JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

COMPARATIVE EFFECTS OF CERAMIC WASTE AND COFFEE HUSK ASH REPLACEMENT WITH CRUSHED STONE FILLER IN HOT MIX ASPHALT

A Thesis submitted to the School of Graduate studies of Jimma University in partial fulfillment of the requirements for the Degree of Masters of Science in Highway Engineering.

By: Bilisumma Lemi Bulti

February, 2021

Jimma, Ethiopia

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Main advisor: Dr.-Ing. Fekadu Fufa (PhD)

Co-advisor: Eng.Abubekir Jamal

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APPROVED BY BOARD OF EXAMINERS

1. **Prof.Dr.-Ing. Alemayehu Gebissa**		11 / 03 / 21
External Examiner	Signature	Date
2. **Eng.Mesfin Dinku**		11 / 03 / 21
Internal Examiner	Signature	Date
3. **Eng.Biruk Yigezu**		11 / 03 / 21
Chairperson of Examiner	Signature	Date
4. **Dr.-Ing. Fekadu Fufa (PhD)**		11 / 03 / 21
Main Advisor	Signature	Date
5. **Eng. Abubekir Jamal**		11 / 03 / 21
Co-Advisor	Signature	Date

DECLARATION

I, the undersigned, announce that this thesis entitled: **"Comparative effect of ceramic waste and coffee husk ash replacement with crushed stone filler in hot mix asphalt"** is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for this thesis have correctly acknowledged and cited.

Candidate:

Mr. Bilisumma Lemi Bulti

Signature ____________ 2/16/2021 Date

As Master's Research Advisors, I hereby certify that I have read and evaluated this MSc Thesis prepared under my guidance by **Mr. Bilisumma Lemi Bulti** entitled: **"Comparative effect of Ceramic waste and Coffee husk ash replacement with Crushed stone filler in Hot-Mix-Asphalt."**

Dr.-Ing. Fikadu Fufa (PhD)

Main Advisor

Signature ____________ 2/16/2021 Date

Engr. Eng.Abubekir Jamal (MSc.)

Co- Advisor

Signature ____________ ____________ Date

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Abstract

The Continual increases in economic escalation, waste disposal problem and deficiency in availability of construction materials have opened the chance to utilize waste materials. The upkeep and easily use of natural resources as well as the intention of waste material utilization are also another current issues of our planet. The agricultural, manufacturing and construction industries are sensitive and midst of massive waste production sectors. Thus, this study will expand the mindfulness about the present issues of materials waste reuse and utilization in order to reduce the environmental pollution. Meantime it improves the shortages of materials during construction besides of cost minimization especially for the road construction.

The partial replacement of crushed stone dust (CSD) was done with Ceramic waste powder (CWP) and Coffee husk ash (CHA) at replacement percent of 0, 25, 50, 75 and 100 % and 1.5, 3, 4.5, 6 and 7.5% by the mass of CSD respectively. And these replacements were conducted for the best fit selected 4% filler content (A_4 gradation) at its corresponding 5.33% optimum binder content. Stability, flow and density-void analysis were determined after these samples were subjected to Marshall Test. The Marshall Properties of control mix design at 4% filler content were 9.34 kN, 3.15 mm, 2.325 g/cm^3, 4%, 15.84% and 74.5% for stability, flow, bulk specific gravity, air void, VMA and VFA respectively.

For this study the total of 93 specimens were prepared including tensile strength ratio (TSR) test. Seventy five (75) of these specimens were done for Marshall Test. And out of these 45 specimens were conducted for determining OBC while 30 specimens were performed for partial replacement and 18 rests were conducted for TSR test.

The result finding shows that CHA can be used as filler in HMA at 4.5% by weight of CSD. And also it indicates that CWP can be used 100% as alternative filler material at 4% CSD for both materials. And the *TSR values of the study are 80.91, 84.17 and 87.04% for CSD-CWP, CSD and CSD-CHA mixes respectively, that are in good performance ranges. At the end, the study recommends the utilization of Coffee husk ash and ceramic waste powder combined with CSD as filler in HMA.*

Key Words: replacement, effects of fillers, coffee husk ash, ceramic waste, hot mix asphalt, crushed stone dust and Stripping.

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ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BPG	Bitumen Penetration Grade
CA	Coarse Aggregate
CHA	Coffee Husk Ash
CSD	Crushed Stone Dust
CSD-CW	Asphalt mix design for partial replacement of CSD with CWP
CSD-CHA	Asphalt mix design for partial replacement of CSD with CHA
CWP	Ceramic Waste Powder
ERA	Ethiopian Road Authority
FA	Fine Aggregate
HMA	Hot Mix Asphalt
IMA	Intermediate Aggregate
ITS	Indirect Tensile Strength
NAPA	National Asphalt Pavement Association
NMAS	Nominal maximum aggregate size
OBC	Optimum Bitumen Content
OFC	Optimum Filler Content
OPC	Ordinary Portland cement
TSR	Tensile Strength Ratio
SMA	Stone Mastic Asphalt
A_4, $B_{5.5}$ and C_7	gradation design corresponding to 4, 5.5 and 7% FC respectively

CHAPTER ONE
INTRODUCTION

1.1 Background

For the longstanding performance of asphalt pavements, the partial replacement of mineral powder of waste materials has gained worldwide considerable research attention in recent years. The continually increasing economic escalation and deficiency of availability have opened the chance to discover nearby obtainable waste material. It is carrying on in view of the present issues of waste materials reuse, reduction in cost of road project and scarcity of mineral fillers.

The hot mix asphalt used in highway construction is an expensive. Due to its high cost, the quantity of good quality material in the HMA is reduced, that demand the alternative source of material. There are lot of debris, construction waste, which are affecting the quality environment, came into to the researcher's concern to do recycled and reusing to prevent the pollution, as well as an alternative natural resources of pavement construction material (Kara, 2017).

In Ethiopia environmental factors such as heavy loads, excessive temperature, high traffic flow and the like are highly affecting the road pavements. Most of the time excessive failures appear at an early age of the road pavement life. The modification of mix design is the main step in upgrading the performance of an existing road pavement and to build the new one.

Having the knowledge of effects of different mineral fillers on asphalt concrete is an important point during the work of asphalt mix design. Fillers fill voids between coarse aggregates in the mixture and alter properties of the binder. Mineral fillers increase the stiffness of the asphalt mix. And also it has different effects on workability, moisture resistance, and aging characteristics of HMA mixtures. Generally, filler plays an important role in properties of bituminous mixture particularly in terms of air voids and VMA (Dr.S.P.Mahendra, et al., 2018).

The investment expense of the highway construction project is massive. The significant investment and trustworthy performance of highway can be achieved through an accurate engineering design. Currently, the mix design in flexible pavement is gaining an attention of using different mineral fillers so as to bring significant change in highway pavement performance.

The partial replacement of mineral filler or binder materials and stabilization of soil are some work of Civil Engineering. It is performed by using various byproducts/wastes for the sake of several purposes like reduction in costs. These wastes utilization would not only be economical but also remedial measures as an environmental pollution management. Instead of discarding or burning the solid waste materials, it is advisable to utilize these wastes materials in construction industry like highway project. Such wastes include industrial, agricultural, waste materials at construction sites and municipal solid waste. Although, it is the first time research conducted on partial replacement of CHA as filler, some researches have done for the case of CWP. It found out that at varying percentage of bitumen content, the stability, flow, voids in the mixtures and the performance tests conducted were met the standard specification.

Considerable amount of literature has been published on reuse of solid waste materials as raw materials in HMA. Generally, there are three ways to announce waste material into HMA. One advent is to introduce the waste material use as a modifier to the asphalt binder. The studies have shown that, when asphalt binder is modified with addition of rubber, polymer and many other waste materials, HMA exhibit better properties (Yildirim, 2007, Ghasemi, M. &Marandi, S. M., 2013 and Mohammed, E-S. A, 2013).

The second advancement is solid waste material use as replacement of conventional filler and aggregates in HMA. Conclusions from several studies confess the importance of the filler used in asphalt concrete (Ravindranath, N.H.,et al., 2005). Furthermore, it is globally accepted that the natural filler can be replaced with any suitable material either natural or artificial (Tapkin, S., 2008). The third method is to use additives such as polymers and fibers to HMA in addition to the binders and aggregates and the results reveal that the replacement or addition makes the mix better (Singh, V. &Sakale, R., 2018), Justo, C. &Veeraragavan, A. , 2002).

One of the remedial measures should be taken for waste disposal problem is reuse of the waste materials. Now a day, several highway studies are undertaking extensive variety of research projects regarding the practicability, environmental appropriateness and performance of reusing waste materials in road construction .It reveals that the adequate combination of the need of safe and economic disposal of waste materials and the need of better and more cost-effective construction materials. Today, using recycled materials in road pavements is considered not only as a positive option in terms of sustainability, but also, as an attractive option in means of providing enhanced performance in service (Justo, C. &Veeraragavan, A. , 2002).

Thus, this study is intended to know the effects of CWP and CHA in hot mix asphalt performance and Marshall Properties. It is aimed to reduce the need to crushed aggregates by producing the new mineral fillers that suitable for the replacement in HMA.

1.2 Statement of problem

With the rapid economic growth and continued increased consumption, a large amount of waste materials is generated (Wu, S., Yang, W. &Yongjie, X., 2004). If the large amount of waste or by-product materials generated were used instead of natural materials in the construction industry, there would be three benefits: conserving natural resources, disposing of waste materials (which are often unsightly) and freeing up valuable land for other uses (Blewett,J.&Woodward, P. K., 2000).

Damping of coffee husk at landfill sites facilitates the threat of wild fires, and generates toxic chemicals that affect the ecology, such as soil, water, and plants. Hence, the flourishing use of by-product of coffee bean processing, Coffee husk, in can be placed forward as one of the environmental responsible and cost-effective eco-friendly ways of adapting coffee husk waste into valuable resources (Abebe Demissew1, Fekadu Fufa2 and Sintayehu Assefa3, 2019).

It has been expected that about 30% of the annual production in the ceramic industry is converted to waste during cutting, grinding, dressing and polishing operations (Muniandy, R.,et al, 2009). This waste ceramic could be easily crushed to the desired size and form ceramic dust which could be utilized as filler.

On the other hand, one of the main problems in the construction of highway pavement is insufficiency of amount of mineral fillers from crushing of rocks (Zemichael, B. M., 2007).

The provision of strong and durable pavement structures that fulfills the debatable transportation demand of the society requires the study of good asphalt mix design. And this can be done using industrial and agricultural by-product wastages such as CWP and CHA as filler material in HMA.

Therefore, this investigation was undertaken to evaluate the practicability of CHA and CWP as mineral filler. On the other hands, sometimes there is a shortage of importing materials from other locations or quarry sites that may results in depletion or scarce of the naturally available materials such as rock to produce the required amount of mineral fillers. Thus, the reuse of waste materials in construction industry is desirable to preserve the natural materials and reduce environmental impacts. Besides of this, it is desirable for cost reduction and improving shortages of materials during construction.

1.3 Research Questions

This study aimed to answer the following questions:

- What are the characteristics of CWP and CHA?
- What are the Marshall Properties of the study mix design on suitability of CHA and CWP?
- What are the comparative effects of CWP and CHA in CSD-CWP and CSD-CHA asphalt mix design of the study respectively?
- Can CSD, CSD-CHA and CSD-CWP mix design of the study fulfill the asphalt performance tests on moisture sensitivity?

1.4 Objective

1.4.1 General objective

The general objective of this research is comparative study on the effects of partial replacement of crushed stone dust with ceramic waste powder and coffee husk ash as filler in hot mix asphalt.

1.4.2. Specific objectives

The chemical compositions, moisture sensitivity, practicability and determination of optimum use of CHA and CWP are the main factors examined in this study. So the specific objectives of study are:-

- to characterize the properties of CWP and CHA;
- to design the bituminous concrete mix using Marshall mix design method and study on suitability of CWP and CHA;
- to determine the effects of CWP and CHA in CSD-CWP and CSD-CHA asphalt mix design of the study respectively;
- to evaluate moisture sensitivity of CSD,CSD-CHA and CSD-CWP mix design of the study.

1.5 Scope and limitation of the study

The scope of this study is focused on sample collection, physiochemical tests of CHA and CWP and bitumen and aggregate quality tests. And also stability- flow test using Marshall Method, density- void analysis for asphalt mix design and ITS test for asphalt performance were part of the scope. The work of sample collection includes aggregate of different size and 80/100 BPG as well as Coffee husk and CWP for the intended replacement.

The other main work was asphalt mix design as per ASTM D1559 procedure of Marshall Mix design method with varying fillers. The details of these activities were Marshall stability-flow tests, the work of density-void analysis like VA, VMA, VFA and bulk density determination. And the replacement asphalt mix design activities for CSD-CHA and CSD-CWP were performed.

Lastly, asphalt performance test was performed in order to evaluate the moisture resistivity of the mix design as per AASHTO T283/ASTM D4867. In this test, indirect tensile strength tests for both dry and wet conditions were undertaken and followed by determination of TSR value of the mixes.

1.6 Significance of the study

This study will expand the mindfulness about the present issues of materials waste reuse in order to reduce the environmental pollution. Meantime it improves the shortages of materials during construction besides of cost minimization especially for the road construction.

It is also helpful for the coffee bean processing sectors, local authorities and owners of ceramic Factories in lessening the costs of waste disposal management. In addition to this it provides extra income for local coffee producers and owners of ceramic factories. Furthermore, this study can be used as a reference for studies will be undertaken in related areas.

CHAPTER TWO
LITRATURE REVIEW

2.1. Introduction

Asphalt concrete is a mixture of aggregate, filler and asphalt binder. These materials are 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 (aggregates, fillers asphalt binder and aggregates), mix proportions and construction process (Asphalt Institute, 1994). All materials of asphalt concrete 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. And it plays play a major role in controlling the mechanical behavior of its mixture (Roman, C., 2017).

2.2 Asphalt binder (bitumen)

Asphalt binder holds aggregates together in HMA is thick, heavy residue remaining after refining crude oil. It consists mostly of carbon and hydrogen, with small amounts of oxygen, sulfur, and several metals. The physical properties of asphalt binder vary considerably with temperature. At high temperatures, asphalt binder is a fluid with a low consistency similar to that of oil. At room temperature most asphalt binders will have the consistency of soft rubber (Transportation Research Board Committee., 2011).

2.3 Aggregate

Aggregate is the major component in HMA. The quality and physical properties of this material has a large influence on mix performance. Aggregates are the dominant ingredient of HMA. 80% to 85 % of the mixture by volume and roughly 95 percent of the mixture by weight is an aggregate. It divided into coarse aggregate, fine aggregates, and filler fractions. The stability of asphalt mixture is affected by several features such as gradation of aggregate, type, and amount of filler materials (Elliot, 1991). According to (ERA Manual, 2002) suggestion, the characteristics of aggregates used in HMA should be; i) angular and not excessively flaky, to provide good mechanical interlock; ii) clean and free of clay and organic material; iii) resistant to abrasion and polishing when exposed to traffic; iv) strong enough to resist crushing during mixing and laying as well as in service; v) non-absorptive - highly absorptive aggregates are wasteful of bitumen and also give rise to problems in mix design. In addition to these properties, the micro texture of the aggregate particles will also strongly influence the performance of a compacted HMA layer. Smooth-surfaced river gravel, even partly crushed, may not generate as much internal friction as a totally crushed aggregate from particles having a coarse micro texture (ERA, 2013).

2.3.1 Mineralogical composition and chemical properties of aggregates

The basic physiochemical properties such as wetting, adhesion and stripping are function of composition and structure of minerals in aggregates. The most important minerals found in aggregates are silica, feldspars, ferromagnesian, carbonates and clay minerals. Quartz (silica) and feldspars are harder and more polish resistant minerals while lime stones are soft.

One of the most important effects of aggregate mineralogy on the performances of HMA is its influence on adhesion and moisture damage. Asphalt cement bonds better to aggregate with certain mineral types. For instance, Asphalt cement bond to carbonate aggregates (limestone) than to siliceous aggregates (gravel). Mineralogy of an aggregate has greater effect on performances of concrete mixes than for asphalt mixes. But; the project specification requirement should be selected so that aggregates having undesirable mineral components are not accepted for use (Freddy, L., et al, 1996).

The chemical properties of aggregate identify the chemical composition that an aggregate undergo due to chemical action. The chemical compositions of aggregates based on chemical analysis are usually given in terms of oxides, regardless of whether such oxides are present in the sample.

Despite the surface chemistry of the aggregate particles plays an important role in HMA performances as asphalt cement must wet the aggregate surface, stick to aggregate and resist stripping of the asphalt films in the presence of water, the Chemical properties of aggregates have little effect on their suitability and performance, except as they affect adhesion of asphalt binder to the aggregate (Freddy, L., et al, 1996).

2.4 Fillers

The term mineral filler is typically referred to the fine mineral particle with physical size passing the 200-mesh sieve (smaller than 75 microns). Mineral fillers are by-products of various stone crushing procedures, manifesting the feasibility of including them in the design of hot mix asphalt (Dr.S.P.Mahendra, et al., 2018). Fillers increase the stiffness of the asphalt mortar matrix. It also affects workability, moisture resistance, and aging characteristics of HMA mixtures. Generally, filler plays an important role in properties of bituminous mixture particularly in terms of air voids and voids in mineral aggregate (Kar, D., 2012).

2.4.1 Fillers derived from waste materials

There are numerous waste materials generated from different industrial, construction, domestic and agriculture sectors. They can mainly be classified under following heads: a) Agricultural waste like biomass wastes; b) Industrial wastes such as fly ash, ceramic waste, slag, cellulose waste; c) Municipal/household/domestic wastes such as incinerator residue, waste glass, and scrap rubber; d) mining wastes such as coal mine refuse and, d) construction and demolition wastes such as recycled fine concrete aggregates and recycled brick dust. This will help researchers to choose optimum filler while taking techno-economic considerations and ensuring the paramount performance of asphalt mixes (Zemichael, B. M., 2007).

i) Ceramic waste

Ceramics are compounds of metallic and nonmetallic elements possess high hardness, high compressive strength, high elastic modulus, low thermal expansion, low density, etc. They have special advantages of lightweight; can withstand very high temperatures and aggressive environments compared to metals used mainly as coatings and sensors (Ameta, N. K., et al, 2013).

It has been expected that about 30% of the annual production in the ceramic industry is converted to waste during cutting, grinding, dressing and polishing operations (Zemichael, B. M., 2007). This waste ceramic could be easily crushed to the desired size and form ceramic dust which could be utilized as filler.

Improvement in Marshall Stability and rutting resistance at higher OBC were observed when CW was introduced in asphalt concrete and SMA as compared to conventional fillers (Aburkaba, E.E. &Munaindy, R., 2010 and Muniandy, R., Aburkaba, E. &Taha, R., 2013). This was due to high strength, porous nature and higher absorption of bitumen on surface of CWP. SMA mixes prepared with CWP filler had better cohesive strength than that prepared with limestone filler in the same size range. This resulted in enhanced resistance to fatigue cracking and moisture-induced damage (Aburkaba, E.E. &Munaindy, R., 2010 and Muniandy, R., Aburkaba, E. &Taha, R., 2013).

The results of Marshall properties indicative that bituminous concrete mix prepared using ceramic dust as mineral filler is superior than mix prepared using stone and brick dust (Dr.S.P.Mahendra, et al., 2018).

So ceramic is a material that has a porous structure and high water absorption. Mixes prepared with ceramic dust show better performance value as compared to control specimens. OBC values increased in the mix, with increasing waste ceramic ratio. And with an increasing waste ceramic ratio, OBC, VMA, flow and specimens height value are increased. According to Turkish Highway construction specifications guideline, up to 30% of ceramic waste for binder course and up to 20% of ceramic waste for wearing course can be used in HMA (Cagdas, K., & Murat K., 2016).

Waste ceramic can be used as a filler and as well as partially replace as aggregate in flexible pavement. And it is feasible to utilize as aggregate material in flexible pavement (Vaghadia, B. K., 2018).

Table 2. 1 Physical properties of ceramic dust

Material properties	Results
Moisture Content (%)	0.41
Specific gravity	2.39
Fineness (%)	17.07
Grain size (micron)	27.35
surface area (µm2)	587.7
Percent insoluble	99.69
Percent soluble	0.3
PH value @ 27 ^{o}C	9.26
Plasticity index	None Plastic

Source: (Muniandy, R., et al., 2013)

The chemical compositions of CWP filler were analyzed quantitatively by using an energy dispersive analysis X-ray (EDX). The data in Table 2-2 indicates that oxides in ceramic waste consists of $CaCO_3$, SiO_2, Al_2O_3, CaO, Ca, Ti, Fe, Feldspar and MgO, the sum total of SiO_2, Al_2O_3, and Fe (Muniandy, R., et al., 2013).

Table 2. 2 Chemical composition of ceramic dust

Material	Weight percent
Calcium Carbonate ($CaCO_3$)	8
Silicon Dioxide (SiO_2)	74.94
Magnesium Oxide (MgO)	0.45
Aluminum Oxide (Al_2O_3)	8.54
Calcium (Ca)	40.77
Titanium (Ti)	0.31
Iron (Fe)	1.11
Sum of SiO_2, Al_2O_3, Fe	84.59
Feldspar, K Potassium oxide	1.55
Available Alkalis oxide as Na_2O	2.02

Source: (Muniandy, R., et al., 2013)

Application of industrial by-products used as a filler material (ceramic waste dust, coal fly ash, steel slag) improves the engineering properties of hot mix asphalt mix. The OBC decreased with the decrease in filler particle size for ceramic waste dust. Ceramic dust mastics had the highest stiffening power and were the stiffest mastics. It improves the overall mix properties of hot mix asphalt so that maintenance and rehabilitation costs of the pavement are reduced (Muniandy, R., et al., 2013).

