)	2.456	2.459	2.443	2.44	2.44464	2.44473	2.4351	2.433	2.4202	2.404
Average Gmm	2.458		2.443		2.444		2.434		2.4121	

Table C 4 Theoretical Maximum Specific Gravity of HMA mixture with 6%CSD filler and GSA at different Replacement Percentage

Replacement %	0%(control)		5%GSA+95%CSD		10%GSA+90%CSD		15%GSA+85%CSD		100%GSA+0%CSD	
Trial	1	2	1	2	1	2	1	2	1	2
Mass of dry sample in air(A)	1241.9	1239.7	1240.2	1238.5	1243.8	1245.7	1247.9	1244.9	1247.5	1249.8
Mass of jar filled with water(B)	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4
Mass of jar filled with water + sample@25^{o}c(C)	3026.1	3024.2	3025	3023.1	3026.7	3027.5	3028.6	3027.1	3027.8	3028.1
Gmm=A/(A+B-C)	2.42464	2.42176	2.424159	2.41989	2.422201	2.42071512	2.41982	2.4210424	2.41717	2.41227562
Average Gmm	2.4232		2.42202		2.4214		2.4204		2.4147	

Table C5 Theoretical Maximum Specific Gravity of HMA mixture with 6%CSD filler and SCBA at different Replacement Percentage

Replacement %	0%(control)		5%SCBA+95%CSD		10%SCBA+90%CSD		15%SCBA+85%CSD		20%SCBA+80%CSD		25%SCBA+75%CSD		100%SCBA+0%CSD	
Trial	1	2	1	2	1	2	1	2	1	2	1	2	1	2
dry Mass in air(A)	1241.9	1239.7	1239.7	1243.1	1243.6	1246.1	1244.7	1243.9	1244.9	1242.9	1240.9	1244.9	1246.5	1245.6
Mass jar +water(B)	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4
Mass of jar+water +sample(C)	3026.1	3024.2	3024.1	3025.8	3025.1	3026.2	3025.2	3024.2	3027	3026.3	3024.5	3026.3	3025.5	3025.3
Gmm=A/(A+B-C)	2.4246	2.4217	2.4212	2.4198	2.4152	2.4135	2.4126	2.4102	2.4205	2.4228	2.4194	2.4172	2.4092	2.4107
Average Gmm	2.4232		2.4203		2.4143		2.4114		2.4212		2.4183		2.4099	

APPENDIX D

Marshall properties of HMA prepared with 5%, 5.5%& 6% CSD filler

Table D1 Marshall properties of HMA prepared with 5% CSD filler

MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559/AASHTO T 245 FILLER CONTENT=5% / Total Aggregate Gsb=2.612/													
BC (%)	Effective bitumen Content B	Spec. ht (mm)	Max. SG 0f the mix (Gmm)	Mass of specimen(g)			Volume of specimen(cc) H	Bulk SG of compacted mix I	VIM (%) J	VMA (%) K	VFA (%) L	Flow (mm)	Stability (KN)
A	A-Pba*Ps/100	C	D	Mass In Air (g) E	Mass in Water (g) F	SSD mass air (g) G	G-F	E/H	(D-I)*100/D	100-[(100-A)*I/Gsb]	(K-J)*100/K		
4	3.74	68		1230.4	691.4	1233.8	542.4	2.268	8.29	16.64	50.18	2.53	7.87
		68		1231.3	694	1234.6	540.6	2.278	7.89	16.28	51.54	2.69	7.64
		69		1233.1	692	1236.1	544.1	2.266	8.37	16.72	49.94	2.56	7.97
Average		68.33	2.473	1231.6	692.5	1234.8	542.4	2.271	8.18	16.53	50.49	2.59	7.83
4.5	4.369	68		1237.3	699.4	1238.8	539.4	2.294	6.25	16.13	60.15	2.761	8.37
		68		1238.4	698	1239.9	541.9	2.285	6.62	16.46	58.67	2.98	8.44
		69		1238	699.1	1239.1	540	2.293	6.29	16.16	59.97	2.83	8.21
Average		68.33	2.447	1237.9	698.8	1239.3	540.4	2.291	6.39	16.24	59.56	2.857	8.34
5	4.768	68		1238.8	706.4	1239.8	533.4	2.322	4.64	15.55	68.34	3.64	8.28
		68		1237.4	708.6	1238.9	530.3	2.333	4.19	15.15	70.6	2.79	8.64
		69		1238	703.1	1239.8	536.7	2.307	5.261	16.09	65.44	2.88	8.41
Average		68.33	2.435	1238.1	706.0	1239.5	533.5	2.321	4.69	15.58	68.06	3.10	8.44
5.5	5.12	69		1240.7	709.4	1242.2	532.8	2.329	3.99	15.74	72.23	3.16	8.89
		68.5		1239.6	710.6	1240.8	530.2	2.338	3.63	15.41	74.22	3.37	8.36
		69		1239.2	711.2	1241.3	530.1	2.338	3.63	15.41	74.22	3.941	9.05
Average		68.83	2.426	1239.8	710.4	1241.4	531.0	2.335	3.75	15.52	73.55	3.49	8.77
6	5.64	67		1240.9	713.5	1242.5	529	2.346	2.53	15.57	81.61	3.62	8.08
		67		1243.4	711.3	1246.1	534.8	2.325	3.41	16.33	76.59	3.83	8.37
		68		1242.1	712.6	1245.7	533.1	2.33	3.19	16.15	77.72	3.91	8.2
Average		67.33	2.407	1242.1	712.5	1244.8	532.3	2.334	3.05	16	78.57	3.79	8.22

