JIMMA UNIVERSITY

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JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

Experimental Study on Potential Use of Blended Steel Slag Dust and Bagasse Ash as Mineral Filler in HMA

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 Civil Engineering.

By: Daniel Alelgn

December. 2022

Jimma, Ethiopia

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By:

Daniel Alelgn Derese

Main Adviser: -Engr. Elmer C. Agon (Asso.prof.)

Co-Adviser: -Engr. Biruk Yigezu

December. 2022

Jimma, Ethiopia

Declaration

I, the undersigned, declare that this thesis proposal entitled "Experimental Study on Potential Use of Blended Steel Slag Dust and Bagasse Ash as Mineral Filler in Hot Mix Asphalt" is my original work; and it 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 to be duly acknowledged

Candidate:

Daniel Alelgn Derese ____________ 23/01/2023

Signature Date

As Master 's Research Advisors, I hereby certify that I have read and evaluated this MSc thesis proposal prepared under my guidance, by **Daniel Alelgn** entitled: "Experimental Study on Potential Use of Blended Steel Slag dust and Bagasse Ash as Mineral Filler in HMA."

Engr.Elmer C. Agon (Asso.prof) ____________ 23/01/2023

Main Advisor Signature Date

Engr. Biruk Yigezu ____________ 23/01/2023

Co-advisor Signature Date

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Approved by Board of Examiners

1.	Prof. Dr.-Ing. Alemayehu Gebissa External Examiner	Signature	18/01/23 Date
2.	Dr. Tarekegn Kumala Internal Examiner	Signature	12/5/2015 Date
3.	Engr. Oluma Gudina Chairperson	Signature	23/01/2023 Date
4.	Engr. Elmer C. Agon Main Advisor	Signature	23/01/2023 Date
5.	Engr. Biruk Yigezu Co-Advisor	Signature	23/01/2023 Date

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ABSTRACT

In highway pavement construction, one of the main problems is the insufficient amount of mineral filler from crushing rocks. This is due to the following: abundance, accessibility, high grinding costs, transportation costs, and the use of conventional filler (lime and crushed stone dust), which are the most commonly used filler in Ethiopia. To solve such a problem, it is important to look at other alternative filler materials that could replace crushed stone dust that can address the gap, whether partially or, if it is possible, fully. The aim of this research is to study the partial replacement of blended bagasse ash and steel slag dust as mineral fillers in hot mix asphalt. To determine the optimal bitumen content, three identical hot mix asphalt specimens were prepared (4.5%, 5.5%, and 6.5% crushed stone dust by weight of aggregates) and five different percentages of bitumen (4.0%, 4.5%, 5.0%, 5.5%, and 6.0% by weight of total mix). According to the procedure of the NAPA (National Asphalt Pavement Association) curve plotting method, the replacement of conventional filler (CSD) with non-conventional filler was done by using optimum conventional filler content (5.5%), optimum bitumen content at 5.10%, and with different replacement proportions (0 control, 10%, 20%, and 30%) of blended bagasse ash and steel slag dust to get the optimum replacement percentage. The study compares the performance of asphalt mixes using stability and flow with corresponding volumetric properties, and at an optimum replacement percentage of non-conventional filler. One hundred two (102) samples were prepared. Forty-five (45) of these were prepared at each percentage of bitumen content and conventional filler content (CSD) in order to determine the optimum bitumen content (OBC) and the optimum filler content (OFC). The remaining forty-five (45) mixes were prepared to determine the optimum replacement proportion of non-conventional filler and twelves (12) for the Indirect Tensile Strength test. From the test results, the optimum replacement percentage of blended BA and SSD was found at 20% (5%BA and 15% SSD) by weight of optimum filler content (5.5%) at a bitumen content of 5.10%. Asphalt mixes prepared with blended BA and SSD filler are not sensitive to the action of water and result in better resistance to moisture-induced damage. The values at 20% blended BA and SSD (by weight of optimum filler content) replacement were stability of 11.0 KN, bulk density of 2.349 gm/cm^3,air void (VA) of 4.0%, and TRS was 87.942%, *which were the best when compared to other percentage replacement ratio values. Hence, 20% (by weight of optimum filler content) was adopted as the optimum replacement ratio of blended BA and SSD. Therefore, it can be concluded that blended BA and SSD can be used as mineral filler materials (crushed stone dust) substituted partially at 20% (5% BA and 15% SSD).*

Key-words; blended bagasse ash & Steel slag dust, crushed stone dust, hot mix Asphalt.