The OBC (5.57% and 5.80%) obtained for mixes containing ceramic filler of is higher than that of lime 5.18% and 5.49% for 3% and 5% filler content respectively. The higher requirement of asphalt binder in mixes with ceramic filler might be due to the larger surface per unit volume and greater absorption of asphalt binder by ceramic waste. Marshall Stability values are higher in the case of ceramic filler at both 3% and 5% filler content as shown in Figure 2-1. The stability values for the ceramic filler is about 10% higher than conventional lime filler at 5% filler content. The flow values obtained for 3% and 5% ceramic filler mixes are within the limits. Mixes containing ceramic filler show a continuous increase in flow values and deform more under the traffic loads and have more flexibility. Industrial ceramic waste can be utilized as a replacement for conventional mineral fillers in asphalt mixes. The utilization of ceramic waste in the asphalt mixes reduce the waste materials requiring disposal and give a means to make the environment safe and clean (Fatima, E., et al, 2014).

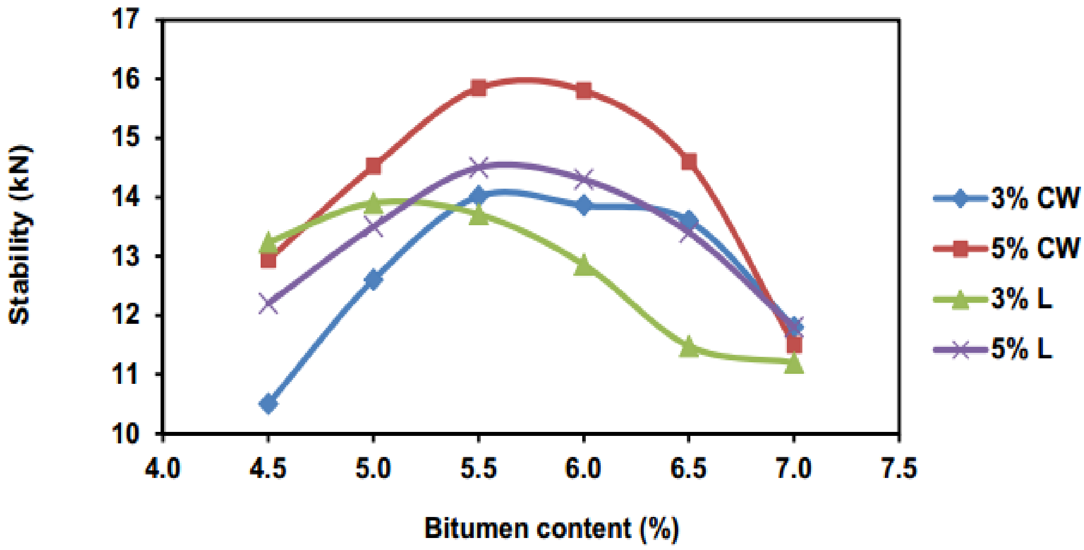


Figure 2. 1 Marshall Stability of ceramic waste and lime

Ceramic production in Ethiopia

The ceramics industry in Ethiopia includes the manufacture of ceramic products like floor and wall tiles, insulator and sanitary, kitchen wares clay structure. Raw materials used for ceramic production include feldspar, quartz, kaolin, clay, silica sand and limestone. The location of raw materials used for the production of ceramic tiles is described as follows (Geological Survey of Ethiopia, 2011).

ii) Coffee husk

Coffee husks are the major solid residues from the processing of coffee, for which there are no current profitable uses, and their adequate disposal constitutes a major environmental problem (Franca, 2015).

Coffee husk is more often considered waste of agricultural activities; when its mass rises, the disposal of coffee husk becomes an ecological crisis, especially around coffee purple centers. The residue from coffee processing factories, predominantly coffee processing waste matter and release from the plant, can be considerable sources for contamination of water sources and people living around coffee processing stations have complains about pollution of rivers and its associated health impact (Ayele, K., 2011 and Mussatto, S. I., 2014).Damping of Coffee husk at landfill sites facilitates the threat of wild fires, and generates toxic chemicals that affect the ecology, such as soil, water, and plants. Hence, the flourishing use of by-product of coffee bean processing, Coffee husk in concrete, can be placed forward as one of the environmental responsible and cost-effective eco-friendly ways of adapting coffee husk waste into valuable resources (Abebe Demissew1, Fekadu Fufa2 and Sintayehu Assefa3, 2019).

The experiment examined the practicability of CHA as partial replacement of cement for concrete material as alternative sustainable construction material. The investigation of the study found that OPC replacement with CHA from 2 to 10% resulted in better compressive strength and density. Therefore, 10% of CHA replacement is the optimum ratio for C-25 concrete production. Similarly, 15% of CHA concrete is good for lower grade of concrete, such as C-20. Based on these preliminary results, it can be concluded that CHA can be used as an alternative cement to replace cementations materials for the production of normal weight concrete with acceptable physical, chemical, and mechanical performances (Abebe Demissew1, Fekadu Fufa2 and Sintayehu Assefa3, 2019).

The results showed that the soil treated with CHA is generally improved in terms of strength. Addition of 20% CHA increases the bearing capacity of the soil by three-fold. In addition, the morphological studies of the soil samples treated with 10% and 15% CHA indicated the formation of hydrated particles and cementations' compounds as a result of the reaction between the soil and CHA. This indicates the potential usage of CHA as a stabilization agent and subsequently, it can address the disposal and environmental concerns related to coffee husk (M.K. Atahu*, F. Saathoff, A. Gebissa, 2018).

Conducted stabilization of expansive soils with coffee husk ash and showed that the addition of CHA reduces the plasticity of the soil and increases both the maximum dry density and the unconfined compressive strength. It is also found that the addition of higher percentages of CHA results in a decrease of both the unconfined compressive strength and maximum dry density of the soil. The swell and shrinkage tests indicated that the swelling and shrinking capacity of the soil stabilized with the addition of 25% CHA reduced by more than half compared to the untreated soil (Atahu,M. K., Saathoff, F. and Gebissa, A, 2017).

Based on (ASTM-C618 2000), Pozzolanic material is a siliceous or siliceous and aluminous material which, in itself, possesses little or no cementitious value but which will finely divided form in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties'. So the result showed that the CHA is not fulfilled the requirements to N & F class of pozzolan where the $SiO_2 + Al_2O_3 + Fe_2O_3 = <22.93\%$ (< 70% and 50%) and LOI

23.8 %(> 10%). Therefore, the stabilizer that used in this study does not have pozzolanic nature (Woldegiorgis, 2019).

Table 2. 3 Chemical composition of coffee husk ash .

Chemical properties	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
Test value	22.3	<0.01	0.6	9.7	1.4	<0.01	<0.01	<0.1	1.1	0.01	0.8	23.8

Source:Woldegiorgis, 2019

Table 2. 4 Properties of coffee husk ash

Properties	observed values	
Particle size gradation	Gravel (%)	0
	Sand (%)	78.9
	Fine (%)	21.9
consistency	Liquid limit (%)	28.26
	Plastic limit (%)	27.7
	Plastic index (%)	0.99
specific gravity		2.54

Source: Yibas Mamuye1 and Anteneh Geremew2, 2018

Coffee availability in Ethiopia

Coffee is one of the world's most popular beverages and important produces. Ethiopia is give with an income a good production environment for growing coffee with appropriate altitude, temperature, rainfall, soil type, and PH. Ethiopia is the origin of coffee Arabica. The country possesses a diverse genetic base for this Arabica coffee with considerable heterogeneity. The major coffee production areas in Ethiopia are Oromia and the Southern Nations, Nationalities, and People Regions (SNNPR) in the south and west of the country (Bart, M., 2014).

According to the (ICO, I. c. o., 2014), Ethiopia is the world's fifth largest coffee producer and Africa's top producer, with estimated 500,000 metric tons during the coffee or marketing season for F/Y 2012/2013.

In the processing of coffee generates significant amounts of agricultural waste, ranging from 50 to 60% the weight of the total coffee produced, depending on the type of processing. Coffee husks are the major solid residues from the processing of coffee and their adequate disposal constitutes a major environmental problem. In Ethiopia 192000metric tons of coffee is husk cast adrift as byproduct per year and there is

134,400 metric ton of coffee husk disposed per year in Jimma area are studied by (Wondwosen,S., et al, 2017).

2.5 Effect of mineral fillers on Marshall Properties of hot mix asphalt

Mineral filler in hot mix asphalt is an essential component of the mixture as the design and performance of hot mix asphalt concrete is greatly influenced by the nature and amount of the mineral filler in the mix. Excess quantity of filler tends to increase stability, brittleness, and proclivity to cracking. Deficiency of filler tends to increase void content, lower stability, and soften the mix. The filler content is particularly important as it has a significant impact on technical properties and, hence on potential end use (Eltaher, A. &Ratnasamy, M., 2016).

Various fillers differ in size distribution, surface area, voids contents, particle shape, mineral composition, and physicochemical properties (Zulkati, A., et al, 2012). This implies that their effects on the characteristics of the asphalt mixture also vary. Anggraini Zulkati et al. carried out studies on the role and effects of fillers on the mechanical properties of the asphalt concrete mixture. According to this study, three wearing course mixtures, including granites, hydrated limes, and kaolin as filler fraction, were assessed by the Marshall Mix design method to determine their OBC. The study showed that the use of hydrated lime or kaolin as filler requires more asphalt because of their relatively higher specific surface area, whereas the highest stiffness performance was found for hydrated lime, followed by granite, and kaolin mixtures. Mixtures with hydrated lime and mixtures with kaolin showed higher deformation resistance than that of the mixture with granite. In generally, the study showed that the existence of filler in asphalt concrete mixture affects the mixture's performance as: i) filler influence the quantity of bitumen content ii) filler affects the workability during mixing and compaction, and iii) resultant properties of asphalt filler mastic contribute to the mixture performance.

In the same way, another researcher called (Muniandy, R., et al., 2013) investigates the effectiveness of new filler materials. The main objective of this study was to facilitate decisions concerning the effectiveness of using new filler types which are byproducts of other industries. The various experimental fillers possessed different particle sizes and were expected to improve the engineering properties of paving mixtures, thereby enhancing pavement performance. The reported improvement in the engineering properties of the paving mixtures containing Ceramic waste filler, Coal fly ash, and Steel sludge filler can be attributed to the bonding and cementation properties of the fillers. These properties tend to increase the viscosity of the filler-asphalt mastic and the texture of the filler particles which consequently increases the frictional resistance among the aggregate particles, increasing the stability of the mix. From the, it can be concluded as : i) filler type and particle size directly affect the engineering properties of the asphalt mixtures; ii) in addition to filling the voids, the fillers' components interact with the binder present in the mix, potentially making it stiff and brittle. The change in mix properties is strongly related to the properties of the filler. iii) Ceramic waste filler and Steel sludge filler used as filler were found to be effective in improving the Marshall stability, resilient modulus, and Marshall Stiffness index, as compared to Lime stone filler. Coal fly ash had the lowest Optimum asphalt content. It did little to improve the Marshall Stability or resilient modulus value as compared with to reference filler iv) Laboratory tests results show that Ceramic waste filler and Steel sludge fillers improve the overall mixture properties of asphalt. The use of these special fillers improves pavement performance, thus reducing the maintenance and rehabilitation costs of the pavement.

In general, different characteristics of HMA were observed when the fillers in the mixture were varied by type and content. This indicates that, mineral fillers are significant ingredients affecting mixture properties. Utilization of industrial wastes and byproducts in asphalt mixes results in the improvement of the engineering properties and a reduction in the optimum asphalt content. The reduction in optimum asphalt content would result in significant cost saving.

2.6 Aggregate gradation

Aggregate gradation is the distribution of particle sizes expressed as a percent of the total weight and total percent passing various sieve sizes. It is determined by sieve analysis, that is, by passing the material through a series of sieves stacked with progressively smaller openings from top to bottom. And weighing the material retained on each sieve. (Freddy, L., et al, 1996).

It is the most important property of an aggregate that affects almost all the properties of a HMA, including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage (Freddy, L., et al, 1996) .

Theoretically, it would seem reasonable that the best gradation for HMA is one that gives the densest particle packing. The gradation having maximum density provides increased stability through increased inter-particle contacts and reduced voids in the mineral aggregate. However, there must be sufficient air void space to permit enough asphalt cement to be incorporated to ensure durability. Meanwhile it is still necessary leaving some air space in the mixture to avoid bleeding and/or rutting. A tightly packed aggregate (low VMA) also results in a mixture that is more sensitive to slight changes in binder content (Freddy, L., et al, 1996).

2.7 Marshall Mix design method

This mix design method was found by Bruce Marshall from the Mississippi highway department in 1939. It is the most widely used asphalt mix design in many world countries because of its equipment is relatively portable and inexpensive. This mix design method criterion allows the designer to choose OBC to be added to the specified aggregate blend to a mix which satisfied the desired properties of the mix like density, stability, and flow. The method uses the standard HMA samples that are 102 mm in diameter or thickness and 63.5 mm specimen height. The production of HMA samples are carefully specified and involves the different procedure, as well as the attention, is paid for heating temperature, mixing and compaction temperature of aggregates and asphalt binder. Samples are compacted by applying different blows on both faces of specimens based on the expected traffic level (Asphalt Institute, 1996).

After the Marshall sample has been prepared, with the help of the Marshall Test machine, stability and flow of the specimen is measured. The stability of the test measures the maximum load supported by the Marshall specimen at a loading rate of 50.8 mm/minute. The load is applied to the specimen until failure made, and the maximum load is recorded as stability. Stability is the maximum load that the sample can withstand at 60^0C. whereas; the amount of plastic deformation that occurs under maximum load is flow. Flow is the vertical deformation of specimens in 0.01-inch units formed at the point of maximum load. Also, a density void analysis is used to determine the bulk unit weight, air void, void in mineral aggregate and percent void filled with asphalt. The OBC is determined as per the asphalt institute based on the combined results of Marshall Stability and flow together with density-void analysis. Furthermore, a plot of bitumen content versus measured results of Marshall Stability, bulk density, VMA, VA, VFA, and flow are developed. The purpose of the Marshall Mix design is to determine the OBC.

Thus, OBC is determined to correspond to the value of maximum stability, maximum unit weight, and at four percent air voids. Then, at the percentage of OBC; stability, flow, VMA, VA, and VFA are checked if they satisfied the requirements of limiting criteria (Asphalt Institute, 1996).

Although Marshall Method impact compaction cannot simulate actual condition and measure shear strength as well as its inability to estimate permanent deformation, the method has many effective advantages. It is easy to use, portable, inexpensive, short testing time and requires less energy relative to Hveem method.

2.8 Moisture susceptibility of hot mix asphalt

Moisture susceptibility is the tendency of HMA toward stripping. The loss of integrity of an HMA mix through the weakening of the bond between the aggregate and the binder is known as stripping. One of the methods to prevent moisture susceptibility is proper mix design. The three mix parameters that are identified in the laboratory tests may influence stripping tendency are gradation, asphalt film thickness (bitumen content) and voids. Gradation, as it relates to asphalt film thickness and the voids in a mix, is important. Mixes with finer gradations (surface mixes) tend to have larger asphalt film thicknesses and lower stripping tendency. Coarser gradations tend to have smaller asphalt film thicknesses and greater stripping tendency (Ethiopian Road Authority , 2002, Abrar Awol. and Kandhal, P.S., et al, 1998).

There has been some abundant evidence to indicate that some aggregate appears to have a greater affinity for water than for asphalt cement. This is called hydrophilic property or water loving and asphalt films on these aggregate particles may become detached or stripped. It is commonly accepted that the nature of electric charges on aggregate surface when in contact with water significantly affects the adhesion between the aggregate and the asphalt cement as well as its resistance to moisture damage. Most aggregate become negatively charged in the presence of water while others bears a positive charges. The electrical repulsion between the two negatively charged surfaces, that is, the asphalt and the aggregate surface, can cause the asphalt to separate (or strip) from the aggregate surface (Freddy, L., et al, 1996).

A commonly used test for this purpose is AASHTO Designation T 283 Standard Test for Resistance of Compacted Bituminous Mixture to Moisture Induced Damage (AASHTO 1997) and ASTEM 4867. In this test, a set of replicate specimens of the asphalt mixtures to be evaluated are compacted to 7 ± 1% air voids. The specimens are divided into two subsets. One subset is tested in the dry condition for indirect tensile strength. The other subset is subjected to vacuum saturation followed by a freeze and warm-water soaking cycle and then tested for indirect tensile strength. The tensile strength ratio, which is calculated by dividing the average tensile strength of the conditioned subset by the average tensile strength of the dry subset, is used as an indicator of stripping resistance.

2.9 Summary of the literature

The properties of asphalt concrete depend on; the quality of its components (asphalt binder and aggregates), mix proportions and construction process. The study on physiochemical properties of aggregate is most important effects of aggregate mineralogy in the performances of HMA. Its influence is on adhesion and moisture damage.

Fillers are one of the most important ingredients of HMA that plays an important role in properties of bituminous mixture particularly in terms of air voids and VMA. Currently, there are numerous waste materials generated from different industrial, construction, domestic and agriculture sectors that helps researchers to choice optimum filler. Application of industrial by-products used as a filler material (ceramic waste dust, coal fly ash, steel slag) and agricultural wastes improves the engineering properties of hot mix asphalt mix. The reported improvement in the engineering properties of the paving mixtures containing Ceramic waste filler, Coal fly ash, and Steel sludge filler can be attributed to the bonding and cementation properties of the fillers. Meantime deficiency of filler tends to increase void content, lower stability, and soften the mix.

Despite there are many methods of asphalt mix design, the Marshall test method has may effective advantages. It is easy to use, portable, inexpensive, short testing time and requires less energy relative to others method. And besides of this, conducting asphalt performance tests like tensile strength test is also an important.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Sampling area

This experimental sampling was conducted in Jimma town at specific location of Jimma institute of Technology Civil laboratory with7°41'N Latitude and 36°50'E Longitude shown in Figure 3:1*(source: ArcGIS 10.3.1 software*). The site sampling in case of CHA and CWP is Jimma town while that of CSD was Danaba which is 81 km from the town.

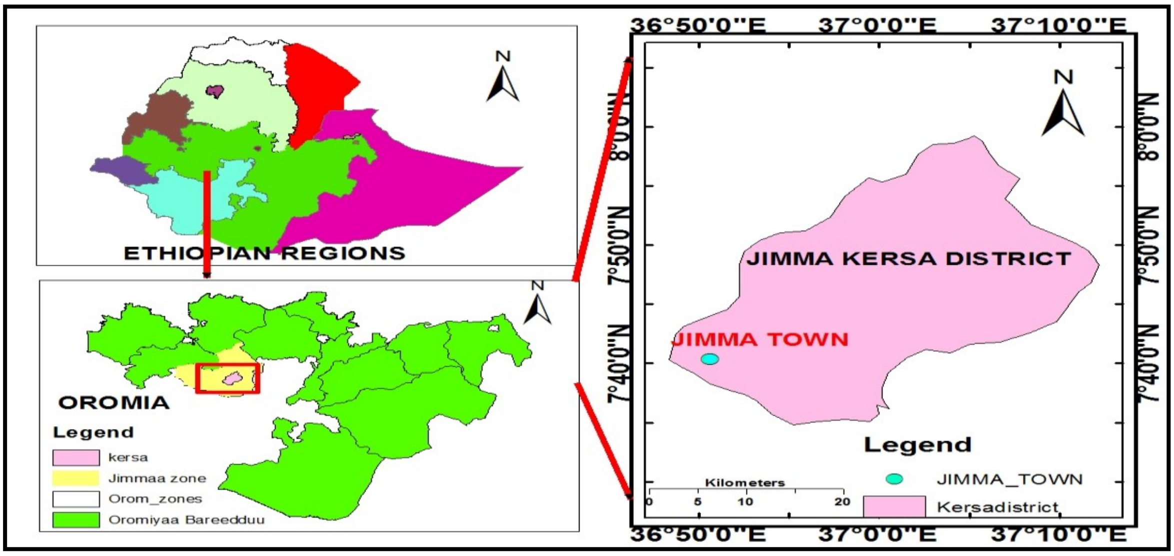


Figure 3. 1 Sampling area map for the study

3.2 Study design

The study is designed to answer the research questions and meet its objectives based on experimental findings. It was performed as per AASHTO, ASTM, ERA and BS laboratory standards for all materials properties (asphalt binder, aggregates, and fillers).

The material selection and sample collection was carried out for the proposed HMA mix design from Ethiopian road Construction Corporation quarry located at Danaba site 81 km from Jimma town. Accordingly, aggregate of different size and 80/100 bitumen penetration grade were collected. The site is selected from the viewpoint of the good quality material besides of its availability in nearest local site of the study area. Coffee husk was collected from local shop (coffee bean processing center) in Jimma town in the form of husk which was solid waste. And ceramic waste was collected from the near construction site in Jimma institute of Technology and near ceramic distribution center in the town.

The next work followed material selection and collection was quality tests for aggregates, bitumen and fillers .The aggregate quality tests conducted were: specific gravity, Los Angles abrasion, Sieve analysis (gradation), water absorption, flakiness index, aggregate crushing value and aggregate impact values .And bitumen quality tests conducted were: softening point, penetration test, ductility test, flashing and firing test as well as specific gravity test.

Afterward, HMA samples were prepared with three different filler contents of CSD from 4.0, to 7.0% with 1.5% increment by weight of total aggregate) and five different bitumen content (4.0 to 6.0% with 0.5% increment by weight of total mix) as per ASTM D1559 procedure. The samples were subjected to Marshall Stability test and aimed to obtain the proper OBC with its respective OFC based on maximum Marshall Stability.

Then, CSD was replaced with CWP and CHA at replacement percent of 0, 25, 50, 75 and 100 % and 1.5, 3, 4.5, 6 and 7.5 % by the mass of CSD respectively. The replacements were performed on the best fit selected gradation, OBC and OFC. Then, stability, flow and volumetric properties were determined. For this study the total of 93 specimens were prepared including Tensile strength ratio test. Seventy five (75) of these specimens were done for Marshall test and out of these 30 specimens were executed for partial replacement (15 specimens for CSD-CHA, 12 specimens for CSD-CWP and 3 for control mix) while 18 specimens out of 93 specimens were conducted for TSR test.