Table D2 Marshall properties of HMA prepared with 5.5% CSD filler

MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559/AASHTO T 245
FILLER CONTENT=5.5% /Total Aggregate Gsb=2.612/

BC (%)	Effective bitumen Content B	Spec. ht (mm)	Max. SG 0f the mix (Gmm)	Mass of specimen(g)			Volume of specimen(cc) H	Bulk SG of compacted mix I	VIM (%) J	VMA (%) K	VFA (%) L	Stability (KN)	Flow (mm)
A	A-Pba*Ps/100	C	D	Mass In Air(g) E	Mass in Water (g) F	SSD mass air (g) G	G-F	E/H	(D-I)*100/D	100-[(100-A)*I/Gsb]	(K-J)*100/K		
4	3.922	67.5		1234.1	692.6	1236.3	543.7	2.27	7.8	16.57	52.93	8.02	2.51
		69.5		1236.6	693	1238.3	545.3	2.268	7.88	16.64	52.65	8.23	2.62
		68		1239.2	698	1242.2	544.2	2.277	7.51	16.31	53.94	8.59	2.79
Average		68.3	2.462	1236.6	694.5	1238.9	544.4	2.272	7.73	16.5	53.13	8.28	2.64
4.5	4.427	69		1237.1	698.6	1238.1	539.5	2.293	6.18	16.16	61.78	8.64	2.79
		69.5		1240.6	700.4	1241.3	540.9	2.294	6.14	16.13	61.94	8.82	2.83
		68		1242.2	701.6	1243.2	541.6	2.294	6.14	16.13	61.94	8.75	2.89
Average		68.8	2.444	1240	700.2	1240.9	540.7	2.293	6.15	16.16	61.94	8.74	2.84
5	4.78	67.5		1244.4	712.2	1246.6	534.4	2.329	4.35	15.29	71.53	9.85	3.18
		68		1240.1	709.3	1243.9	534.6	2.32	4.72	15.62	69.76	8.91	3.24
		68		1243.7	710.2	1247.8	537.6	2.313	5.01	15.87	68.44	9.56	3.09
Average		67.8	2.435	1242.7	710.6	1246.1	535.5	2.321	4.7	15.58	69.87	9.44	3.17
5.5	5.06	67		1241.6	709.9	1242.2	532.3	2.333	3.95	15.59	74.66	9.51	3.69
		68		1244.8	716.9	1246.7	529.8	2.35	3.25	14.98	78.29	9.82	3.09
		68		1248.2	713.1	1249.2	536.1	2.328	4.16	15.77	73.64	10.2	3.29
Average		67.7	2.429	1244.9	713.3	1246	532.7	2.337	3.79	15.45	75.53	9.84	3.36
6	5.59	67		1242.7	713.3	1244.8	531.5	2.338	2.99	15.86	81.16	8.65	3.85
		66.5		1246.7	716.1	1248	531.9	2.344	2.74	15.64	82.5	8.83	3.74
		68.5		1247.6	715.4	1249.5	534.1	2.336	3.07	15.93	80.73	8.54	3.37
Average		67.3	2.41	1245.7	714.9	1247.4	532.5	2.339	2.93	16.57	81.47	8.67	3.65