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ACRONYM

ACV	Aggregate crushing value
AC	Asphalt Concrete
AIV	Aggregate Impact value
BBASSD	Blended of bagasse ash and steel slag dust
BC	Binder Content
BS	British standard
CSD	Crushed stone dust
ERA	Ethiopia Road Authority
ERCC	Ethiopia Road Construction Corporation
HMA	Hot Mix Asphalt
LAA	Los angles abrasion
MAS	Maximum aggregate size
NMAS	Nominal maximum aggregate size
NAPA	National Asphalt Pavement Association
NP	Non-Plasticity
OBC	Optimum bitumen Content
OFC	Optimum filler content
SSD	Steel slag dust
SBA	Sugarcane bagasse ash
Std	average tensile strength of the dry subset (unconditioned)

Stm	average tensile strength of the moisture (conditioned)
TSR	Tensile strength ratio
VFA	Voids filled with asphalt
VA	Air voids
VIM	percentage of voids in total mix
VMA	Voids in mineral aggregate
C°	Degree Centigrade
%	Percent

CHAPTER ONE
INTRODUCTION

1.1.Background

As a developing country, roads and highways play an important role in connecting one place to another. Ethiopia is one of the developing countries of the world, where roads and highways play an important role in connecting one place to another, because roads are an important activator of regional development. Hence, a good road network is a key to the development of the country (P. C. Yuan, 2008). So, the Ethiopian roads have used to move goods, people, and military from rural to urban and vice versal. Therefore, transportation infrastructure inevitably has a greater or more distinguishable impact on the economic growth and trade activities of the nation.

In road construction, pavement design is a crucial stage, which has to be done carefully in order to be economical and increase the service period of the road. The majority of roads in Ethiopia are flexible pavement types. Flexible pavement typically consists of asphalt mixture placed over a granular base layer supported by the compacted soil, called sub grade. Flexible pavement structure consists of sub grade, sub-base, base course, and surface course. The surface course is the upper layer, which is directly in contact with the traffic load. It is made of asphalt concrete, which consists of high-quality materials compared to materials in other layers. Asphaltic pavement design is incomplete or becomes unstable without filler. Mineral filler consists of very fine, inert mineral matter that is added to the Hot Mix Asphalt (HMA) to improve the density and strength of the mixture.

Filler is generally selected on the basis of its ability to increase the stiffness of the binder mastic or improve adhesion between the binders and aggregate (U.S. Imam, 2010). The filler is the mineral fine part with physical size passing the number 200 standard mesh sieve (75 µm) which devoid of organic matter and displayed almost non plastic behavior (M.J. Choi et al,2019). Fillers may be of natural origin when derived from the crushing of rocks or can be manufactured as it is in the case of lime, cement, ash or slag. Their main functions are filling the voids in the aggregate skeleton to create a denser mixture and improving the cohesion of the asphalt binder and the stability of the mixture. As a result, the asphalt mixture pavement should be resistant to water and frost, plastic deformations, fatigue cracks and low temperature cracks. Conclusions from several studies confess the importance of the filler used in asphalt mixture (Marta Wasilewski et al., 2017).

A higher percentage of very fine filler may stiffen the mixture excessively, making it difficult to work with and resulting in a crack susceptible mixture (Asmael, 2010).