Near the end, the indirect tensile strength (ITS) test was conducted for CSD, CSD-CHA and CSD-CWP mix design to evaluate water resistivity of the mix against moisture damage.

Lastly, analyses, interpretation and discussion of the laboratory test results were done and followed with conclusions and recommendation as shown in Figure 3.2.

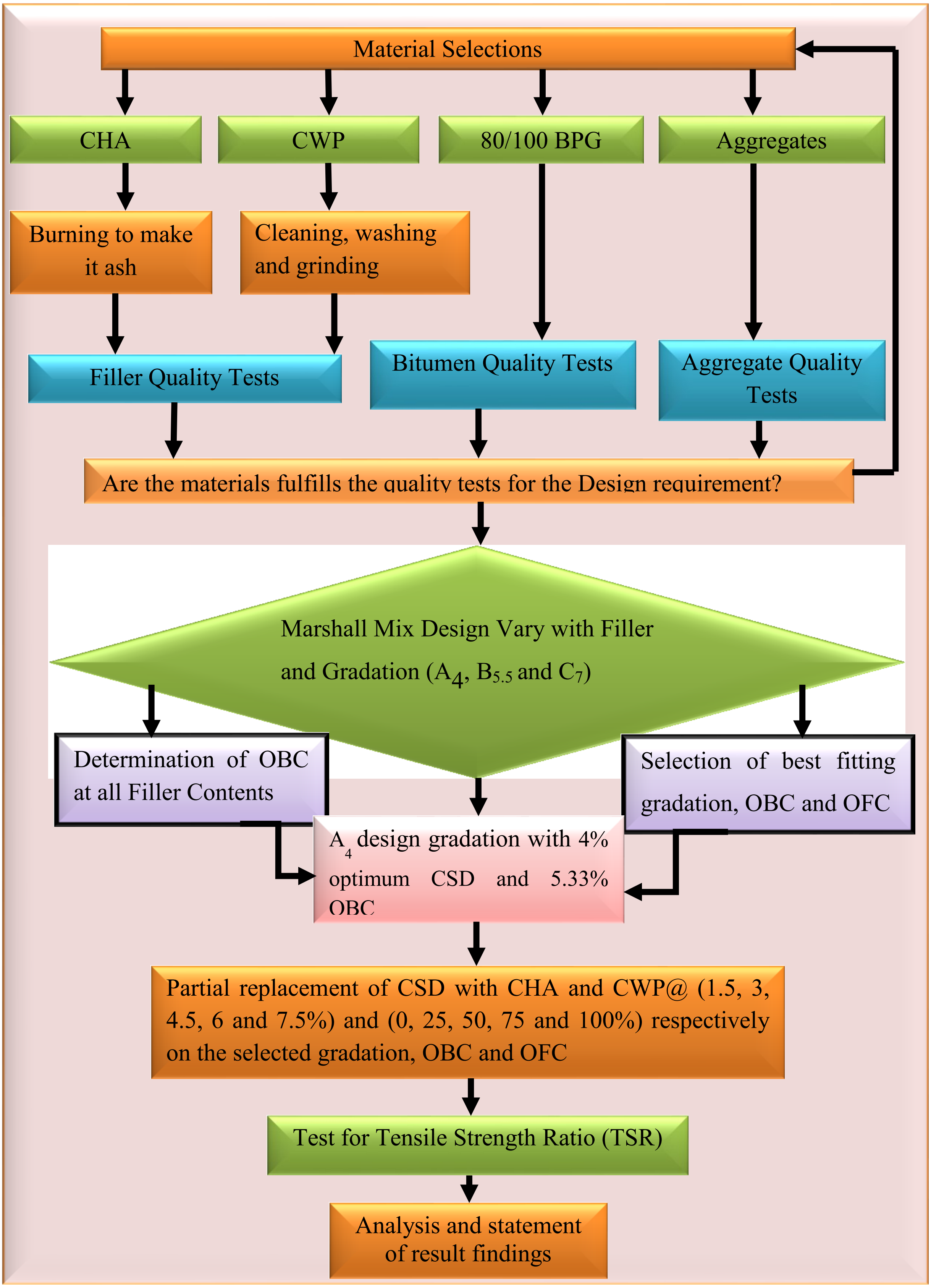


Figure 3. 2 Study design flow chart

3.3 Source of data

The primary sources of data were laboratory tests on aggregate properties, Marshall Stability test, TSR test, chemical composition tests for mineral fillers and bitumen quality tests. And the secondary sources of data were the existing relevant documents, pavement design manuals, literatures and scientific researches as well as standards.

3.4 Study variables

3.4.1 Dependent variable

The dependent variable is almost linked with the main objective. The dependent variable of this study is comparative effects of CWP and CHA replacement with CSD in HMA.

3.4.2 Independent variables

The independent variables of this study are properties of aggregate, bitumen properties, physiochemical properties, types and contents of fillers, Marshall Properties of the mix design, gradation and percent of replacements.

3.5 Experimental setup

This study is laboratory based research intended to determine comparative effects of CWP and CHA replacement with CSD in HMA. The primary data were collected from experimental conducted at Highway laboratory, Jimma institute of Technology. And every experiment was done following the guidelines specified in study design and standards.

3.5.1 Material selection

All quality pavements should be engineered to contain requirements for items such as: properly selected asphalt binder grades for the climate and traffic; aggregate characteristics including material quality and gradation; HMA volumetric requirements; and HMA performance criteria (Asphalt Institute, 2014) .The mix design of this research started with selection and evaluations of different size of aggregate, bitumen grade and filler materials. Accordingly, aggregate materials and binder selection was carried out for the proposed HMA mix design from Ethiopian road Construction Corporation quarry located at Danaba site 81 km from Jimma town. The site is selected from the viewpoint of the good quality material besides of its availability in nearest local site of the study area.

After selection of materials, different quality test of all collected materials were conducted based on international and local standards. The quality tests are required to evaluate whether or not the selected materials meet the mix design requirement.

3.5.2 Properties of materials

i) Physical properties of Aggregates

Aggregate used in mix design should be clean, angular (not excessively flaky), strong enough, resistant to abrasion and polishing, not highly absorptive and have good affinity with bitumen. As indicated in Table 4.2, the physical properties of aggregates were conducted pre-Marshall Tests. And then it was compared with local and international standards.

ii) Physical properties of mineral fillers

In this research ceramic waste from industrial as well as construction work and coffee husk, the byproduct of agricultural wastes were partially replaced with CSD as filler in HMA.

a) Ceramic waste powder as filler

Ceramic waste was collected from the nearby construction site in Jimma institute of Technology as well as Ceramic distribution shop center in Jimma town. Then, manual grinding was performed on the dried conglomerate in order to obtain its dust which pass number two hundred (#200) sieve size. Following this its physical and chemical properties were performed as shown in Table 4.4 and 4.5 respectively.

Figure 3. 3 Preparation of dust passing 0.075mm of CWP (Captured.by: Achalu Kebede)

b) Coffee husk ash

The coffee husk was collected from local shop (coffee bean processing center) in Jimma town in the form of husk. And it was solid waste and burnt in uncontrolled temperature. Then the ash was subjected to physical tests like plasticity index, specific gravity, sieve analysis as well as chemistry test as shown in Table 4.4 and 4.5. Coffee husk is a non-plastic material as indicated in *appendix F* .And the variation in specific gravity of CHA (observed in different literature) may be due to the production environment and burning temperature.

a) Burning of coffee husk

b) sieve analysis of fillers

c) PI test for CHA

d) specific gravity test for fillers

Captured by :Mekonnen Bayisa

Figure 3. 4 a) burning; b) sieve analysis; c) specific gravity; and d) PI test for CHA

iii) Chemical composition of aggregate fillers

The chemical properties of aggregate filler identify the chemical composition based on chemical analysis. It is given in terms of oxides, regardless of whether such oxides are present in the sample. For this study the chemistry tests for both CWP and CHA were performed at Geological Survey of Ethiopia as shown in Table 4.5. The detail of this test data illustrated in *appendix I.*

iv) Asphalt binder material

For this study 80/100 bitumen penetration grade were collected from Ethiopian road Construction Corporation quarry located at Danaba site 81 km from Jimma town. This grade of bitumen has very strong viscosity compare to other grades. This is due to its high penetration with lower softening point and such type of bitumen is worthy for moderate weather condition. The reason behind the selection of this grade is due to its widely used across this country. And almost nearly half of this country has moderate weather condition besides of its local availability as well as ease of use and flexibility.

The physical properties of this bitumen were done and compared with standards as shown in Table 4.6.

3.5.3 Hot mix asphalt design method of the study

Asphalt is the combination of aggregates, fillers and bitumen. The determination of mix design method and material proportioning is a critical task of the study. In this study, the HMA samples were prepared using CSD with three different filler content from 4.0, to 7.0% with 1.5% increment by weight of total aggregate) and five different bitumen content (4.0 to 6.0% with 0.5% increment by weight of total mix). Three trial samples were prepared for each of bitumen contents. Accordingly, the total mix design carried out in the Marshall test were 3 (types of filler content or 4, 5.5 and 7% CSD by weight of total aggregate) × 15 samples (five different bitumen contents × three samples for each bitumen) plus 30 samples [(five different percentages of CHA (1.5 ,3 ,4.5 ,6 and 7.5% by total weight of CSD) and five different percentages of CWP (0,25,50,75 and 100% by total weight of CSD)) × three samples for each] =75 Marshall specimens were prepared in both OBC determination and partial replacement.

i) Marshall specimen preparation and test procedures of the study

The preparation of Marshall Specimen is the series tasks of experimental procedure guided by standards. Firstly, the blended aggregates having total weighing of 1200gm (for a single specimen) was heated in an Oven to a temperature of 105 to 110 °C for above 16 hours as shown in Figure 3.5. Then, the asphalt binder also heated at 155 - 165°C and added to the pre-heated aggregate and mixed thoroughly at desired temperature of 160°C (from 130-165°C for 80/100 bitumen grade) for two minutes. Next, after placing a paper disc in the mold, the mixed sample is poured into a mold. And then another paper disk is placed on the top of the mix. Afterward, the mixture is compacted with a compaction effort of 75 blows on each side by a 4.5kg hammer free-falling from 457mm height. After compaction, the specimens were put to cool for some hours (over 12 hours). And later, it was removed from the mold with the help of extruder. Then, the height of specimens, dry mass in air, sub-merged weight and saturated surface dry mass were taken. After that, the Marshall Stability and flow were tested following the removal of the specimen from immersed in water bath at 60˚C for 30 ± 5 minutes as per ASTM D1559 and witnessed in Figure 3.5 c.

a) placing prepared specimen in an oven b) bitumen heating c) Marshall Test

Captured by **Dejene Dereje**

Figure 3. 5 a) placing prepared specimen in an oven; b) bitumen heating; c) Marshall test

ii) Determination of optimum bitumen content (OBC)

Here, asphalt mixes for the three different gradations (A_4, $B_{5.5}$, and C_7) corresponding to the variation in fillers from 4 to 7% with 1.5% incremental by the weight of total CSD were conducted. And it was aimed to obtain the design gradation with its respective OBC and OFC. In this way, for each individual bitumen contents and different gradation (3 filler vary x 5 bitumen content x 3 trial specimens = 45 specimens) were prepared for determination of OBC.

In this study, the NAPA (National Asphalt Pavement Association) method is adopted for OBC determination. According to NAPA: i) the bitumen content which corresponds to the specification's median air void content (4 percent typically) of the specification. This is the optimum bitumen content; ii) The bitumen content is then used to determine the value for Marshall Stability, VMA, flow, bulk density and percent voids filled from each of the plots; iii) Compare each of these values against the specification values for that property and if all are within the specification range, the bitumen content at 4 percent air voids is optimum bitumen content. If any of these properties is outside the specification range, the mixture should be redesigned.

This optimum binder content determination was done after the former specified 45 specimens were subjected to Marshall stability-flow test. The details of this work are presented *as section 4.2 of result and discussion in Table 4.7 and Figures 4.3 to 4.5*. And furthermore, every detail work is placed in *appendix E1, E2 and E3.*

Based on this method, the graphical analysis was carried out with Microsoft excel sheet using the collected data through laboratory work. And then the relationship between volumetric parameters and bitumen contents were examined. Finally, the best fit gradation design was selected parallel to OBC determination. Then, the whole resulted Marshall Properties were compared with specification as per ERA 2002 pavement design as shown in Table 3.1.The details of this work is presented *as Table 4.8 of section 4.2.*

Table3. 1 Mechanical properties of asphalt wearing course

Total traffic (10^6 ESA)	<1.5		1.5-10		>10	
Traffic classes	T1,T2,T3		T4,T5,T6		T7,T8	
Mix Parameters	Min.	Max.	Min.	Max.	Min.	Max.
Stability (kN at 60^0C	3.5	-	6	-	7	-
Number of blow (compaction level)	2*35		2*50		2*75	
Flow (mm)	2	4	2	4	2	4
AV (%(	3	5	3	5	3	5
VFA (%)	70	80	65	78	65	75
VMA (%)	13	-	13	-	13	-

Source: ERA Manual, 2002

iii) The mix design replacement method of the study

After completing determination of OBC, the intended partial replacement of CSD with CHA and CWP was undertaken. CSD was replaced with CWP and CHA at replacement percent of 0, 25, 50, 75 and 100% and 1.5, 3, 4.5, 6 and 7.5% by the mass of CSD respectively. *As it is shown in Table 4.9 and 4.10*, the mean values and standard deviations of each Marshall parameters were computed. And the study was made on comparative effect of CHA and CWP in the replacement. The general steps followed by partial replacement were: i) the coffee husk and ceramic waste were collected; ii) drying and burning of the husk and cleaning as well as grinding of ceramic waste were undertaken; iii) the replacement percent of each fillers was determined (based on studied properties of the materials and by referring different literatures on the issues); iv) the replacements of CSD with CHA and CWP were made and added to the blended aggregates and heated to a temperature of 105 to 110 °C prior to adding bitumen; v) bitumen was heated between 130 to 165°C before adding to the blended aggregate specimen and the standard Marshall Mold were also heated to 90 to 150 °C vi) then, the determined 5.33% of OBC was added to the heated aggregate and mixed thoroughly until a homogenous mixture is obtained; vii) the hot mixture is poured into the mold and subjected to 75 blows of compaction efforts on each face of the specimen after packing the mold by non-absorbent filter paper in each side. In general, the preparation of the Specimens, compaction, and testing were done as per ASTM D 1559 Marshall Standards.

a)Compacted specimens of CSD-CWP mixes; b) Compacted specimens of CSD-CHA mixes

Captured by Yerosan Feyissa

Figure 3. 6 a) Compacted specimens of CSD-CWP mixes; b) Compacted specimens of CSD-CHA mixes

3.5.4 Density and void analysis

Density-void analysis is one of the tasks that should be performed to the compacted specimen after determination of height and masses of the specimen in different condition.

In this section, volumetric properties which determine the performance of asphalt mixes were discussed.

i) The bulk specific gravity of compacted specimen

Bulk specific gravity is the ratio of the mass in air of a unit volume of permeable material. It includes both permeable and impermeable voids normal to the material. And it takes place at a stated temperature to the mass in the air (of equal density) of an equal volume of gas-free distilled water. The bulk specific gravity determination was performed on the compacted specimens after it extruded from the mold. Normally this value is utilized to determine the mass per unit volume of the compacted mixture. In this study, the bulk specific gravity of compacted mixtures was determined by using saturated surface dry specimen as per AASHTO T 166/ ASTM D 2726. The standard bulk specific gravity test is expressed as:

$$Gmb = \frac{A}{B-C} \quad (1)$$

Where: Gmb= Bulk specific gravity of compacted specimen, A = Mass of the dry specimen in air, g, B = Mass of the saturated surface-dry specimen in air, g, and, C = Mass of the specimen in water, g.

Source: Freddy, L., et al, 1996.

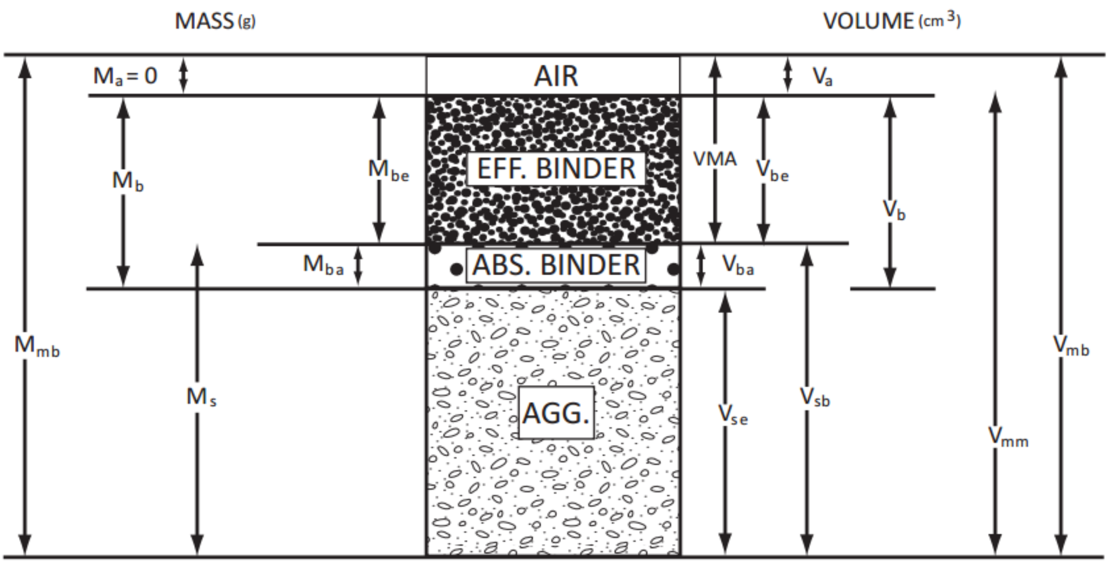


Figure 3. 7 Representation of volumes in a compacted HMA specimen

VMA = Volume of voids in mineral aggregate V b = Volume of asphalt binder

V mb = Bulk volume of compacted mix M s =mass of total aggregate

V mm = Void less volume of paving mix   Mb = mass of asphalt binder

V ba = Volume of absorbed asphalt binder   M s= Mass of aggregate

V sb = Volume of mineral aggregate   M air = Mass of air = 0

M be = Mass of effective asphalt binder and M ba = Mass of absorbed asphalt binder

ii) The theoretical maximum specific gravity of loose specimen

It is defined as the ratio of the weight in air of a unit volume of loose asphalt mixture at a stated temperature to the weight of an equal volume of gas-free distilled water at a stated temperature. The theoretical maximum specific gravity (Gmm) at various asphalt binder content was used to determine the air void percentage in the mix. Experimentally it could be determined as

$$\text{Gmm} = \frac{A}{A+B-C} \tag{2}$$

Where: Gmm= Maximum Theoretical Specific Gravity is calculated as per ASTM D 2041, A = Mass of the dry sample in air, g, B = Mass of Jar Filled with Water, g, and C = Mass of Jar Filled with Water + Sample, g.

iii) Air void (VA)

According to Asphalt Institute, (2003), the total compacted paving mixture consists of the small air spaces between the coated aggregates particles. The voids in a compacted mixture are obtained in accordance with ASTM D3203- 94 standard test method. The voids in a compacted mixture are obtained as follows.

$$\text{VA} = \frac{\text{Gmm}-\text{Gmb}}{\text{Gmm}} \tag{3}$$

Where: VA = Air voids in compacted mixture and Gmb= bulk specific gravity of compacted mixture.

iv) Voids in mineral aggregates (VMA)

According to Asphalt Institute,(2003), the voids in the mineral aggregates, are defined as the inter-granular void space between the aggregate's particles in a compacted paving mixture that includes the air voids and the effective bitumen content, expressed as a percent of the total volume of the sample. The VMA are calculated based on the bulk specified gravity of the aggregates. And is a percentage of the bulk volume of the compacted paving mixture. It is calculated as:

$$\mathrm{VMA} = 100 - \frac{\mathrm{Gmb}}{\mathrm{Gsb}} * \mathrm{Ps} \quad (4)$$

Where: VMA = voids in the mineral aggregate, Gsb= bulk specific gravity of total aggregate and Ps = aggregate content, percent by mass of total mixture.

v) Voids filled with asphalt (VFA)

According to Asphalt Institute, (2003), VFA is the percentage portion of the volume of inter-granular Void space between the aggregate particles that is occupied by the effective asphalt. It is expressed as the ratio of (VMA-VA) to VMA. VFA is the percentage of the integral void space between the aggregate particles (VMA) that are filled with asphalt. The mathematical relationship has shown as:

$$\mathrm{VFA} = 100 * \frac{VMA-VA}{VMA} \quad (5)$$

Where: VFA = Voids filled with asphalt, percent of VMA and VMA = Voids in mineral aggregates, percent of the bulk volume.

3.6 Moisture susceptibility

The deteriorations of asphalt concrete due to detrimental influence of moisture results in stripping .And it consequences the loss of strength through weakening the bond between binder and aggregate. This loss of strength subsequently brings rutting and shoving in the wheel paths over a period of years since asphalt peels off the aggregate. (Freddy, L., et al, 1996)

3.6.1 Indirect tensile strength test (ITS)

The indirect tensile test (ITS) is useful in characterizing HMA through evaluation of water susceptibility and cracking potential of an asphalt mixture. It is one of HMA performance test. The test involves loading a cylindrical specimen with a compressive load along two opposite sides in the diametrical plane. Tensile strength ratio (TSR) is the relation of the strength values before and after water storage. The indirect tensile strength was calculated using the equation given in ASTM D 4867.

$$\mathrm{St} = \frac{2000P}{\pi DH} \quad (6)$$

Where: St= Tensile strength (kPa), P= maximum load (N), D= Diameter of the specimen (mm) and H= thickness of specimen (mm).