Table D3 Marshall properties of HMA prepared with 6.0% CSD filler

MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559/AASHTO T 245 FILLER CONTENT=6.0% /Total Aggregate Gsb=2.612/													
BC (%)	Effective bitumen Content B	Spec ht (mm)	Max. SG 0f the mix (Gmm)	Mass of specimen(g)			Volume of specimen(cc) H	Bulk SG of compacted mix I	VIM (%) J	VMA (%) K	VFA (%) L	Stability (KN)	Flow (mm)
A	A-Pba*Ps/100	C	D	Mass In Air(g) E	Mass in Water (g) F	SSD mass air (g) G	G-F	E/H	(D-I)*100/D	100-[(100-A)*I/Gsb]	(K-J)*100/K		
4	3.98	69		1237.6	694.8	1239.1	543.7	2.274	7.5	16.43	54.38	8.29	2.83
		68.5		1240.6	694.1	1242.6	545.3	2.262	7.98	16.87	52.69	8.53	3.04
		67.5		1236.8	696.9	1238.3	544.2	2.284	7.06	16.04	55.96	8.13	2.97
Average		68.3	2.458	1238.3	695.3	1240	544.4	2.273	7.51	16.45	54.32	8.32	2.95
4.5	4.437	69.5		1245.6	709.8	1247.1	539.5	2.318	5.11	15.24	66.49	9.09	3.23
		69.5		1241.6	705.1	1244.6	540.9	2.301	5.8	15.86	63.44	8.33	3.17
		69		1242.4	701.9	1243.3	541.6	2.295	6.07	16.1	62.3	8.63	3.08
Average		69.3	2.443	1243.2	705.6	1245	540.7	2.305	5.66	15.73	64.04	8.68	3.16
5	4.68	67.5		1241.4	711.5	1242.7	534.4	2.337	4.22	15	71.86	9.98	3.23
		68		1246.8	714.3	1248.4	534.6	2.334	4.33	15.1	71.33	9.82	3.37
		69		1244.7	712.2	1246.3	537.6	2.33	4.49	15.24	70.54	9.53	3.29
Average		68.2	2.44	1244.1	712.7	1245.8	535.5	2.334	4.35	15.13	71.27	9.78	3.3
5.5	4.98	68.5		1245.1	715.6	1247.2	532.3	2.342	3.77	15.26	75.28	10.16	3.48
		68.5		1248.5	717.4	1250.3	529.8	2.343	3.75	15.24	75.42	10.09	3.38
		69		1242.2	716.3	1244.8	536.1	2.351	3.42	14.96	77.1	10.24	3.43
Average		68.7	2.434	1245.3	716.4	1247.4	532.7	2.345	3.65	15.15	75.93	10.16	3.43
6	5.55	67		1259.8	716.3	1260.7	531.5	2.314	4.06	16.72	75.73	9.07	4.02
		66		1246.5	717.1	1247.4	531.9	2.351	2.55	15.41	83.47	9.1	3.84
		66.5		1252.7	718.4	1254.1	534.1	2.339	3.04	15.84	80.8	8.97	3.87
Average		66.5	2.412	1253	717.3	1254.1	532.5	2.334	3.22	15.99	79.89	9.05	3.91

Table D4 Marshall properties of HMA prepared with 6.0% CSD filler and GSA at different replacement percentage

MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559/AASHTO T 245 prepared With different percentage of GSA as partial replacement to CSD at 6.0% filler content															
BC (%)	Mineral filler type & proportion B		Spec ht (mm)	Max. SG 0f the mix (Gmm)	Mass of specimen(g)			Volume of specimen(cc) H	Bulk SG of compacted mix I	VIM (%) J	VMA (%) K	VFA (%) L	Flow (mm)	Stability (KN)
A	% GSA	% CSD	C	D	Mass In Air(g) E	Mass in Water (g) F	SSD mass air (g) G	G-F	E/H	(D-I)*100/D	100-[(100-A)*I/Gsb]	(K-J)*100/K		
5.248	0	100	68		1251.1	712.7	1252.5	539.8	2.318	4.33	15.91	72.79	3.23	9.41
			67		1249.3	712.2	1250.7	538.5	2.32	4.25	15.84	73.16	2.98	9.17
			67		1246.6	710.3	1247.8	537.5	2.319	4.29	15.88	72.97	3.11	9.54
Average			67.3	2.423	1249	711.7	1250.3	538.6	2.319	4.29	15.88	72.97	3.11	9.37
5.248	5	95	67		1245.6	708.2	1246.8	538.6	2.313	4.5	16.09	72.04	3.24	9.64
			68		1247.7	711.3	1249.6	538.3	2.318	4.29	15.91	73.02	3.19	9.27
			68		1244.3	708.6	1245.1	536.5	2.319	4.25	15.88	73.21	3.31	9.34
Average			67.7	2.422	1245.9	709.4	1247.2	537.8	2.317	4.35	15.95	72.73	3.25	9.42
5.248	10	90	68		1246.6	711.1	1247.5	536.4	2.324	4.01	15.7	74.47	3.38	9.31
			69		1245.8	710.1	1246.1	536	2.324	4.01	15.7	74.47	3.47	10.2
			69		1247.1	712.1	1248.8	536.7	2.324	4.01	15.7	74.47	3.45	9.81
Average			68.7	2.421	1246.5	711.1	1247.5	536.4	2.324	4.01	15.7	74.47	3.433	9.76
5.248	15	85	69		1250.1	712.4	1251.9	539.5	2.317	4.26	15.95	73.31	4.28	9.16
			68		1252.3	713.1	1254.8	541.7	2.312	4.46	16.13	72.33	4.71	10.2
			69		1249.8	711.8	1250.1	538.3	2.322	4.05	15.77	74.32	4.49	9.78
Average			68.7	2.42	1250.7	712.4	1252.3	539.8	2.317	4.26	15.95	73.31	4.49	9.71
5.248	100	0	69		1248.2	711.4	1251.7	540.3	2.31	4.35	16.2	73.17	4.96	8.98
			68		1250.4	712.6	1252.8	540.2	2.315	4.14	16.02	74.16	4.57	9.26
			67		1249.2	711.8	1250.3	538.5	2.32	3.93	15.84	75.17	5.04	9.64
Average			68	2.415	1249.3	711.9	1251.6	539.7	2.315	4.14	16.02	74.16	4.86	9.29

Table D5 Marshall properties of HMA prepared with 6.0% CSD filler and SCBA at different replacement percentage

MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559/AASHTO T 245 prepared With different percentage of SCBA as partial replacement to CSD at 6.0% filler content

BC (%) A	Mineral filler type & proportion B: % SCBA	% CSD	Spec ht (mm) C	Max. SG 0f the mix (Gmm) D	Mass of specimen(g): Mass In Air(g) E	Mass in Water (g) F	SSD mass air (g) G	Volume of specimen(cc) H: G-F	Bulk SG of compacted mix I: E/H	VIM (%) J: (D-I)*100/D	VMA (%) K: 100-[(100-A)*I/Gsb]	VFA (%) L: (K-J)*100/K	Stability (KN	Flow (mm)
5.248	0	100	68		1251.1	712.7	1252.5	539.8	2.318	4.345	15.924	72.711	9.41	3.23
			67		1249.3	712.2	1250.7	538.5	2.32	4.252	15.842	73.157	9.17	2.98
			67		1246.6	710.3	1247.8	537.5	2.319	4.282	15.867	73.016	9.54	3.11
Average			67.3	2.423	1249	711.7	1250.3	538.6	2.319	4.293	15.878	72.961	9.37	3.11
5.248	5	95	69		1245.6	708.2	1246.8	538.6	2.314	4.386	16.063	72.697	9.74	3.12
			68		1247.7	711.3	1249.6	538.3	2.311	4.499	16.162	72.165	8.87	3.23
			69		1244.3	708.6	1245.1	536.5	2.31	4.541	16.2	71.967	10.02	3.43
Average			68.7	2.42	1245.9	709.4	1247.2	537.8	2.312	4.475	16.142	72.275	9.54	3.26
5.248	10	90	69		1246.6	711.1	1247.5	536.4	2.312	4.231	16.136	73.776	10.09	2.73
			69		1245.8	710.1	1246.1	536	2.312	4.224	16.13	73.811	9.91	3.41
			67		1247.1	712.1	1248.8	536.7	2.312	4.218	16.124	73.84	9.63	3.21
Average			68.3	2.414	1246.5	711.1	1247.5	536.4	2.312	4.225	16.13	73.809	9.88	3.12
5.248	15	85	68		1250.1	712.4	1251.9	539.5	2.314	4	16.068	74.888	10.07	3.89
			69		1252.3	713.1	1254.8	541.7	2.314	4.04	16.07	74.88	10.21	3
			69		1249.8	711.8	1250.1	538.3	2.316	3.96	16.003	75.253	10.18	3.48
Average			68.7	2.411	1250.7	712.4	1252.3	539.8	2.314	4.01	16.047	75.007	10.15	3.46
5.248	20	80	69		1248.2	711.4	1251.7	540.3	2.321	4.149	15.821	73.772	9.24	2.74
			69		1250.4	712.6	1252.8	540.2	2.316	4.345	15.993	72.83	9.41	2.98
			68		1249.2	711.8	1250.3	538.5	2.311	4.543	16.166	71.9	9.62	3.17
Average			68.7	2.421	1249.3	711.9	1251.6	539.7	2.316	4.346	15.993	72.827	9.42	2.96