In this study, the indirect tensile test was undertaken to estimate the moisture sensitivity of asphalt mixtures as per ASTM D4867 test method. It was conducted for eighteen specimens (six for each CSD-CWP, CSD and CSD-CHA) on dry and wet specimens at displacement rate of 50mm/min with target 7.0% ± 0.5% air void. The peak compressive load and indirect tensile strength of each specimen was determined using Marshall immersion tensile test after chamber conditioning for 2 h at 25°C in case of dry condition while partial vacuum saturation for 24 h at 60°C was done for wet condition. And later tensile strength ratios (TSR) of the three mixes were performed. The results of the test were *presented as section 4.6 and Chapter 4 as well as appendix G.*

$$\text{TSR} = \frac{\text{St condition}}{\text{St uncondition}} \quad (7)$$

Where TSR= Tensile Strength Ratio (%)

St (conditioned) = Average tensile Strength of Conditioned Sample (kpa)

St (unconditioned) = Average tensile Strength of Unconditioned Sample (kpa)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Engineering properties of materials

4.1.1 Aggregate

Aggregate affects almost all the properties of hot mix asphalt concrete. The properties of asphalt concrete that can be affected by aggregates are stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage. So, in order to obtain a good quality asphalt mix design, it is must to study the aggregate properties properly.

The design of aggregate proportion is the output of trials based on local or international standards. It needs a critical gradation concept since it governs almost all properties of HMA. Obtaining the best appropriate mix proportioning requires investigations of individual properties of HMA components (aggregates, fillers and binder) in addition to their combined effect on mixture of asphalt concrete. For instance, as filler contents increase the asphalt absorption increase with an increase in aggregate filler surface area. This results in the finer the asphalt mixture gradation that requires the greater amount of binder to uniformly coat the particles. An increment in the binder requirements, again leads to the decrease in total void of the mixture that outcomes dryness. And this dryness in turns ends in poor durability as a result of raveling and disintegration. Thus, the proportions of the mix design gradation should be neither too finer nor too coarser.

As shown in Table 4.1 and Figures 4.1 to 4.2, almost middle bound aggregate gradation (A_4 Gradation) with a NMAS of 19 mm was selected for this study. And from the three trials of aggregate proportions with their corresponding trial gradations, the A_4 Gradation was applied as per ASTM D3515. This final selection was based maximum Marshall Stability of the three trials. The detail of this work is illustrated in *appendix A*.

Table 4. 1 Aggregate gradation of the study and specification for NMAS 19 mm

Sieve size (mm)	Percent of passing corresponding to each three filler			ASTM D3515 specification	
	4%	5.5%	7%	Lower limit	upper limit
25	100	100	100	100	100
19	90.5	90.5	95	90	100
12.5	79.5	79.5	88	71	88
9.5	68	68	80	56	80
4.75	50	50	60	35	65
2.36	36	36	45	23	49
1.18	26	26	35	15	37
0.6	19	19	26	10	28
0.3	12	12	19	5	19
0.15	8	8.5	12	4	13
0.075	4	5.5	7	2	8

Trials of aggregate blending proportions

Gradation design	Coarse aggregate	Intermediate aggregate		Fine aggregate	Filler	Combined
	14-25mm	6-14 mm	3-6mm	0-3mm	#200 pass	
A_4 Gradation	23.03%	37.53%	12.72%	25.70%	1.02%	100%
$B_{5.5}$ Gradation	22.91%	37.34%	12.66%	25.70%	1.39%	100%
C_7 Gradation	20.34%	35.97%	12.85%	29.34%	1.50%	100%

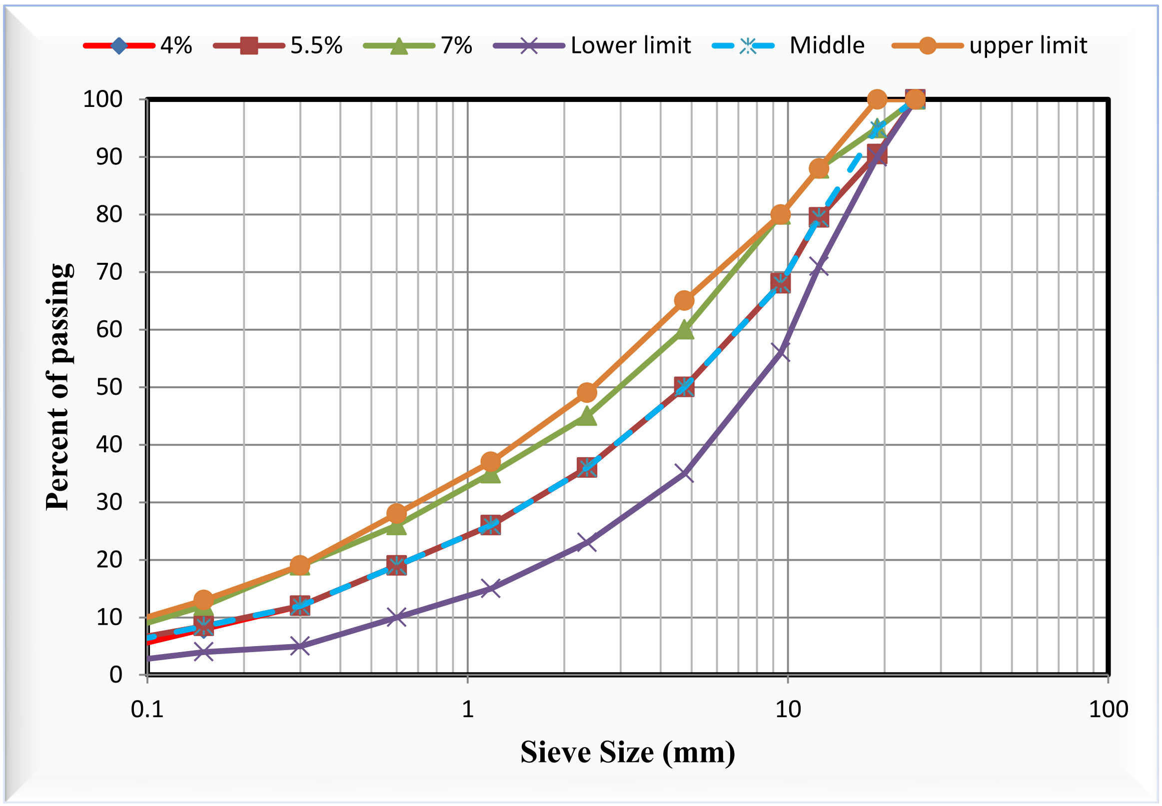


Figure 4. 1 The three combined aggregate gradations and limits

As it is shown in Figure 4.2, the gradation design of the study almost overlap the middle bound limit with only little deviation incase of 19, 0.15 and 0.075 mm aggregate sizes.

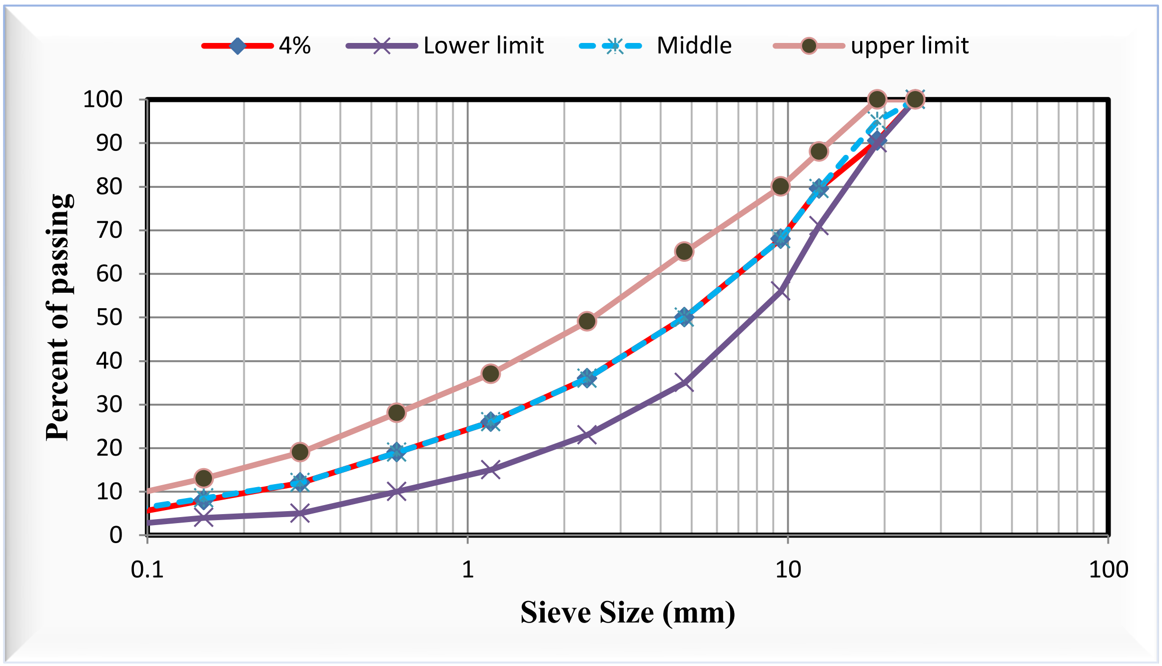


Figure 4. 2 Mix gradation design of the study with 4% CSD filler (A_4 gradation)

The characteristics of the materials are given in Table 4.2. These characteristics are the main factors for suitability of the materials. And the material met the standard requirements of AASHTO, ASTM, BS and ERA so that the intended mix design.

Table 4. 2 Materials quality tests

Tests	Test Method	Test results		ERA 2002 Specifications
		Coarse aggregate	Fine aggregate	
Bulk dry specific gravity	AASHTO T 85 – 91	2.623	2.609	-
Bulk SSD specific gravity		2.703	2.643	-
Apparent specific gravity		2.715	2.702	-
Water absorption (%)	BS 812, part 2	1.28	1.32	< 2
Flakiness index (%)	BS 812 part 105	21	-	< 45
Los Angeles Abrasion (%)	AASHTO T 96	13.4	-	< 35
Aggregate Crushing Value (%)	BS 812 part 110	14.1	-	< 25
Aggregate Impact Value (%)	BS 812 part 112	6.82	-	< 25

4.1.2 Filler

As shown in table 4.3, CHA have lowest water absorption while CWP possess the highest among CSD, CWP and CHA filler types. This could be due to the fact of the difference in physiochemical nature of the materials that influence the porosity of the materials.

Table 4. 3 Water absorption of Fillers

Characteristic	Filler type		
	CSD	CWP	CHA
Water Absorption (%)	0.828	0.917	0.512

As Table 4.4, CWP has lower specific gravity than CHA. It occurred because of difference in absorption capacity of the two materials that depend on their porosity. And also it is noticeable that the higher absorption capacity material has lower specific gravity and higher surface area.

Table 4. 4 Plastic index and specific gravity of CWP and CHA

No	Test description	Test Methods	Filler type and test results		ERA,2013 specification
		ASTM	CHA	CWP	
1	Plastic Index (%)	D 4318	NP	NP	≤ 4
2	Specific gravity	D 854	2.556	2.526	-

Chemical compositions of CWP and CHA

The chemical compositions of aggregate fillers are specified in terms of oxides, unrelatedly of whether such oxides are present in the sample. It is chemical properties of aggregate fillers that undergo due to chemical action. It plays significant role in HMA performances as asphalt cement resist stripping of the asphalt films in the presence of water. But, different literatures signifies that it has little effects on suitability and performance of aggregates fillers, except as they affect adhesion of asphalt binder to the aggregate. Mineralogy of an aggregate has greater effect on performances of concrete mixes than for asphalt mixes (Freddy, L., et al, 1996). Table 4.5 shows chemistry test results of CWP and CHA conducted at Geological Survey of Ethiopia.

Table 4. 5 Chemical Composition of CWP and CHA

Filler type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
CHA	17.9	3.25	0.96	8.12	1.84	0.38	36	0.1	2.6	0.1	5.5	22.6
CWP	74	18.5	2.38	1.84	0.32	2.16	0.7	0.04	0.2	0.3	0.3	0.72

4.1.3 Bitumen

The characteristics qualities of bitumen are presented as Table 4.6. And the material met the standard requirements of Ethiopian road authority so that the intended mix design. The detail work of this section is illustrated in *appendix C.*

Table 4. 6 Bitumen quality test of 80/100 penetration grade

Test types	Test Methods	Value	ERA, 2013 specification
Penetration @ 25°C (0.1mm)	AASHTO T49-93	89.8	80-100
Ductility @ 25°C (cm)	AASHTO T51-94	96	Min.75
Softening point (°C)	AASHTO T53-92	46	42-51
Flash Point(°C)	AASHTO T 48-94	271	Min.219
Specific gravity @ 25°C	ASTM D 70	1.015	-

4.2 Marshall Properties of Asphalt mixes

The Marshall Properties of the study design are presented as in Table 4.7 with its respective different filler contents. The parameters were: Gmb, VA, VMA, VFA, stability and flow.

As described in the Table 4.7, the values of VA decreased with an increased in bitumen contents. This is due to an increased in Gmb of the compacted mixes as the binder occupies the space available for further densification under traffic. And this may leads to over-asphalted mix design that susceptible to rutting. So the design of VA is a crucial issue in the mix design since it can easily affect other Marshall parameters. In other words, the decrease in VA as bitumen content goes higher and higher again leads to an increase in Marshall Flow which is the indicator of resistance in plastic deformation of the mix. Thus, Marshall Flow increase with an increase and decrease in binder content and VA of asphalt mixtures respectively.

The VMA decreased with an increased in bitumen contents from 4-6%. This could be due to the increase in effective binder that causes the decline in VA of the total mix.

In the same way the value of stability increased up to certain peak point and then decreased as percent of binder contents increases. The increased in stability indicates an improved in adhesion between aggregate and the binder that strongly resist rutting and shoving under traffic. In other words, an excess in the binder results in low stability of the mix design since stability can be affected by internal frictions and cohesion of the binder.

Thus, as indicated in Figure 4.3 to 4.5, 4% air void was taken as a mean value and from which 5.33,5 and 4.68% of OBC were determined. This was done since the value of VA can strongly influence the others Marshall Properties. The values of VA lower than 4% cause bleeding in asphalt mix while the higher VA value leads to dryness.

Table 4. 7 Marshall Properties of asphalt mixes conducted for OBC determination

BC,%	Gmb, g/cc	VA (%)	VMA (%)	VFA (%)	Stability, kN	Flow, mm
	Marshall properties of asphalt mix with 4% CSD filler and vary in binder contents					
4	2.269±0.014	10.185±0.569	16.510±0.595	38.317±2.369	8.760±0.117	2.660±0.067
4.5	2.288±0.007	6.346±0.268	16.470±0.240	61.490±1.068	9.180±0.152	2.900±0.157
5	2.301±0.004	5.365±0.157	16.450±0.138	67.400±0.682	9.670±0.187	3.020±0.040
5.5	2.336±0.048	3.5322±1.970	15.600±1.721	78.160±10.889	9.150±0.102	3.210±0.030
6	2.349±0.018	2.715±0.749	15.580±0.647	82.690±4.133	8.970±0.025	3.570±0.044
	Marshall properties of asphalt mix with 5.5% CSD filler and vary in binder contents					
4	2.300±0.017	5.953±0.711	15.582±0.637	61.881±3.068	8.160±0.140	2.620±0.115
4.5	2.314±0.023	4.913±0.952	15.510±0.848	68.478±4.320	8.610±0.283	3.050±0.040
5	2.327±0.007	3.986±0.300	15.481±0.265	74.270±1.509	8.880±0.193	3.130±0.031
5.5	2.341±0.012	3.074±0.492	15.443±0.431	80.142±2.633	8.810±0.222	3.480±0.026
6	2.354±0.014	2.036±0.584	15.412±0.500	86.860±3.362	8.410±0.176	3.620±0.155
	Marshall properties of asphalt mixes with 7% CSD filler and vary in binder contents					
4	2.301±0.012	5.510±0.491	15.570±0.445	64.630±2.134	8.060±0.093	1.810±0.257
4.5	2.322±0.010	4.350±0.427	15.250±0.381	71.537±2.096	8.870±0.215	2.040±0.117
5	2.335±0.011	3.440±0.452	15.210±0.394	77.433±2.408	9.320±0.211	2.480±0.070
5.5	2.348±0.007	2.420±0.274	15.187±0.239	84.097±1.536	9.330±0.215	2.770±0.046
6	2.361±0.013	1.290±0.531	15.161±0.450	91.530±3.291	8.540±0.196	3.140±0.167

Where, Gmb = bulk density, VA =air voids, VMA =Voids in mineral aggregates, VFA = voids filled with bitumen, BC= bitumen content,CSD =crushed stone dust.

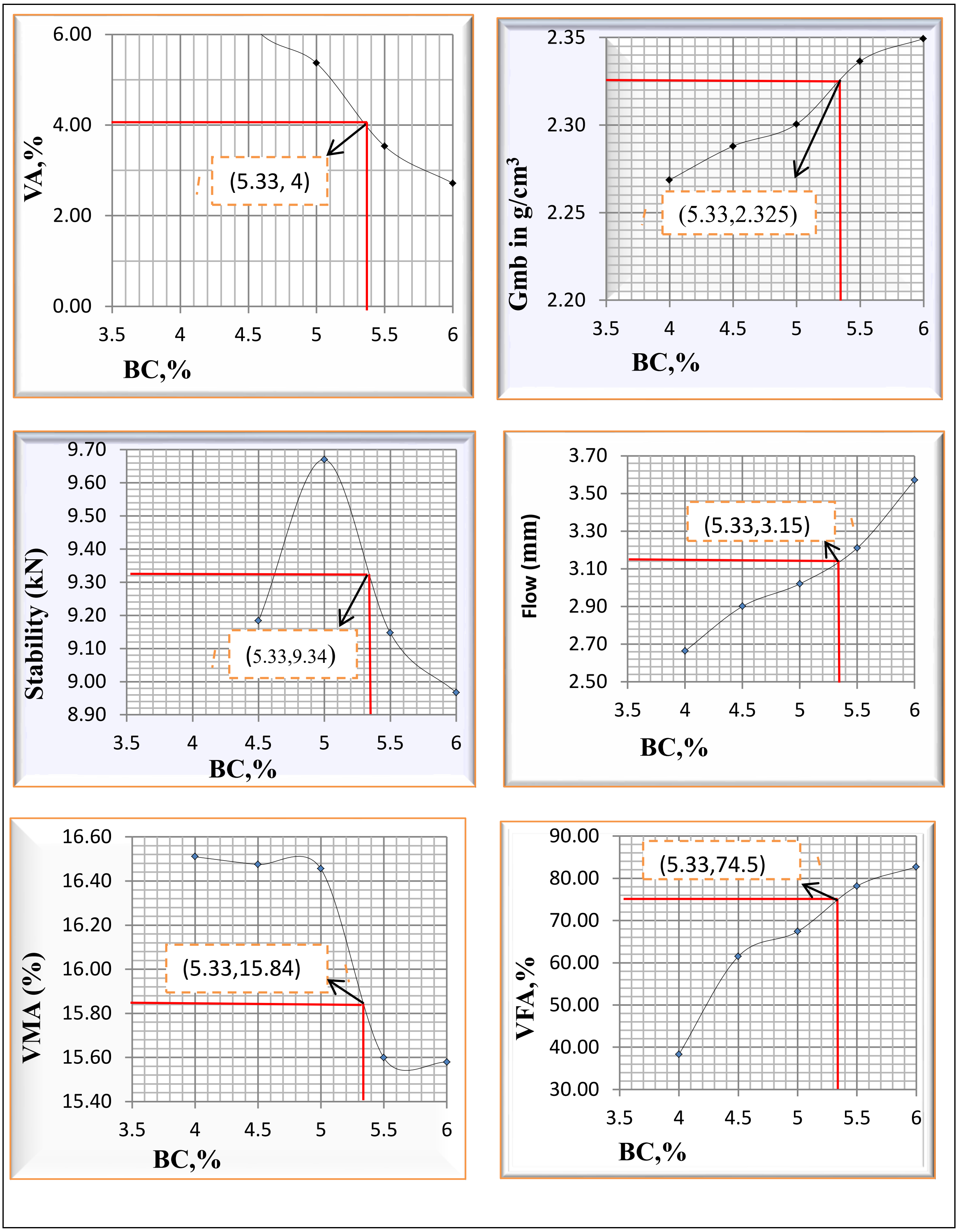
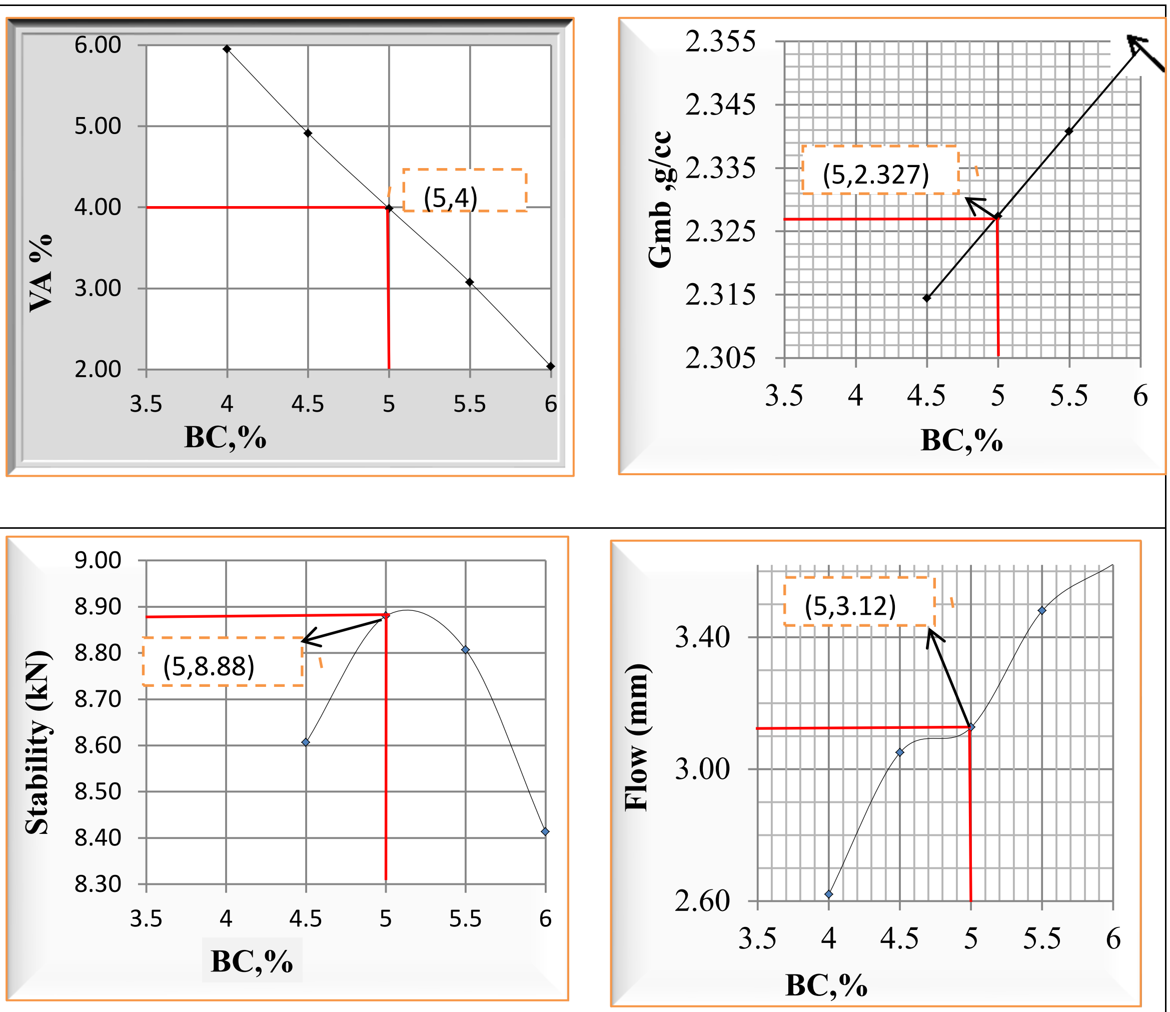


Figure 4. 3 Marshall Properties of mixes with 4% filler content and its 5.33% OBC

As indicated in Figure 4.3, the optimum bitumen content of A_4 gradation is 5.33% at 4% air void recommended by NAPA.



where: BC = Binder content; VFA =void filled with asphalt; VMA = void in mineral aggregate and Gmb =bulk specific gravity of compacted specimen

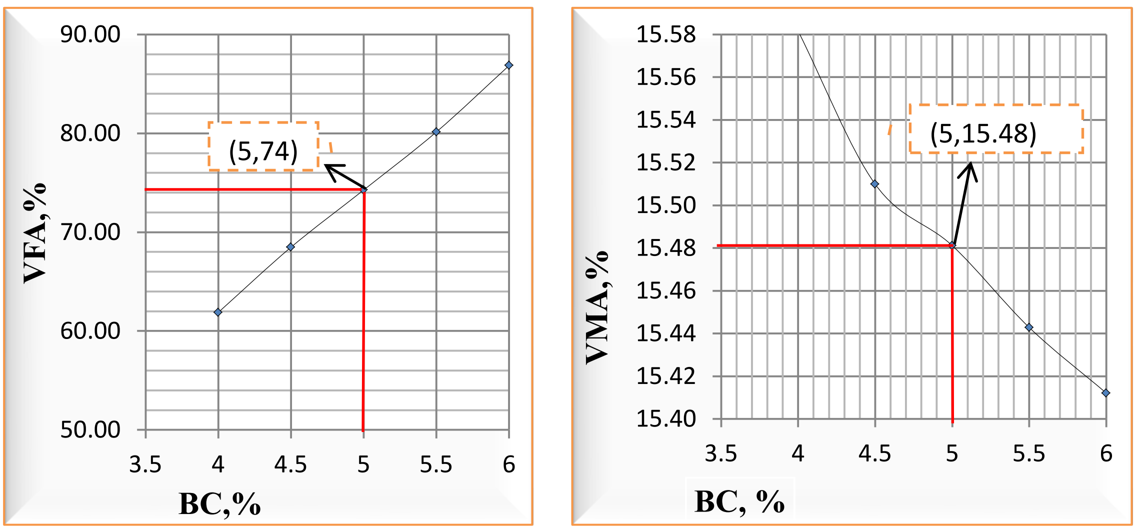


Figure 4. 4 Marshall Properties of mixes with 5.5% filler content and its 5% OBC

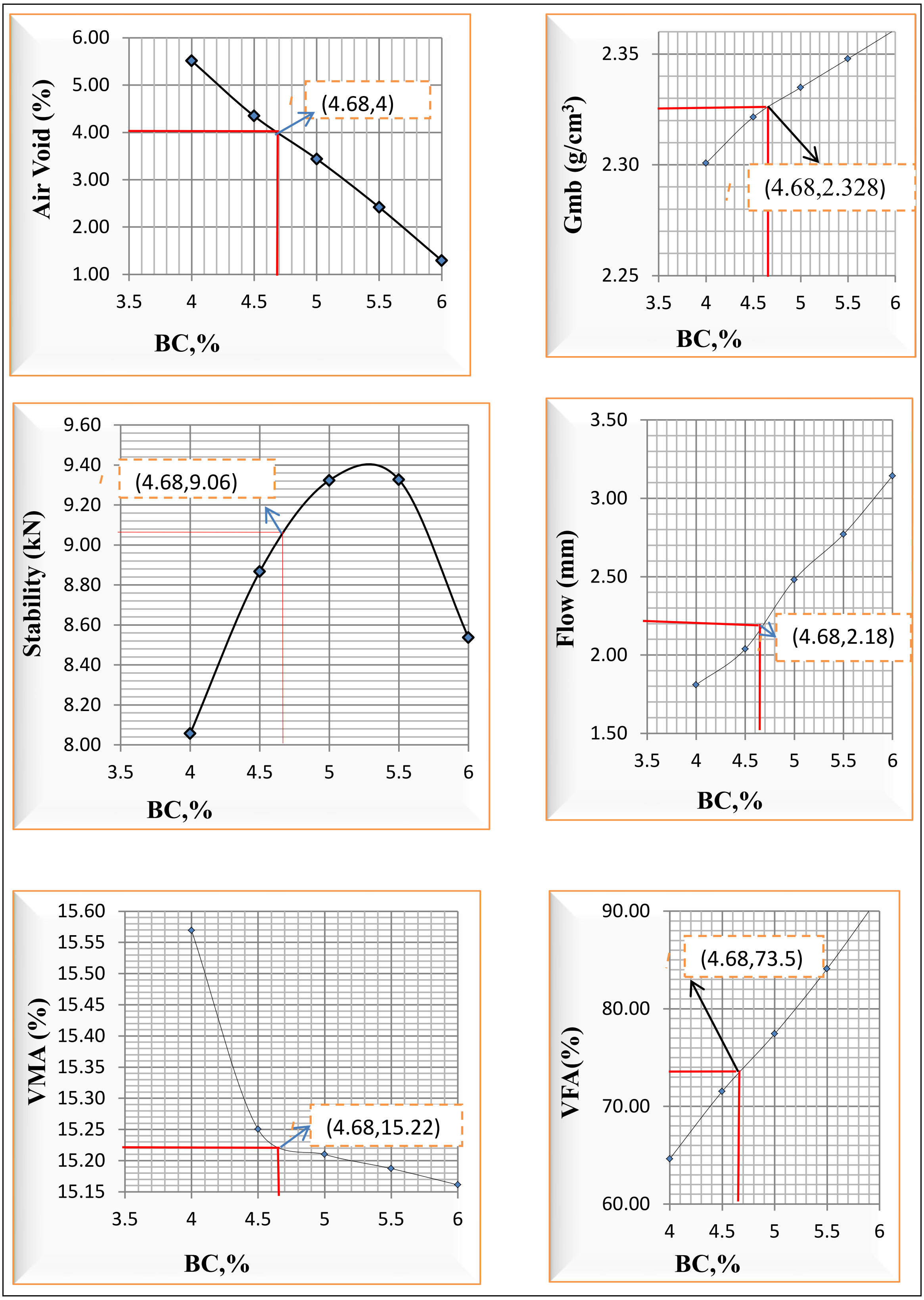


Figure 4. 5 Marshall Properties of mixes with 7% filler content and its 4.68% OBC

Where, Gmb = bulk density, VA =air voids, VMA =Voids mineral aggregates, VFA% =voids filled with bitumen, BC= bitumen content.

Table 4.8 indicates the values of Marshall Properties obtained from the plotted bitumen content versus each Marshall Parameter. It was done following OBC determination as in Figures 4.3 to 4.5. It shows the result summaries of Marshall Tests and density -void analysis of the three design gradation with its corresponding filler contents (4, 5.5 and 7%).

Figure 4.6 indicates that OBC decreased from 5.33 to 4.68% as filler increase from 4 to 7%. This resulted from the fact that the void space between the aggregates filled by mineral fillers. And it signifies that there is small room for the binder to occupy. In this case, despite an increment in filler contents literally needs more binder, the available space for incoming binder is already occupied by an increased surface area of fillers which again results in dryness of the mixture.

Stability decreased from 9.34 to 8.88 kN and then increased to 9.06 kN as filler contents increase from 4 to 7%. This was due to insufficient binder to uniformly coat the particles. Such type of mixture may have high stability and low flow which is brittle mix design.

Flow decreased from 3.15 to 2.18 mm as filler content increases from 4 to 7% due to decrease in binder content that required to coat the mixture. In similar way, VMA as well as VFA decreased from 15.86 to 15.22% and 74.5 to 73.5% respectively, as filler contents increased from 4 to 7%. This is due to the decreased in space available to accommodate the asphalt binder with an increased in amount of fillers.

The bulk specific gravity of the compacted specimens increased from 2.325 to 2.328 g/cm^3 as filler contents increased from 4 to 7% (Figure 4.6). This is resulted from the fact that the higher the density of the mixture leads to the lower the percentage of voids in the mix. It occurred as a result of the decreased in VMA of the mixtures.

Therefore, despite all parameters corresponding to the three fillers (4, 5.5 and 7%) met the standard requirements, the 4% CSD with its respective 5.33% of OBC and A_4 gradation was selected as the best fit. And the determination was based on maximum Marshall Stability so that 4% OFC and 5.33% OBC were used for replacement mix design of this study.

Table 4. 8 Marshall Properties of mix design summaries at 5.33, 5 and 4.68% of OBC

Marshall Properties	Result			ERA manual specification		Asphalt Institute	
	A_4 Gradation	$B_{5.5}$ Gradation	C_7 Gradation	Min.	Max.	Min.	Max.
Bitumen (%)	5.33	5.00	4.68	4	10	4	10
Air void (%)	4.00	4.00	4.00	3	5	3	5
VMA (%)	15.84	15.48	15.22	13	-	13	-
VFA (%)	74.50	74.00	73.50	65	75	65	75
Stability (kN)	9.34	8.88	9.06	7.0	-	8.06	-
Flow (mm)	3.15	3.12	2.18	2	4	2	3.5
Gmb (g/cm^3)	2.325	2.327	2.328	-	-	-	-

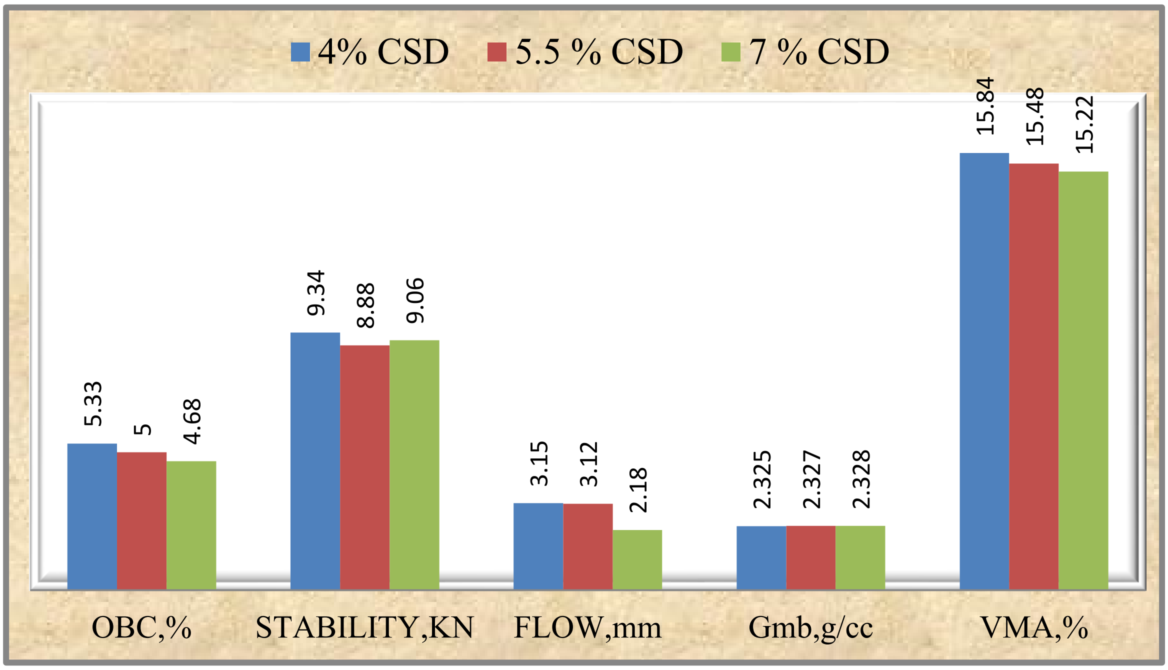


Figure 4. 6 Comparison of Marshall Parameters for the three varies of filler content

4.3 Replacement of CSD with CWP

Table 4.9 indicates the Marshall Properties for the partial replacement of CSD with CWP. And the result values are presented in mean plus standard deviation for each percent of replacement (0, 25, 50, 75and 100% by weight of crushed stone dust). The detail work of this section is also placed as *appendix E4and interpreted as section 4.5.*

Table 4. 9 Marshall Properties of CSD-CWP asphalt mixes in Ȳ±STDV

(CSD:CWP),%	Gmb, g/cc	VA (%)	VMA (%)	VFA (%)	Stability, kN	Flow, mm
	Marshall Properties of CSD-CWP asphalt mixes at 5.33% OBC					
100:0	2.322±0.004	4.280±0.144	16.000±0.130	73.230±0.685	9.480±0.050	2.980±0.087
75:25	2.318±0.004	4.490±0.144	16.140±0.126	72.220±0.675	9.650±0.040	2.960±0.091
50:50	2.316±0.003	4.640±0.123	16.240±0.110	71.430±0.565	9.780±0.060	2.930±0.040
25:75	2.313±0.003	4.780±0.113	16.340±0.097	70.720±0.516	9.890±0.021	2.890±0.020
0:100	2.310±0.012	4.950±0.475	16.450±0.418	69.910±2.115	10.050±0.066	2.860±0.035

Where: Gmb = bulk density, VA =air voids, VMA =Voids mineral aggregates, VFA = voids filled with bitumen, BC= bitumen content,CSD =crushed stone dust and Ȳ±STDV =Mean ± standard deviation.

4.4 Partial Replacement of CSD with CHA

Table 4.10 indicates the Marshall Properties for the partial replacement of CSD with CHA. And the result values are presented in mean plus standard deviation for each percent of replacement (0, 1.5, 3, 4.5,6 and 7.5% by weight of crushed stone dust). The detail works of this section is also placed as *appendix E5 and interpreted as section 4.5.*

Table 4. 10 Marshall Properties of CSD-CHA asphalt mixes in Ȳ±STDV

(CSD:CHA),%	Gmb, g/cc	VA (%)	VMA (%)	VFA (%)	Stability, kN	Flow, mm
	Marshall Properties of CSD-CHA asphalt mixes at 5.33% OBC					
100:0	2.322±0.004	4.280±0.144	16.000±0.130	73.230±0.685	9.480±0.050	2.980±0.087
98.5:1.5	2.323±0.004	4.200±0.177	15.960±0.151	73.690±0.862	9.490±0.021	3.010±0.106
97:3	2.324±0.004	4.140±0.344	15.950±0.300	74.040±1.667	9.510±0.012	2.940±0.083
95.5:4.5	2.325±0.009	4.060±0.074	15.910±0.062	74.480±0.364	9.540±0.026	3.090±0.101
94:6	2.324±0.002	4.050±0.135	15.930±0.120	74.600±0.661	8.070±0.168	3.510±0.036
92.5:7.5	2.323±0.003	4.030±0.092	15.950±0.078	74.750±0.451	7.810±0.030	3.740±0.078

Where:Gmb = bulk density, VA =air voids, VMA =Voids mineral aggregates, VFA = voids filled with bitumen, BC= bitumen content,CSD =crushed stone dust and$\bar{Y}$±STDV =Mean ± standard deviation.

4.5 Effects of the replacements on Marshall Properties of HMA

As Table 4.11 and Figures 4.7 to 4.12 illustrates, the values of Marshall Parameters resulted from the effects of partial replacements were studied in details.

Table 4. 11 Marshall Properties for partial replacement of CSD with CHA and CWP

Marshall Properties	Mix design types and values with incremental percent of the replacements									
	(CHA:CSD),%					CSD,%	(CWP:CSD),%			
	1.5:98.5	3:97	4.5:95.5	6:94	7.5:92.5	100	25:75	50:50	75:25	100:0
VA,%	4.200	4.140	4.060	4.050	4.030	4.280	4.490	4.640	4.780	4.950
Gmb, g/cm^3	2.323	2.324	2.325	2.324	2.323	2.322	2.318	2.316	2.313	2.310
VMA,%	15.960	15.950	15.910	25.930	15.950	16.000	16.140	16.240	16.340	16.450
VFA,%	73.690	74.040	74.480	74.600	74.750	73.230	72.220	71.430	70.720	69.910
Stability, kN	9.490	9.510	9.540	8.070	7.810	9.480	9.650	9.780	9.890	10.050
Flow, mm	3.010	2.940	3.090	3.510	3.740	2.980	2.960	2.930	2.890	2.860

4.5.1 Effects of CWP and CHA on air void of HMA

As Figure 4.7 indicates, the VA in CSD-CHA mix is decreased from 4.28 to 4.03% .Meantime it increased from 4.28 to 4.95% in case of CSD-CWP mixture with an increase in percent of replacements. It occurred as a result of difference in effective binder and surface area of both CWP and CHA in the mixtures. The decreased in VA of CSD-CHA mix arise from an increased in effective binder that coated the mixture uniformly. In another way, the increased in VA in case of CSD-CWP mixture is due to the decreased in effective binder resulted from the lost binder film. And also the variation of the VA is due to the difference in percent of replacements of the two mixtures.

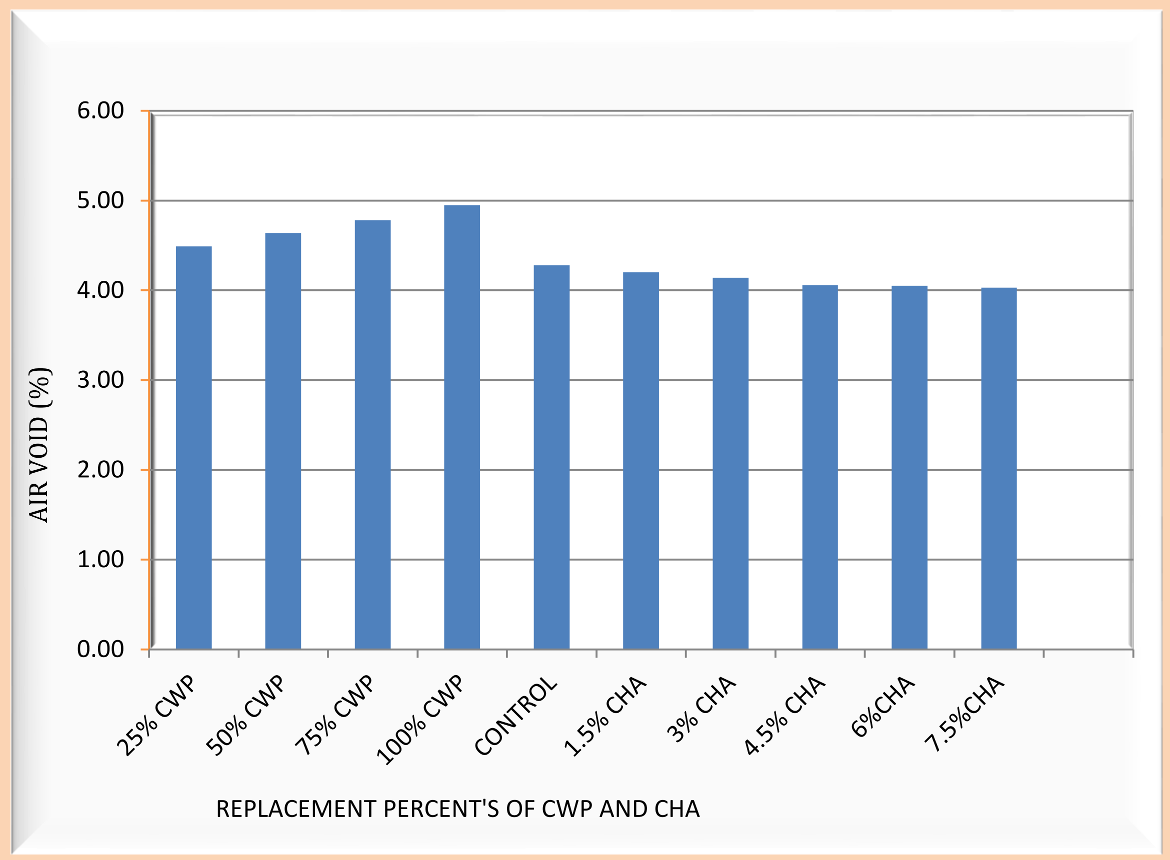


Figure 4. 7 Comparative effect of CWP and CHA on VA

4.5.2 Effects of CWP and CHA on bulk specific gravity of HMA

Figure 4.8 shows that the bulk specific gravity of compacted specimens of CSD-CWP asphalt mix is decreased from 2.322 to 2.310 g/cm^3 as percent of replacement rises from 0 to 100%. In the meantime it showed an increment from 2.322 to 2.325 g/cm^3 and then decreased in case of CSD-CHA mix as percent of replacement increased from 0 to 7.5%. Since density is depend on closeness packing of materials, the greater density of the compacted specimen is the less in void content with higher in effective binder. Thus, the decreased in Gmb of the compacted specimens in CSD-CWP mix is due to an increase in voids (VMA).The increased in void resulted from the lost in effective binder that absorbed into internal surface of the mixtures as percent of replacement rises and the reverse is true for CSD-CHA mixtures.