			68		1251.1	712.7	1252.5	539.8	2.316	4.222	15.989	73.595	8.32	4.15
	25	75	69		1249.3	712.2	1250.7	538.5	2.313	4.33	16.083	73.08	8.88	4.06
			68		1246.6	710.3	1247.8	537.5	2.322	3.989	15.784	74.729	8.65	4.21
Average			68.3	2.418	1249	711.7	1250.3	538.6	2.317	4.181	15.952	73.794	8.62	4.14
			69		1248.1	709.9	1249.3	539.4	2.311	4.088	16.15	74.685	8.58	4.46
	100	0	68		1245.7	707.3	1246.3	539	2.32	3.752	15.856	76.338	8.02	4.17
			67		1246.3	708.6	1248.1	539.5	2.296	4.728	16.709	71.703	8.44	5.04
Average			68	2.41	1246.7	708.6	1247.9	539.3	2.309	4.189	16.24	74.203	8.35	4.56

APPENDIX E

Moisture susceptibility of mix Prepared with GSA and SCBA at varying replacement proportion

Table E1Indirect test strength and tensile strength ratio of control /100%CSD/mix

		WET GROUP			DRY GROUP		
Trial		1	2	3	1	2	3
Thickness, mm	t	68	69	69	68.5	68	68.5
Diameter, mm	D	100	100	100	100	100	100
Max. load for dry in N	P				6940	6980	6890
Dry strength in Kpa (2000*P*1000)/иtD)	S1				645.311	653.8029	640.66
Average strength of dry group	S1 avg.					646.5921	
Max. load for wet in N	P′	5980	6070	6090			
Wet strength in Kpa (2000*P*1000)/иtD)	S2	560.135	560.3249	562.171			
Average strength of wet group	S2 avg.		560.8769				
TSR(S2avg./S1avg.)							86.744

Table E2 Indirect test strength and tensile strength ratio of 5%GSA+95%CSD mix

		WET GROUP			DRY GROUP		
Trial		1	2	3	1	2	3
Thickness, mm	t	69	68.5	67.5	69	67	69
Diameter, mm	D	100	100	100	100	100	100
Max. load for dry in N	P				7005	6990	6960
Dry strength in Kpa (2000*P*1000)/иtD)	S1				646.174	664.512	642.481
Average strength of dry group	S1 avg.					651.056	
Max. load for wet in KN	P′	6170	6090	6140			
Wet strength in Kpa (2000*P*1000)/иtD)	S2	569.556	566.275	579.3892			
Average strength of wet group	S2 avg.		571.737				
TSR(S2avg./S1avg.)							87.817

Table E3 Indirect test strength and tensile strength ratio of mix

With10%GSA+90%CSD filler and OBC

		WET GROUP			DRY GROUP		
Trial		1	2	3	1	2	3
Thickness, mm	t	69	68	69	69	68	68
Diameter, mm	D	100	100	100	100	100	100
Max. load for dry in N	P				7010	7050	7030
Dry strength in Kpa (2000*P*1000)/иτD)	S1				647.097	660.359	658.48
Average strength of dry group	S1 avg.					655.314	
Max. load for wet in KN	P′	6220	6310	6250			
Wet strength in Kpa (2000*P*1000)/иτD)	S2	574.1715	591.045	576.941			
Average strength of wet group	S2 avg.		580.719				
TSR(S2avg./S1avg.)							88.6169