For the case of CSD-CHA, the decreased in bulk specific gravity after replacement of 4.5% is due to insufficient void in the mix beyond this point. The only left void after this stage was the void left for expansion of the binder and additional over densification under traffic load.

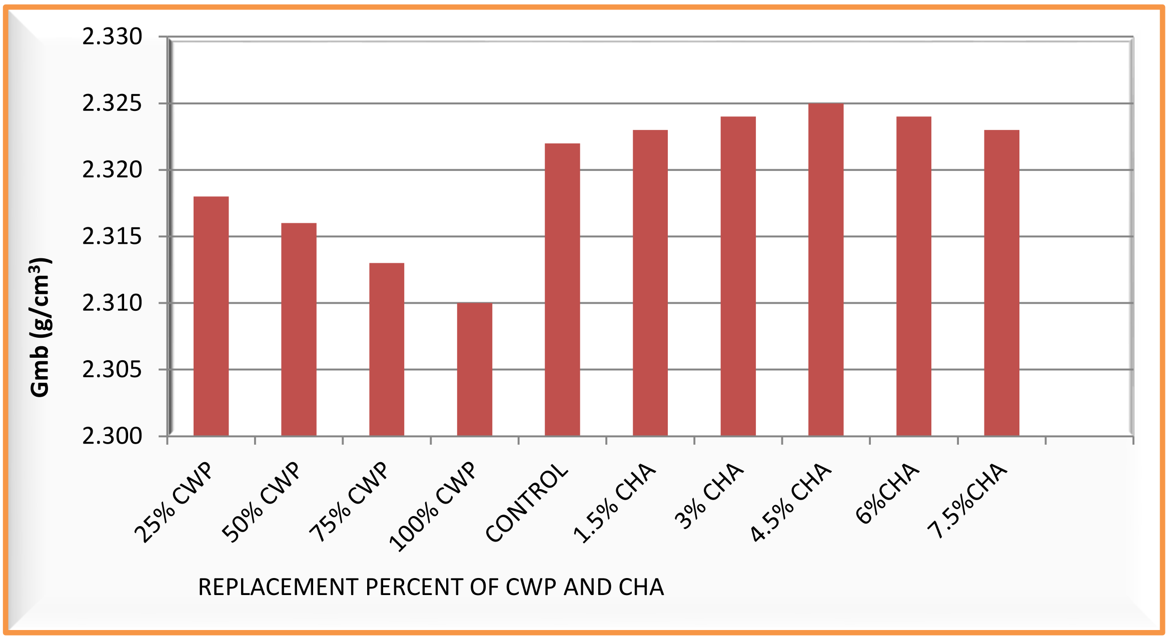


Figure 4. 8 Comparative effect of CWP and CHA on Gmb of compacted specimen

4.5.3 Effects of CWP and CHA on void in mineral aggregate of HMA

The knowledge of space occupy by the particles of aggregates including the pores with in the particles is necessary for mixture proportioning. Different fillers have different properties like particle shape, surface area, surface texture, mineral composition, physiochemical properties, and water contents.

The VMA of asphalt mix with different fillers at the same binder and filler content can be different. In this study, the VMA of CSD-CWP mixture is slightly increased from values of VMA in control mix (16 g/cm^3) to 16.45 g/cm^3. In the meantime it is slightly decreased to 15.91 g/cm^{3}and then increased in case of CSD-CHA mix as illustrated in Figure 4.9. It occurred due to the difference in mineral composition nature of the fillers that influences the absorption capacity of the filler. As indicated in Table 4.3, the absorption capacity of CWP is the highest among the three fillers while that of CHA is the lowest. And this can be reason for the increase and decrease in VMA of CSD-CWP and CSD-CHA mixtures respectively. The variation in effective binder happen when the portion of binder required to form bonding film on aggregate surface is lost by absorption into aggregate. It occurred due to high in internal porosity (absorption capacity) of the filler. Here, the binder portion lost due to absorption into aggregate surface is the reason for increased in VMA of CSD-CWP mix while the opposite is true in case of CSD-CHA.

The other factor that may cause the variation in VMA of CSD-CWP and CSD-CHA mixtures is the difference in percent of replacement in the two mixtures. This difference can influence the surface area of both fillers differently. The variation in surface area at the similar weight also arises from difference in specific gravity of the materials. This variation in surface area of the filler again affects the effective binder since the greater in surface area filler cause for more effective bitumen to be lost and vice versa.

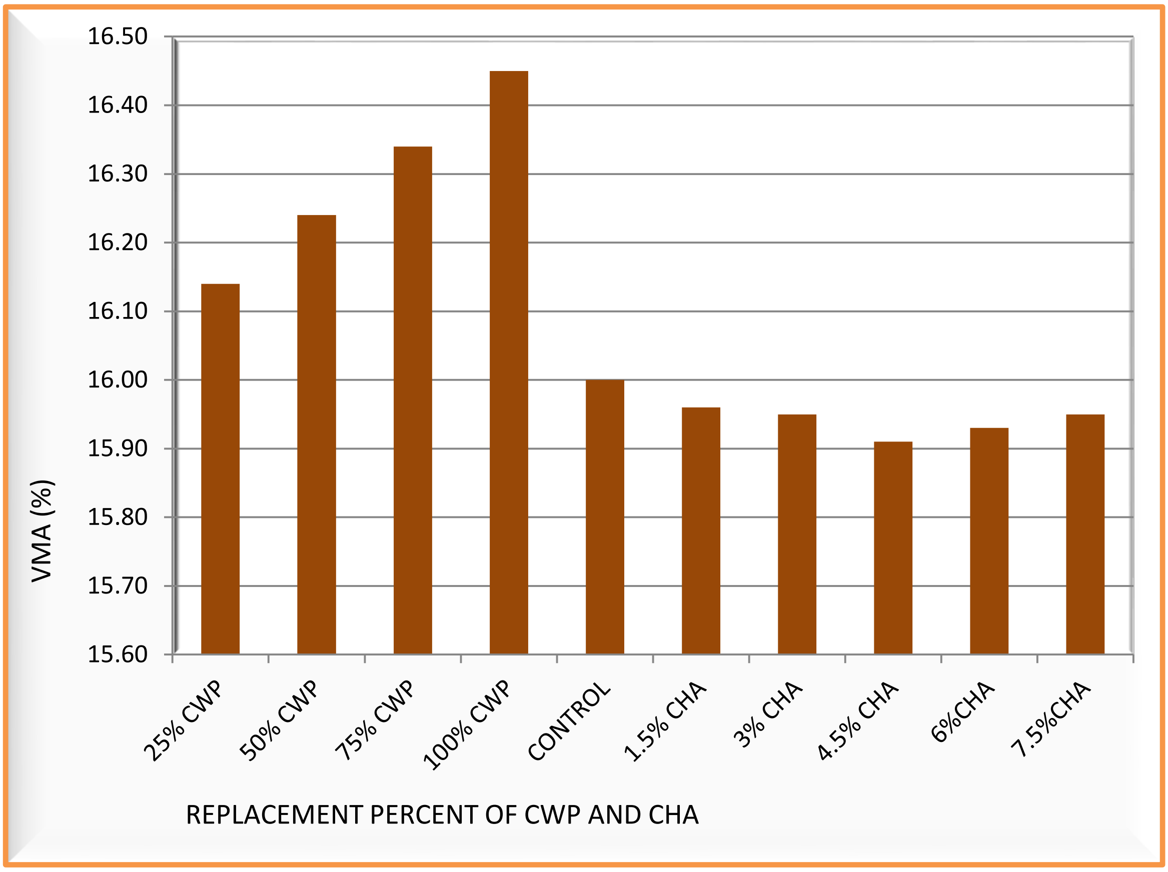


Figure 4. 9 Comparative effect of CWP and CHA on VMA

4.5.4 Effects of CWP and CHA on void filled with asphalt of HMA

The void in asphalt concrete mix is highly influenced by the nature of aggregates and filler used in the mixture. As the void in the mixture tends decreases, the VFA shows an increment and vice versa. Figure 4.8 indicates that, the VFA of CSD-CWP decreased from 73.23 to 69.91% whereas it showed an increment in case of CSD-CHA mix. The increment in VFA is due to the reduction in the lost effective binder in case of CSD-CHA mix. Meantime the decreased in VFA in case of CSD-CWP mix is due to an increased in the lost effective binder.

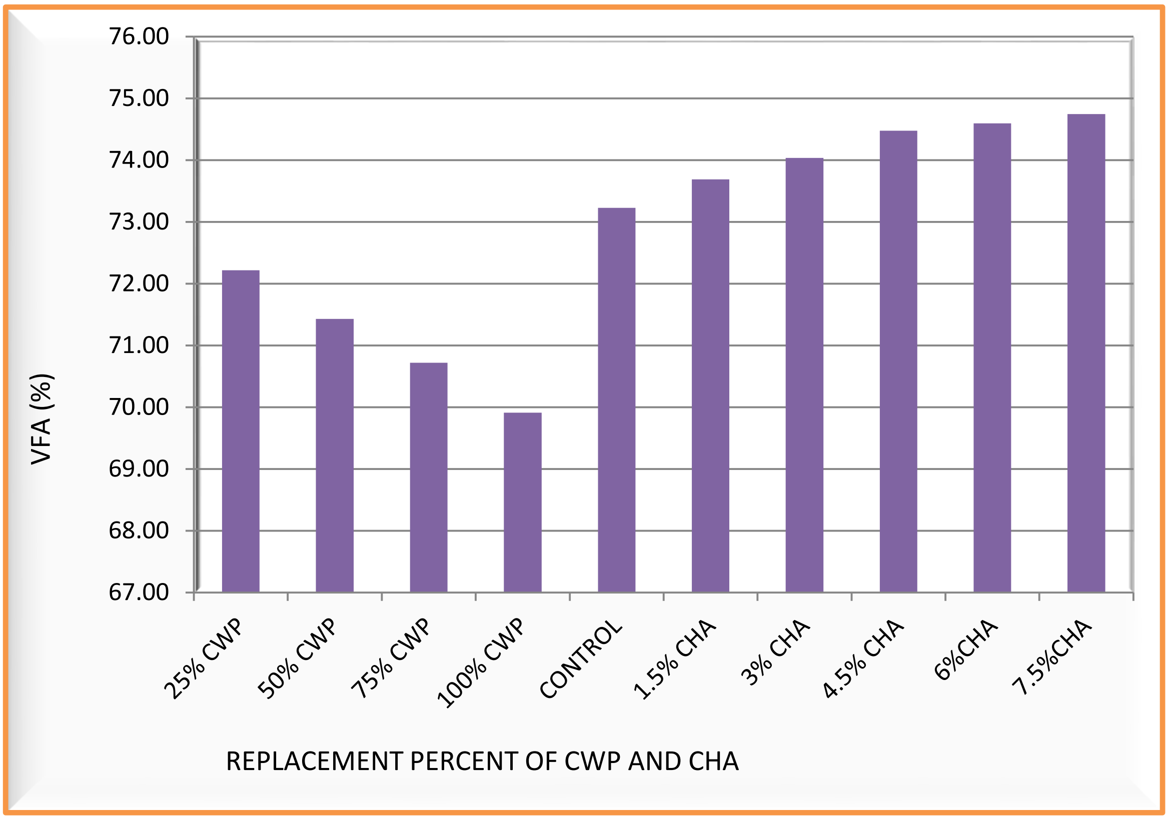


Figure 4. 10 Comparative effect of CWP and CHA on VFA

4.5.5 Effects of CWP and CHA on stability of HMA

Stability is the measure of resistance to deformation which influenced by inter-particle frictions of aggregates and cohesions. This friction in turns depends on the different properties of aggregates like surface texture, shape, absorption and structure of aggregates. The cohesion in turns depends on bonding ability of the bitumen that affected by bitumen grade due to variation in viscosity.

As indicated in Figure 4.11, the stability of CSD-CWP mix specifies an increasing from 9.48 to 10.05 kN as the percent of replacement increased from 0 to 100%. It increased from 9.48 to 9.54 kN and then declined in case of CSD-CHA. An increase in stability indicates the strong adhesion between aggregates and binder for this mix design while it signifies poor adhesion for the decreased case.

This study reveals that it is possible to use CWP as conventional filler and partial replacement since stability of CSD-CWP is greater than that of CSD mix. And also it makes known that CHA can be used as filler in HMA up to optimum of 4.5% by weight of CSD which is 9.54 kN in stability.

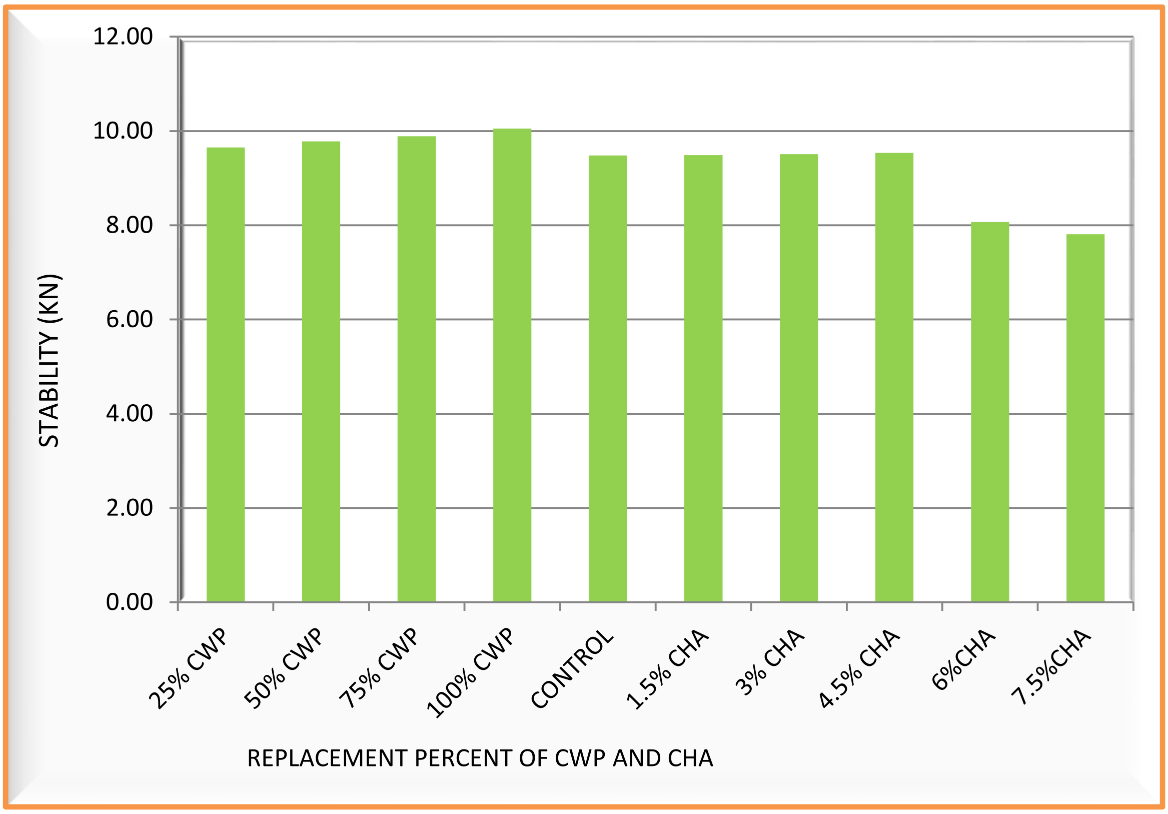


Figure 4. 11 Comparative effect of CWP and CHA on stability

4.5.6 Effect of CWP and CHA on flow of HMA

Flow is the measure of elastic and plastic (deformation) and change in shape of mixture due to a load to the boundary of failure. It is measured from start of loading to the decline of stability.

In this study, the flow values of CSD-CWP mixtures is slightly decreased from that of control mix which is 2.98 mm as the values of stability increased. This indicates a little increase in dryness for the subsequent mixes due to decreased in effective binder to coat the mixture uniformly as the surface area of CWP increased. In case of CSD-CHA mix the flow value oscillates around the control mix value and then very increased after 4.5% of CHA replacement and this indicates the excess in asphalt binder. In general the flow values of both CSD-CWP and CSD-CHA indicates the middle values of the specification which is 2-4 mm except the values after declined stability in case of CSD-CHA.

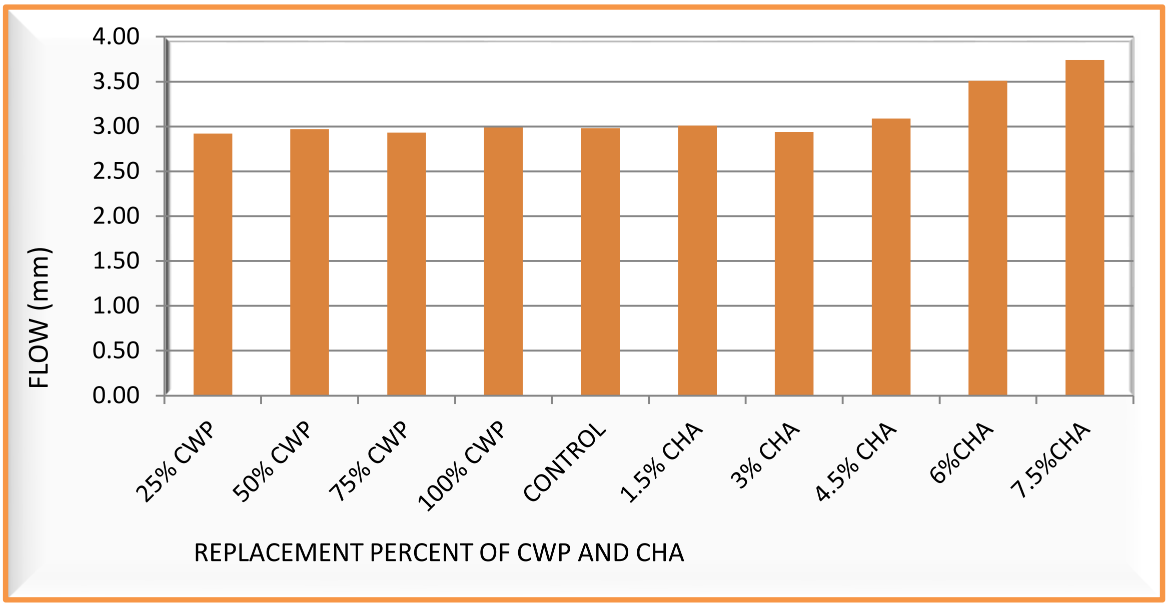


Figure 4. 12 Comparative effect of CWP and CHA on flow

At the end, the study declares the possibility for optimum replacement of CWP and CHA as 100 and 4.5% respectively. As indicated in Table 4.12, all Marshall Parameters particularly the values of maximum stability, VA and Gmb at 4.5% CHA and 100% CWP respectively met the standard requirements.

Therefore, CHA can be used as filler in HMA at 4.5% by weight of CSD while 100% replacement is possible for CWP as alternative filler material. The study is responsible for this statement only at 4% filler content of A_4 gradation design indicated for both CHA and CWP.

Table 4. 12 Optimum replacements of CSD with CWP and CHA

Marshall Parameters	Optimum replacements		ERA manual specification		Asphalt Institute, specification		Remarks
	CSD-CHA mix @ (95.5:4.5),%	CSD-CWP mix @ (0:100),%	Lower	Upper	Lower	Lower	
Bitumen (%)	5.33	5.33	4	10	4	10	ok
Air void (%)	4.06	4.95	3	5	3	5	ok
VMA (%)	15.91	16.45	13	-	13	-	ok
VFA (%)	74.48	69.91	65	75	65	75	ok
Stability, kN	9.54	10.05	7.0	-	8.06	-	ok
Flow, mm	3.09	2.86	2	4	2	3.5	ok
Gmb, g/cm^3	2.325	2.310	-	-	-	-	ok

4.6 Effects of CWP and CHA on moisture susceptibility

Moisture damage of asphalt mixtures is one of the major distresses in asphalt pavements. The moisture damage is the result of two failure mechanisms, the loss of cohesive bond within asphalt binder and the loss of adhesive bond between the aggregate and the binder (Airey, G.D., et al, 2008, Ghabchi, R., et al, 2014, Kakar, M.R., et al, 2015 & Sengoz, B., Agar, E., 2007). The adhesion failure is caused by moisture between the aggregate and asphalt binder and stripping away asphalt film from the aggregate surface (Kok, B.V., Yilmaz, M., 2009). Meanwhile the cohesion failure manifests as a softening of mastics in asphalt concrete. The moisture damage is a function of many variables like types of aggregate and source binder, mix design, asphalt film thickness, and environmental conditions (Nejad, F.M., et al, 2013, Sengul, C.E., et al, 2012, Shafiei, A., Namin, M.L, 2014, Xiao, F., Amirkhanian, S.N., 2009 & Xiao, F., et al, 2010).

As indicated in Table 4.13, the asphalt mixes prepared with partial replacement of CHA at 4.5% by weight of CSD provide the highest TSR value. Meanwhile the mix prepared with 100% CWP replacement provides the minimum relatively. Here, despite the values of both CSD-CHA and CSD-CWP mixtures are in good performance range, the mix made with CWP replacement possesses lower TSR value comparatively. It occurred due to the difference in the physiochemical nature of ceramic waste powder and coffee husk that influences the asphalt film thickness, the adhesion forces in the two mixtures (CSD-CWP and CSD-CHA) and voids of the mix prepared.

The study reveals that as percent of CWP increases at constant 5.33% of OBC, there was slightly increase in dryness of the mixes. This is due to the existence of fewer portions of binder films on aggregate surface as a result of lost in effective binder because of internal absorption of aggregate. And this indicates that the mix prepared with CWP require higher OBC than that of CHA to coat the mix uniformly. And this may be what pulled-down the TSR value of CSD-CWP below that of CSD-CHA.

Therefore, the relative difference in TSR values of CSD-CWP and CSD-CHA mixes is the difference in adhesive bond between aggregate and binder of the two mixtures. As the mix design with greater total void allows more water permeability; the mix with higher absorption capacity is more susceptible to stripping. This is due to the greater in lost effective binder of the mix. For whatever so far, despite of the difference in asphalt film thickness, the TSR values of the study are in good performance range that are 80.91, 84.17 and 87.04% for CSD-CWP, CSD and CSD-CHA, respectively.

Table 4. 13 Effects of CSD, CSD-CHA and CSD-CWP mixes on moisture sensitivity

Type of mixes	Replacements (%)	ITS ,kpa		TSR (%)	Asphalt institute
		unconditioned	Conditioned		
CWP:CSD	100:0	702.7±6.18	568.5±1.80	80.91±0.46	≥70
CSD	100	732.7±7.02	616.7±13.10	84.17±1.10	
CHA:CSD	4.5:95.5	766.8±6.07	667.5±5.27	87.04±0.38	

Where: ITS =indirect tensile strength, TSR = tensile strength ratio

CHAPTER FIVE
CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions

Asphalt is a combination of aggregate, filler and bitumen. In order to meet the objective of this study, the characterization of these asphalt components and Marshall Mix design study on suitability and effects of CHA and CWP were performed. In addition to this, the asphalt performance test on water susceptibility was conducted. Accordingly, the following conclusions are drawn based on experimental findings:

- The absorption capacity of CWP is higher than that of CHA by 44.2%.
- The OBC decreased from 5.33 to 4.68% as filler increased from 4 to 7%. It occurred due to the fact that the void space between the aggregates filled by mineral fillers. And it signifies that there is small room for the binder to occupy.
- All Marshall Properties of the study mix design corresponding to the three fillers 4, 5.5 and 7% are fulfilled the local and international standards. The mix design made with 4% filler content was selected as control mix design. And the determination was based on maximum Marshall Stability so that the 4% OFC and 5.33% OBC were used for replacement mix design of the study.
- The VA of CSD-CHA mix is decreased from 4.28 to 4.03% while it increased from 4.28 to 4.95% in case of CSD-CWP with an increase in percent of replacements.
- The Gmb of CSD-CWP mx is decreased from 2.322 to 2.310 g/cm^3 while that of CSD-CHA mix is increased from 2.322 to 2.325 g/cm^3 and then decreased. This resulted because of increase in voids as a result of lost effective binder that absorbed into internal surface of the aggregates as percent of replacement rises. On the other hand, Gmb showed an increment due to an increased in effective binder for the case of CSD-CHA mixtures.
- The VMA of CSD-CWP mix is slightly increased from 16 to 16.45 g/cm^3. Meantime it is decreased from 16 to 15.91 g/cm^3 and then increased in case of CSD-CHA mix. It occurred due to the difference in mineral composition nature of the fillers that influences its absorption capacity.
- The VFA of CSD-CWP mix decreased from 73.23 to 69.91% while that of CSD-CHA mix is increased from 73.23 to 74.75% as percent of replacement rises. The increment in VFA is due to the reduction in the lost effective binder in case of

CSD-CHA mix. Meantime the decreased in VFA in case of CSD-CWP mix is due to an increased in the lost effective binder.

- Stability of CSD-CWP mix specifies an increasing from 9.48 to 10.05 kN. And it increased from 9.48 to 9.54 kN and then declined in case of CSD-CHA. An increase in stability indicates the strong adhesion between aggregates and binder for this mix design while it signifies poor adhesion for the decreased case.
- The flow value of CSD-CWP mixtures is slightly decreased from that of control mix (2.98 mm) as the values of stability increases. In case of CSD-CHA mix the flow value oscillates around the control mix value and then very increased after 4.5% of CHA replacement and this indicates an excess in asphalt binder.
- The mixes prepared with partial replacement of CHA at 4.5% by weight of CSD provide the highest TSR. Meanwhile the asphalt mix prepared with 100% CWP replacement provides the minimum relatively. It occurred due to the difference in the physiochemical nature of CWP and CHA that influences the asphalt film thickness, the adhesion forces in the two mixtures (CSD-CWP and CSD-CHA) and voids in the mix prepared. For whatever so far, the TSR values of the three mixtures (CSD-CWP, CSD and CSD-CHA) are in good performance range that are 80.91, 84.17 and 87.04%, respectively.
- Therefore, the study shows that CHA can be used as filler in HMA at 4.5% by weight of CSD while 100% replacement is possible for CWP as alternative filler material at 4% filler content.

5.2 Recommendations

Based on the study results the following recommendations are given:

- CWP can be used fully or as partial replacement when combined with CSD to realize the best HMA mixture.
- CHA can be utilized as partial replacement at 4.5% by weight of CSD when combined with CSD to realize the best HMA mixture.
- It is advisable for road construction agencies and local authorities to use coffee husk and ceramic waste. And these materials are useful in reduction of environmental pollution and improve material shortages of road constructions besides of cost minimization.

The followings are the necessary further investigation desired for the extension of the study:

- It is better if another asphalt performance tests like rutting test will be performed besides of indirect tensile strength test. Here, it is worthy for JiT and its students as well as for the county if the wheel tracker test machine will be supplied for the Civil laboratory of the institute.
- It is advisable if further investigation will be performed for coffee husk taken from different geographical areas.
- Further study is necessary using controlled condition of burning coffee husk.
- Another further study is required using different bitumen grades to know the variation may happen due to difference in binder viscosity.
- Finally, economic evaluation of this study is important so that the amount in cost reduction as a result of using CHA and CWP is known when compared with that of CSD.

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Appendix A: Particle size distribution and gradation test

AASHTO T27 and T11

Sizes of Aggregate	CA (25-14 mm)			IMA (14-6 mm)			IMA(6-3 mm)			FA (3-0 mm)		
Dry sample weight (g)	5065			5018			2531			2000		
After wash dry sample (g)	5057.4			5009.3			2520.6			1704.2		
Sieve Size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing	Mass of Retained (g)	Cummulative passing (g)	cummulative passing (%)	Mass of Retained (g)	cummulative passing (g)	cummulative passing (%)
25	0.0	5065.00	100.00	0.0	5018.0	100.00	0.0	2531.0	100.00	0.0	2000.0	100.0
19	2089.8	2975.18	58.74	0.0	5018.0	100.00	0.0	2531.0	100.00	0.0	2000.0	100.0
12.5	2129.3	845.86	16.70	175.6	4842.4	96.50	0.0	2531.0	100.00	0.0	2000.0	100.0
9.5	294.8	551.07	10.88	1220.9	3621.5	72.17	0.0	2531.0	100.00	0.0	2000.0	100.0
4.75	528.8	22.29	0.44	2121.6	1499.9	29.89	151.9	2379.1	94.00	0.0	2000.0	100.0
2.36	8.6	13.68	0.27	1424.6	75.3	1.50	626.4	1752.7	69.25	12.0	1988.0	99.40
1.18	6.1	7.60	0.15	25.1	50.2	1.00	1123.8	629.0	24.85	322.0	1666.0	83.30
0.6		7.60	0.15	35.1	15.1	0.30	480.9	148.1	5.85	336.0	1330.0	66.50
0.3		7.60	0.15	6.4	8.7	0.17	63.3	84.8	3.35	516.4	813.6	40.68
0.15		7.60	0.15		8.7	0.17	26.6	58.2	2.30	300.6	513.0	25.65
0.075		7.60	0.15		8.7	0.17	47.8	10.4	0.41	293.0	220.0	11.00
Pan	0.0			0.0			0.0			**0.0**		
wash lose	7.6			8.7			10.4			295.8		
Total	**5065.0**			**5018.0**			**2531.0**			**2000.0**		

Cumulative percent of passing per size of aggregate

Aggregate size (mm)	Percent of passing per Sieve Size										
	25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
25-14	100.00	58.74	16.70	10.88	0.44	0.27	0.15	0.15	0.15	0.15	0.15
14-6	100.00	100.00	96.50	72.17	29.89	1.50	1.00	0.30	0.17	0.17	0.17
6-3	100.00	100.00	100.00	100.00	94.00	69.25	24.85	5.85	3.35	2.30	0.41
3-0	100.0	100.0	100.0	100.0	100.0	99.4	83.3	66.5	40.68	25.65	11.0
Filler	100	100	100	100	100	100	100	100	100	100	100

The mix design gradation (A_4) and blending of 4% filler content

Aggregate size (mm)	Blending (%)	Percent of blending per Percent of passing per Sieve Size										
		25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
25-14	23.03	23.03	13.53	3.85	1.47	0.10	0.06	0.03	0.03	0.03	0.03	0.03
14-6	37.53	37.53	37.53	36.22	27.09	11.22	0.56	0.38	0.11	0.07	0.07	0.07
6-3	12.72	12.72	12.72	12.72	12.72	11.96	8.81	3.16	0.74	0.43	0.29	0.05
3-0	25.7	25.70	25.70	25.70	25.70	25.70	25.55	21.41	17.09	10.45	6.59	2.83
Filler	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Total	**100**	**100**	**90.5**	**79.5**	**68.0**	**50.0**	**36.0**	**26.0**	**19.0**	**12.0**	**8.0**	**4.0**

Appendix B: Physical properties of mineral filler test results

Test Method: ASTM D-854

Table B1: Physical properties of fillers

Material Type	CSD		CWP		CHA	
Pycnometer No:	1	2	1	2	1	2
A.Weight of Oven Dry Sample in Air,(gm)	25.00	25.00	25.00	25.00	25.00	25.00
B.Weight of Pycnometere +Water (gm)	127.34	127.66	121.60	127.20	127.70	127.03
C.Weight of Pycnometere+Sample+ Water (gm)	142.76	143.20	136.60	142.40	142.96	142.21
Observed Temperature of H2O,Ti	20°C	20°C	20°C	20°C	20°C	20°C
k=	1.00	1.00	1.00	1.00	1.00	1.00
Temperature when Mpsw was taken,Tx	20°C	20°C	20°C	20°C	20°C	20°C
K for Tx	1.00	1.00	1.00	1.00	1.00	1.00
Specific gravity @ 20 °C,Gs=A*K/(A+B-C)	2.610	2.643	2.500	2.552	2.567	2.546
Average Gs @ 20 °C	2.627		2.526		2.556	

Appendix C: Bitumen quality tests

Penetration	Test Method	Test No.	Test Temp.(0c)	Time of Test (s)	Test Load (g)	Reading Date (0.1mm) 1st Time	2ndTime	3rd Time	Average (0.1mm)
	AASHTO T49-93	1	25	5	100	88	93	91.6	90.9
		2	25	5	100	90	87.8	89.2	89.0
		3	25	5	100	89	92.4	86.8	89.4
average penetration									**89.8**
Ductility	Test Method	Test No.	Test Temp. (°C)	Speed (cm/min)		Ductility (cm)			**Average(cm)**
	AASHTO T 51-94	1	25	5		95			**96**
		2	25	5		97			
		3	25	5		96			
Softening Point	Test Method	Test No.	Temp. when starting heating (°C)			Record of liquid temp. in beaker 4min	5min	6min	Softening point (°C)
	AASHTO T 53-92	1	6						45.6
		2	6						46.4
Average (°C)									**46**
Flashing Point	Test Method							AASHTO T 48-94	
	Test No.							1	2
	Test results							273	269
Average (°C)								**271**	

Appendix D: Theoretical maximum specific gravity of HMA

Test Method: ASTM Designation: D 2041-90

Table D1: Theoretical maximum specific gravity of HMA mixtures with 4% filler content

BC (%)	4		4.5		5		5.5		6	
Trial No	1	2	1	2	1	2	1	2	1	2
A	1220.45	1224.24	1252.7	1248.6	1266.45	1268.9	1276.89	1275.6	1282	1283.11
B	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6	2317	2316.6
C	3054.98	3055	3056.5	3054.2	3062	3063.6	3066.8	3065.1	3068	3068.78
Gmm	2.532	2.52	2.443	2.444	2.431	2.431	2.424	2.42	2.414	2.417
Mean of Gmm	2.526		2.443		2.431		2.422		2.415	

Table D2: Theoretical maximum specific gravity of HMA mixtures with 5.5% FC

BC (%)	4		4.5		5		5.5		6	
Trial No	1	2	1	2	1	2	1	2	1	2
A	1236.5	1237.8	1243.6	1245.7	1256.6	1256.8	1265.5	1264	1274.7	1273
B	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6
B	3047.68	3048.21	3049.1	3050.6	3054.8	3054.9	3057.3	3058	3059.6	3061
Gmm	2.446	2.445	2.433	2.434	2.424	2.424	2.411	2.419	2.397	2.408
Mean of Gmm	2.446		2.434		2.424		2.415		2.403	

Table D3: Theoretical maximum specific gravity of HMA mixtures with 7% FC

BC (%)	4		4.5		5		5.5		6	
Trial No	1	2	1	2	1	2	1	2	1	2
A	1243.5	1246	1257.4	1256.8	1264.8	1265.4	1270.6	1274.7	1281	1283.5
B	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6	2316.6
B	3049.2	3051.3	3055.3	3056.1	3059.4	3057.8	3058	3062.6	3062	3063.6
Gmm	2.434	2.437	2.424	2.43	2.423	2.414	2.401	2.411	2.392	2.392
Mean of Gmm	2.435		2.427		2.418		2.406		2.392	

Table D4: Theoretical maximum specific gravity of HMA mixtures for CSD-CWP mixes

Replacements (CSD:CWP),%	100:0		75:25		50:50		25:75		0:100	
Trial No	1	2	1	2	1	2	1	2	1	2
A	1241.6	1242	1243.4	1243.7	1246	1245.8	1248.7	1251.5	1256.4	1255.9
B	2318.2	2318.2	2318.2	2318.2	2318.2	2318.2	2318.2	2318.2	2318.2	2318.2
C	3048.2	3048	3049	3049.9	3051	3050.88	3052.9	3054.2	3057.8	3057.2
Gmm	2.427	2.425	2.426	2.429	2.428	2.428	2.429	2.428	2.431	2.43
Mean of Gmm	2.426		2.427		2.428		2.429		2.430	

Table D5: Theoretical maximum specific gravity of HMA mixtures for CSD-CHA mixes

Replacements (CSD:CHA),%	100:0		98.5:1.5		97:3		95.5:4.5		94:6		92.5:7.5	
Trial No	1	2	1	2	1	2	1	2	1	2	1	2
A	1241.6	1242	1243.4	1243.7	1246	1245.8	1248.7	1251.5	1256.4	1255.9	1264.8	1265.3
B	2318.2	2318.2	2318.2	2318.2	2318.2	2318.2	2318.2	2318.2	2318.2	2318.2	2318.2	2318
C	3048.2	3048	3049.1	3049	3050.3	3049.8	3051.7	3053	3055.6	3055.8	3061	3060.6
Gmm	2.427	2.425	2.426	2.425	2.425	2.423	2.424	2.422	2.421	2.423	2.423	2.42
Mean of Gmm	2.426		2.425		2.424		2.423		2.422		2.421	

Where: k = 1.0 at 25^{0}c, A= Mass of Dry Sample in Air,B=Mass of Jar Filled With Water,C=Mass of Jar Filled With Water + Sample, Gmm (Maximum Theoretical Specific Gravity) = K*A/(A+B-C), FC =filler content and BC =binder contents.

Appendix E: Test results of Marshall Mix design

Tested by: Bilisumma Lemi	Specific gravity of Aggregates	
Center of Study: JiT, Highway Lab.,JU	Fraction size (mm)	Gsb
Purpose: MSC Thesis	Combined (Gsb)	2.616
Marshall Compaction : 2*75 Blows		
Type of Bituminous Mixture: Wearing course		
Asphalt Grade: 80/100		
Gradation Type: A_4 with 4% FC		
Specific gravity of Asphalt: 1.015		

Table E1: Marshall Properties of asphalt mixes with 4% CSD filler (A_4 Gradation type)

Bitumen Content (%)	% Filler	Trial code	Specimen Height (mm)	% of Aggregate	Mass of specimen (g) in			volume of Specimen (cc)	Gsb of Agg.	Gmm	Gmb of compacted specimen (g/cc)	VA (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
					Air Dry	Water	Air SSD									
4	4	1A1	68	96	1228.6	692.1	1229.9	537.8	2.616	2.53	2.284	9.561	16.17	40.86	8.67	2.68
		1A2	67.5	96	1231.4	691.12	1234.7	543.58			2.265	10.319	16.17	36.17	8.89	2.59
		1A3	68	96	1230.6	689.6	1235	545.4			2.256	10.676	17.2	37.93	8.71	2.72
		Mean	67.83	96	1230.2	690.94	1233.2	542.26			2.269	10.185	16.51	38.317	8.76	2.66
4.5		2A1	67.5	95.5	1240.8	706.11	1247.1	540.99	2.616	2.44	2.294	6.117	16.27	62.41	9.32	3.01
		2A2	69	95.5	1235.7	703.6	1243.3	539.7			2.29	6.279	16.42	61.75	9.02	2.72
		2A3	68.5	95.5	1239.75	702.23	1245.8	543.57			2.281	6.641	16.74	60.32	9.21	2.97
		Mean	68.33	95.5	1238.75	703.98	1245.4	541.42			2.288	6.346	16.47	61.49	9.18	2.9
5		3A1	69	95	1243.6	708.1	1249	540.9	2.616	2.43	2.299	5.424	16.51	67.14	9.82	3.06
		3A2	66	95	1241.2	705.5	1245.7	540.2			2.298	5.485	16.56	66.88	9.46	2.98
		3A3	67.5	95	1243.45	707.41	1246.89	539.48			2.305	5.187	16.3	68.17	9.73	3.02
		Mean	67.5	95	1242.75	707	1247.2	540.19			2.301	5.365	16.45	67.4	9.67	3.02
5.5		4A1	67	94.5	1236.8	722.8	1240	517.2	2.616	2.42	2.391	1.266	13.62	90.7	9.03	3.21
		4A2	67.5	94.5	1252.4	711.6	1255	543.4			2.305	4.841	16.74	71.09	9.22	3.24
		4A3	67	94.5	1245.3	709.9	1248.23	538.33			2.313	4.489	16.44	72.69	9.19	3.18
		Mean	67.17	94.5	1244.83	714.77	1247.74	532.98			2.336	3.5322	15.6	78.16	9.15	3.21
6		5A1	68	94	1254.1	726.1	1255.5	529.4	2.616	2.42	2.369	1.909	14.88	87.17	8.94	3.62
		5A2	68.5	94	1263.4	723.9	1265.4	541.5			2.333	3.389	16.16	79.03	8.99	3.55
		5A3	68	94	1257.2	724.11	1259.95	535.84			2.346	2.848	15.69	81.85	8.97	3.54
		Mean	68.17	94	1258.23	724.7	1260.28	535.58			2.349	2.715	15.58	82.69	8.97	3.57

Table E2: Marshall Properties of asphalt mixes with 5.5% CSD filler ($B_{5.5}$ Gradation type)

Bitumen Content (%)	% Filler	Trial code	Specimen Height (mm)	% of Aggregate	Mass of specimen (g) in			volume of Specimen (cc)	Gsb of Agg.	Gmm	Gmb of compacted specimen (g/cc)	VA (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
					Air Dry	Water	Air SSD									
4	5.5	1B1	68	96	1235.8	703.5	1236.1	532.6	2.616	2.446	2.32	5.138	14.85	65.4	8.32	2.51
		1B2	68.5	96	1238.9	698.7	1240.1	541.4			2.288	6.446	16.02	59.77	8.12	2.74
		1B3	69	96	1237.8	699.98	1239.9	539.92			2.293	6.273	15.87	60.47	8.05	2.61
		Mean	68.5	96	1237.5	700.73	1238.7	537.973			2.3	5.953	15.582	61.881	8.16	2.62
4.5		2B1	69	95.5	1239.2	710.3	1251.8	541.5		2.434	2.288	5.98	16.46	63.67	8.35	3.01
		2B2	69	95.5	1240	715.5	1247	531.5			2.333	4.149	14.83	72.03	8.56	3.05
		2B3	68.5	95.5	1242.6	713.1	1248.3	535.2			2.322	4.612	15.24	69.74	8.91	3.09
		Mean	68.83	95.5	1240.6	712.97	1249.03	536.07			2.314	4.913	15.51	68.478	8.61	3.05
5		3B1	68.5	95	1250.7	719.54	1255.1	535.56		2.424	2.335	3.659	15.19	75.92	9.05	3.16
		3B2	68.5	95	1247.8	715.8	1252.3	536.5			2.326	4.051	15.54	73.93	8.67	3.1
		3B3	68	95	1250.1	717.5	1256.1	538.6			2.321	4.248	15.71	72.96	8.92	3.12
		Mean	68.33	95	1249.53	717.61	1254.5	536.89			2.327	3.986	15.481	74.27	8.88	3.13
5.5		4B1	68.5	94.5	1251.82	720.6	1255.2	534.6		2.415	2.342	3.039	15.41	80.28	8.56	3.47
		4B2	68	94.5	1253	722.21	1254.9	532.69			2.352	2.6	15.03	82.7	8.99	3.51
		4B3	68.5	94.5	1248.8	719.11	1255.43	536.32			2.328	3.583	15.89	77.44	8.87	3.46
		Mean	68.33	94.5	1251.21	720.64	1255.18	534.54			2.341	3.074	15.443	80.142	8.81	3.48
6		5B1	66	94	1259	724.2	1262.2	538		2.403	2.34	2.616	15.91	83.56	8.51	3.51
		5B2	67	94	1262	730.5	1263.4	532.9			2.368	1.449	14.91	90.28	8.21	3.8
		5B3	67.5	94	1257.2	725.4	1259.5	534.1			2.354	2.045	15.42	86.74	8.52	3.56
		Mean	66.83	94	1259.4	726.7	1261.7	535			2.354	2.036	15.412	86.86	8.41	3.62