Table E4 Indirect test strength and tensile strength ratio of mix

With 5%SCBA+95%CSD filler and OBC

		WET GROUP			DRY GROUP		
Trial		1	2	3	1	2	3
Thickness, mm	t	69	68	69	69	68	67.5
Diameter, mm	D	100	100	100	100	100	100
Max. load for dry in N	P				7020	6920	7000
Dry strength in Kpa (2000*P*1000)/иtD)	S1				648.019	648.1828	660.533
Average strength of dry group	S1 avg.					652.24531	
Max. load for wet in KN	P′	6200	6180	6210			
Wet strength in Kpa (2000*P*1000)/иtD)	S2	572.325	578.8684	573.248			
Average strength of wet group	S2 avg.		574.8140				
TSR(S2avg./S1avg.)	88.12850928						

Table E5 Indirect test strength and tensile strength ratio of mix

With 10%SCBA+90%CSD filler and OBC

Table E6 ITS and TSR of mix with 15%SCBA+85%CSD filler and OBC

		WET GROUP			DRY GROUP		
Trial		1	2	3	1	2	3
Thickness, mm	t	68	69	68.5	68	69	69
Diameter, mm	D	100	100	100	100	100	100
Max. load for dry in N	P				7060	7100	7050
Dry strength in Kpa (2000*P*1000)/иtD)	S1				661.3	655	650.78
Average strength of dry group	S1 avg.					656	
Max. load for wet in KN	P′	6240	6270	6300			
Wet strength in Kpa (2000*P*1000)/иtD)	S2	584.49	578.79	585.8			
Average strength of wet group	S2 avg.		583.03				
TSR(S2avg./S1avg.)							88.899

		WET GROUP			DRY GROUP		
Trial		1	2	3	1	2	3
Thickness, mm	t	68.5	69	69	68	69	67.5
Diameter, mm	D	100	100	100	100	100	100
Max. load for dry in N	P				7094	7132	7086
Dry strength in Kpa (2000*P)/иtD)	S1				664.294	658.3587	668.648
Average strength of dry group	S1 avg.					663.7669	
Max. load for wet in N	P′	6380	6420	6410			
Wet strength in Kpa (2000*P*1000)/иtD)	S2	593.240	592.6336	591.711			
Average strength of wet group	S2 avg.		592.5281				
TSR(S2avg./S1avg.)							89.26748973

Table E7 ITS and TSR result of mix with 20%SCBA+80%CSD filler and OBC

		WET GROUP			DRY GROUP		
Trial		1	2	3	1	2	3
Thickness, mm	t	69	69	70	68	69	68
Diameter, mm	D	100	100	100	100	100	100
Max. load for dry in N	P				7010	6970	7020
Dry strength in Kpa (2000*P*)/иtD)	S1				656.613	643.4044	657.549
Average strength of dry group	S1 avg.					652.5223	
Max. load for wet in N	P′	6210	6260	6190			
Wet strength in Kpa (2000*P*1000)/иtD)	S2	573.248	577.8639	563.239			
Average strength of wet group	S2 avg.		571.4505				
TSR(S2avg./S1avg.)							87.576

APPENDIX F

Laboratory Pictures

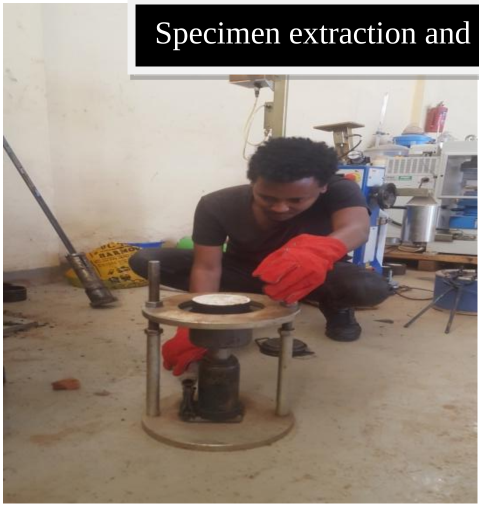
Material preparation

Gmm test procedure

Aggregate specific gravity test

Softening point test

Specimen extraction and recording its SSD weight



Recoding IDT test results and checking for broken aggregates