Table E3: Marshall Properties of asphalt mixes with 7% CSD filler (C_7 Gradation type)

Bitumen Content (%)	% Filler	Trial code	Specimen Height (mm)	% of Aggregate	Mass of specimen (g) in			volume of Specimen (cc)	Gsb of Agg.	Gmm	Gmb of compacted specimen (g/cc)	VA (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
					Air Dry	Water	Air SSD									
4	7	1C1	67	96	1239.3	703.21	1240.11	536.9	2.616	2.44	2.308	5.21	15.29	65.96	8.12	1.52
		1C2	67.5	96	1238.35	702.65	1239.4	536.75			2.307	5.25	15.33	65.75	7.95	1.9
		1C3	68	96	1241.23	700.43	1243.2	542.77			2.287	6.08	16.08	62.16	8.1	2.01
		Mean	67.5	96	1239.63	702.1	1240.9	538.81			2.301	5.51	15.57	64.63	8.06	1.81
4.5		2C1	68	95.5	1242.3	711.99	1249.8	537.81		2.43	2.31	4.82	15.67	69.22	8.65	1.91
		2C2	68	95.5	1242.62	714.34	1247.6	533.26			2.33	3.99	14.93	73.3	9.08	2.14
		2C3	68.5	95.5	1239.89	712.88	1246.3	533.42			2.324	4.23	15.14	72.09	8.87	2.06
		Mean	68.17	95.5	1241.6	713.07	1247.9	534.83			2.322	4.35	15.25	71.537	8.87	2.04
5		3C1	68	95	1250.6	716.8	1254.2	537.4		2.42	2.327	3.76	15.49	75.74	9.35	2.4
		3C2	68	95	1255.7	717.5	1256.4	538.9			2.33	3.63	15.38	76.37	9.52	2.53
		3C3	67.5	95	1252.12	720.2	1253.63	533.43			2.347	2.92	14.76	80.19	9.1	2.51
		Mean	67.83	95	1252.81	718.17	1254.74	536.58			2.335	3.44	15.21	77.433	9.32	2.48
5.5		4C1	69.5	94.5	1255.3	723.6	1257.21	533.61		2.41	2.352	2.22	15.02	85.19	9.33	2.82
		4C2	67	94.5	1250.6	720.21	1252.22	532.01			2.351	2.3	15.08	84.76	9.11	2.76
		4C3	68	94.5	1254.2	719.7	1255.61	535.91			2.34	2.73	15.46	82.34	9.54	2.73
		Mean	68.17	94.5	1253.37	721.17	1255.01	533.84			2.348	2.42	15.187	84.097	9.33	2.77
6		5C1	68	94	1258.8	724.86	1259.67	534.81		2.39	2.354	1.6	15.42	89.63	8.52	3.01
		5C2	67.5	94	1262.1	726.89	1263.1	536.21			2.354	1.6	15.42	89.63	8.35	3.33
		5C3	68	94	1259.6	730.2	1260.41	530.21			2.376	0.68	14.64	95.33	8.74	3.09
		Mean	67.83	94	1260.17	727.32	1261.06	533.74			2.361	1.29	15.161	91.53	8.54	3.14

Table E4: Marshall Properties of CSD replacement with CWP at 4% OFC and 5.33% OBC

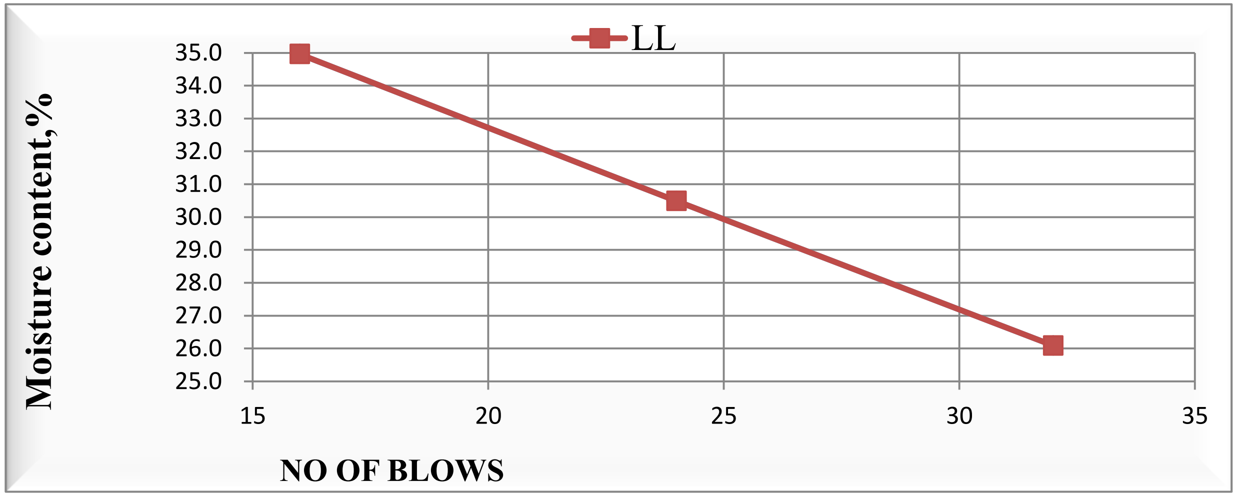
Replacement (%)	% Filler	Trial code	Specimen Height (mm)	% of Aggregate	Mass of specimen (g) in Air Dry	Mass of specimen (g) in Water	Mass of specimen (g) in Air SSD	volume of Compacted Specimen (cc)	Gsb of Agg.	Gmm	Gmb of compacted specimen (g/cc)	VA (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
0% CW and 100% CSD	4	T01	66.5	94.63	1246.83	713.8	1250.78	536.98	2.616	2.426	2.322	4.290	16.01	73.20	9.49	2.96
		T02	67	94.63	1247.2	715.1	1253	537.90			2.319	4.426	16.13	72.56	9.43	2.91
		T03	67.5	94.63	1245.6	712.4	1248	535.60			2.326	4.138	15.87	73.93	9.53	3.08
		Mean	67	94.63	1246.54	713.77	1250.59	536.83			2.322	4.28	16.00	73.23	9.48	2.98
25% CW and 75% CSD		T11	68.5	94.63	1246.85	714.1	1252.7	538.60		2.427	2.315	4.619	16.26	71.59	9.69	2.95
		T12	68.5	94.63	1246.5	715	1252.8	537.80			2.318	4.504	16.16	72.12	9.64	2.92
		T13	68	94.63	1247.84	716.5	1253.91	537.41			2.322	4.332	16.01	72.93	9.61	2.88
		Mean	68.33	94.63	1247.06	715.20	1253.14	537.94			2.318	4.49	16.14	72.22	9.65	2.92
50% CWand 50% CSD		T21	69	94.63	1247.54	716.54	1255.3	538.76		2.4282	2.316	4.638	16.24	71.44	9.77	2.95
		T22	69.5	94.63	1246.89	715.7	1253.5	537.80			2.319	4.518	16.13	71.99	9.72	2.96
		T23	69	94.63	1247.6	714.1	1253.6	539.50			2.313	4.764	16.35	70.86	9.84	2.99
		Mean	69.17	94.63	1247.34	715.45	1254.13	538.69			2.316	4.64	16.24	71.43	9.78	2.97
75% CW and 25% CSD		T31	68.5	94.63	1246.4	715.84	1254.9	539.06		2.429	2.312	4.810	16.36	70.60	9.91	2.92
		T32	69	94.63	1247.1	714.06	1253.83	539.77			2.310	4.881	16.42	70.28	9.88	2.98
		T33	68.5	94.63	1246.14	716.7	1254.8	538.10			2.316	4.660	16.23	71.29	9.87	2.89
		Mean	68.67	94.63	1246.55	715.53	1254.51	538.98			2.313	4.78	16.34	70.72	9.89	2.93
100% CW and 0% CSD		T41	69	94.63	1247.11	715.55	1255.13	539.58		2.430	2.311	4.894	16.39	70.15	10.11	2.98
		T42	69	94.63	1247.49	716.39	1253.98	537.59			2.321	4.513	16.06	71.90	10.06	2.88
		T43	68.5	94.63	1246.21	714.9	1257.3	542.40			2.298	5.457	16.89	67.69	9.98	3.1
		Mean	68.83	94.63	1246.94	715.61	1255.47	539.86			2.310	4.95	16.45	69.91	10.05	2.99

Table E5: Marshall Properties of CSD Replacement with CHA at 4% and 5.33% OBC

Replacement (%)	% Filler	Trial code	Specimen Height (mm)	% of Aggregate	Mass of specimen (g) in			volume of Compacted Specimen (cc)	Gsb of Agg.	Gmm	Gmb of compacted specimen (g/cc)	VA (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
					Air Dry	Water	Air SSD									
0% CHA and 100% CSD	4	T01	66.5	94.63	1246.83	713.8	1250.78	536.98	2.616	2.426	2.322	4.290	16.01	73.20	9.49	2.96
		T02	67	94.63	1247.2	715.1	1253	537.90			2.319	4.425	16.13	72.56	9.43	2.91
		T03	67.5	94.63	1245.6	712.4	1248	535.60			2.326	4.138	15.87	73.93	9.53	3.08
		Mean	67	94.63	1246.54	713.77	1250.59	536.83			2.322	4.28	16.00	73.23	9.48	2.98
1.5% CHA and 98.5 %CSD		T11	68.5	94.63	1246.3	712.8	1248.14	535.34		2.425	2.328	3.998	15.79	74.68	9.47	3.12
		T12	67.5	94.63	1245.81	711.35	1248.05	536.70			2.321	4.279	16.03	73.31	9.51	2.91
		T13	68.5	94.63	1245.63	710.23	1247.11	536.88			2.320	4.325	16.07	73.09	9.5	2.99
		Mean	68.17	94.63	1245.91	711.46	1247.77	536.31			2.323	4.20	15.96	73.69	9.49	3.01
3% CHA and 97% CSD		T21	68.5	94.63	1244.71	711.33	1248.9	537.57		2.424	2.315	4.479	16.24	72.43	9.5	2.85
		T22	67.5	94.63	1245.09	711.95	1247.89	535.94			2.323	4.159	15.96	73.95	9.52	2.97
		T23	68	94.63	1246.96	710.77	1245.46	534.69			2.332	3.791	15.64	75.76	9.52	3.01
		Mean	68.00	94.63	1245.59	711.35	1247.42	536.07			2.324	4.14	15.95	74.04	9.51	2.94
4.5% CHA and 95.5% CSD		T31	68	94.63	1246.5	711.15	1246.9	535.75		2.423	2.327	3.977	15.84	74.89	9.56	2.98
		T32	68.5	94.63	1247.2	711.65	1248.5	536.85			2.323	4.120	15.96	74.19	9.55	3.11
		T33	68	94.63	1246.18	710.49	1246.7	536.21			2.324	4.084	15.93	74.37	9.51	3.18
		Mean	68.17	94.63	1246.63	711.10	1247.37	536.27			2.325	4.06	15.91	74.48	9.54	3.09
6% CHA and 94% CSD		T41	69	94.63	1247.32	711.55	1247.5	535.95		2.422	2.327	3.910	15.81	75.28	8.22	3.47
		T42	68.5	94.63	1246.7	710.4	1246.9	536.50			2.324	4.056	15.94	74.56	7.89	3.54
		T43	68.5	94.63	1248.73	710.8	1248.87	538.07			2.321	4.180	16.05	73.96	8.11	3.52
		Mean	68.67	94.63	1247.58	710.92	1247.76	536.84			2.324	4.05	15.93	74.60	8.07	3.51
7.5% CHA and 92.5% CSD		T41	68	94.63	1246.26	710.6	1246.38	535.78		2.421	2.326	3.921	15.86	75.27	7.81	3.72
		T42	67.5	94.63	1245.42	709.5	1245.83	536.33			2.322	4.084	16.00	74.47	7.78	3.83
		T43	68	94.63	1246.2	709.78	1246.4	536.62			2.322	4.076	15.99	74.51	7.84	3.68
		Mean	67.83	94.63	1245.96	709.96	1246.20	536.24			2.323	4.03	15.95	74.75	7.81	3.74

Appendix F: Plastic index of coffee husk ash

Determination	***Liquid Limit***			***Plastic Limit***	
Number of blows	*32*	*24*	*16*		
Test No	1	2	3	1	1
Container Code	T4	C	T1	B	H
Wt. of container + wet CHA, g	14.98	16.39	15.96	12.65	14.52
Wt. of container + dry CHA, g	13.12	13.96	13.45	11.17	12.82
Wt. of container, g	5.99	5.99	6.27	6.10	7.06
Wt. of water, g	1.86	2.43	2.51	1.48	1.70
Wt. of dry CHA, g	7.13	7.97	7.18	5.07	5.76
Moisture content, %	*26.1*	*30.5*	*35.0*	29.19	29.51
Average Moisture Content, %				29.4	
PI = LL-P L= 30-29.4 = 0.6					



Appendix G: Test results of Tensile Strength Ratio (TSR)

		TYPES OF MIX DESIGN REPLACEMENTS																	
		CSD-CW Mix @ 100% CW replacements						Control Mix @100 % CSD						CSD-CHA Mix @ 4.5 % CHA replacements					
		Wet group			Dry group			Wet group			Dry group			Wet group			Dry group		
Specimen ID		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Thickness,mm	t	67	67.5	68.5	67.5	68	67	68	67.5	69.5	68	68	67.5	68	67	67.5	68	67.5	69
Diameter,mm	D	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6	101.6
Dry mass in air,g	A	1245.5	1246.1	1244.5	1245	1246.97	1245.9	1245.4	1245	1244.5	1247	1246.9	1246.7	1245	1248	1246.54	1248	1246.82	1245.76
SSD mass,g	B	1248.5	1249.4	1247.52	1247	1249	1248.7	1249.8	1248.7	1247.9	1249.5	1248.78	1248.9	1246.5	1249	1247.5	1249.2	1247.2	1247
Mass inwater,g	C	699.8	700	697.57	698	700	699	702	701	698.6	701.8	701	699.21	697.5	700	698	699	697.1	698
Volume (B-C),cm3	E	548.7	549.4	549.95	549	549	549.7	547.8	547.7	549.3	547.7	547.78	549.69	549	549	549.5	550.2	550.1	549
BulkSp.gr.(A/E),g/cc	Gmb	2.27	2.27	2.26	2.27	2.27	2.27	2.27	2.27	2.27	2.28	2.28	2.27	2.27	2.27	2.27	2.27	2.27	2.27
%Air Void,%	VA	6.43	6.51	6.72	6.52	6.37	6.57	6.29	6.30	6.61	6.15	6.17	6.51	6.52	6.30	6.49	6.50	6.57	6.47
Volume ofVA (VA*E/100),cm3	Va	35.30	35.76	36.97	35.81	35.00	36.14	34.44	34.51	36.32	33.69	33.81	35.80	35.81	34.57	35.67	35.77	36.16	35.50
SSD mass,g	B'	1250.4	1251.2	1249.68				1250.2	1249.7	1249.5				1249.65	1252.5	1251.2			
Volume of absorbed water (B'-A),cc	J'	4.9	5.1	5.18				4.8	4.7	5				4.65	4.5	4.66			
% Saturation (100*J'/Va)	S'	76.2	78.4	77.1				76.3	74.6	75.6				71.3	71.5	71.8			
Max.load for Dry, N	P				7515	7697	7488				8030	7880	7873				8380	8261	8370
S1 = 2000P/3.14*t*D ,Kpa	S1				697.96	709.61	700.64				740.31	726.48	731.21				772.58	767.25	760.47
Avg.strength of dry groups,Kpa	S1avg.				1641.12						732.67						1793.31		
Max.load for Wet,N	P'	6056	6140	6213				6813	6486	6870				7306	7105	7149			
S2 =2000P/3.14*t*D ,Kpa	S2	566.65	570.26	568.61				628.11	602.39	619.70				673.56	664.81	663.97			
Avg.strength of Wet group, Kpa	S2 avg.	1326.45						616.73						1559.69					
Calculated % TSR= (S2 avg./S1 avg.)*100		80.83						84.18						86.97					
Tensile Strength of Machine read ,Kpa		566.7	570.3	568.6	697.9	709.7	700.6	628.1	602.4	619.7	740.3	726.5	731.2	673.5	664.8	664	772.6	767.3	760.5
Max.load o machine read,kpa		6056	6140	6213	7515	7697	7488	6813	6486	6870	8030	7880	7873	7306	7105	7149	8380	8261	8370
TSR (%) o machine read values		80.90						84.18						87.04					

Appendix H: Photograph during Laboratory work

a) Material sampling at quarry site

b) Aggregate sieve analysis

c)Preparing Coffee husk for burning

d) Aggregate washing

e) Burning of Coffee husk: **captured by Achalu Kebede**

f) Aggregate blending and Sample preparation of Marshall mix

g) Placing prepared sample in an Oven h) Bitumen penetration test

i)Checking binder heating temperature

j) Adding bitumen to prepared sample for mix

k)Marshall compaction test

l) Compacted specimen of asphalt mix

Captured by Muleken Geremu

m)Extruding compacted specimens n) Taking height of compacted specimen

o)Recording Weight of compacted specimen p) Taking Sub-merged mass of specimen

Captured by Asebew Almaw

q) Marshall stability-flow test

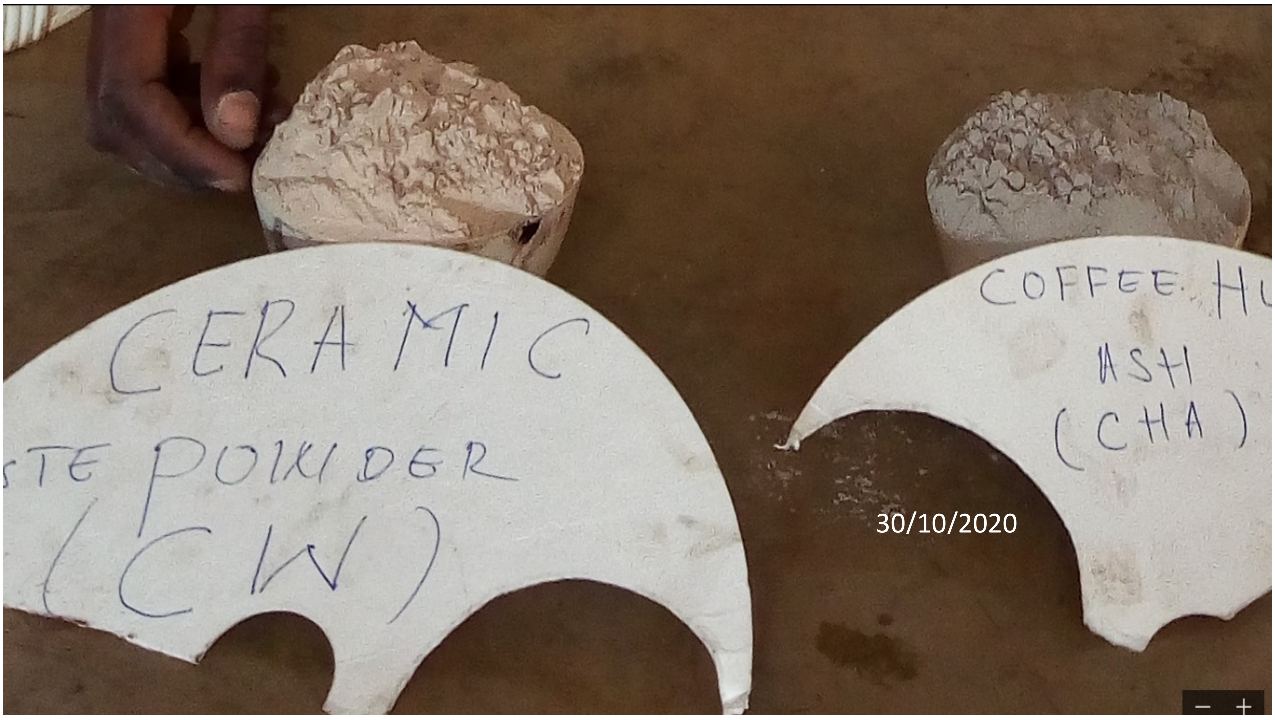
r) ITS test

s)Aggregate Specific gravity test for CWP and CHA

t) Gmm test for lose mix

u)Compacted specimens of CHA and CWP replacements

v) PI test for CHA



w) CWP and CHA: Captured **by Yerosan Fayissa**

Appendix I: Chemical composition of CHA and CWP

GEOLOGICAL SURVEY OF ETHIOPIA	Doc.Number: GLD/F5.10.2	Version No: 1
GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title: Complete Silicate Analysis Report	Effective date:	May, 2017

Issue Date: -21/01/2021

Customer Name:- Bilisumma Lemi

Request No:- GLD/RQ/484/20

Report No:- GLD/RN/78/21

Sample type :- Ceramic Dust & Coffe Husk

Sample Preparation: - 200 Mesh

Date Submitted :-18/12/2020

Number of Sample:- Two (02)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
Coffee husk ash	17.90	3.25	0.96	8.12	1.84	0.38	36.34	0.10	2.56	0.07	5.52	22.62
Ceramic Dust	74.00	18.48	2.38	1.84	0.32	2.16	0.70	0.04	0.21	0.25	0.25	0.72

Note: - This result represent only for the sample submitted to the laboratory.

Analysts: Lidet Endeshaw, Nigist Fikadu

Checked By: Tizita Zemene

Approved By: For Yohannes Getachew

Quality Control: Gosa Haile