In civil engineering works, various waste products have been used for several purposes, amongst which are stabilization of soil and replacement of filler or binder materials. waste utilization would not only be economical but may also result in foreign exchange earnings and environmental pollution controls (A.O. Apata,2017). In highway construction technology, efforts are being made in the area of utilizing waste materials instead of discarding or incinerating them. Such waste includes industrial, agricultural and municipal solid waste (A.A. Manurana et al,2015)

According to (F. T. Jegede et al, 2013) there are a number of filler types used in the pavement industry which include fly ash, hydrated lime, marble dust, crushed stone dust, waste glass powder, silt, Portland cement, mineral sludge, recycled brick powder, sugarcane bagasse ash, steel slag and waste ceramic materials were satisfactorily used as filler in different asphalt mixes. Therefore, it is important to come across an alternative type of filler material. Hence, an attempt is made to find effective types of cheap and non-conventional filler on the behavior of bituminous mixes.

According to various studies, the properties of mineral fillers, especially the material passing 0.075 mm (No. 200) sieve have a significant effect on the performance of asphalt paving mixture in terms of deformation, Fatigue cracking, and moisture susceptibility (Kandhal, et al, 1998). Various conventional materials such as cement, lime, granite powder, bagasse ash, steel slag was normally used as filler in asphalt concrete mixture in the world. From an environmental safety and economic point of view, my present study has been taken in order to study the effect of blending steel slag dust and bagasse ash used as a partial fill in a mineral filler material instead of crushed stone dust as a filler material in hot mix asphalt production. Ever-growing concern about protecting the environment focuses on the attention of society on the possible reprocessing of different agricultural and industrial wastes in road construction. Furthermore, it is globally accepted that the natural filler can be replaced with any suitable material either natural or artificial (Tapkin, 2008).

1.2.Statement of problem

Road construction is one of the major sectors that affects economic development, social life standards, environmental quality and interaction between societies. Currently, upgrading and construction of highway roads are increasing in Ethiopia. The construction of highway roads industry uses crushed stone dust mainly as filler material (ERA,2013), but the amount of crushed stone dust from crushing aggregate is not sufficient. Then, to fulfill these filler materials, directly obtained by mining the earth's resources in the quarry areas, their continuous use in asphalt mixes has led to their scarcity and exhaustive mining for conventional fillers leads to problems like vegetation loss, loss of water retaining strata, and disturbance in the existing ecosystem, because to produce the required amount of mineral filler (B. Ribeiro et al., 2020). According to (Ako T.A., 2014), field observations conclude that landscape degradation, depletion of agricultural and grazing land, collapsing riverbanks, deforestation, and water pollution are the environmental impacts generated by sand and gravel mining in the natural area. The disposal of this large quantity of waste, especially non-decaying waste materials, has become a problematic issue in developed and developing countries in worldwide (Mohammed Atta El-Saikaly,2013). Then, from these industrial waste materials, bagasse ash and steel slag are included. Then the production of steel slag and bagasse ash was rapidly increasing in the world.

The bagasse ash is taking 40%. The average annual production is estimated as 600 million tons in the world, which is a bulky waste from the sugar industry and that in un burned matter, silica and alumina (Prof. Sonali Nawkhare, et al., 2018) while about 2,000,000 tons/year of the aggregate fillers for asphalt road construction are used (Kroekphon Rachabut,2020). which is a problem for the environment because of its disposal.in addition, in 2020, world steel slag production was estimated to be between 180 million and 270 million tons per year (JianYang,2022 et al.). The generation of the solid waste worldwide is dramatically increasing each year (Hussein I. et al,2018) Since there is a continuous increase in the production of bagasse ash and steel slag worldwide, Therefore, they are not applicable directly and accumulated as waste. Storage of these materials has many restrictions because of their huge volume, besides serious environmental hazards (Mansourian A,2021).

To reduce the environmental effect and to save the conventional filler material, introducing bagasse ash and steel slag used as pavement filler material was essential. Hence, an investigation was made to find effective types of cheap and non-conventional fillers on the behavior of bituminous mixes. For this purpose, it used steel slag dust and bagasse ash as a conventional filler. In this study, there was the possibility of replacement of blended steel slag dust and bagasse ash used as mineral fillers (CSD) in hot mix asphalt production. To enhance waste materials is one good option for achieving cost reductions, as waste management is another area that is the focus of the research fraternity all over the world. Thus, the combination of waste management with cost reductions for the development of innovative low-cost construction materials provides the best of both worlds (Jijo James et al., 2016).

The production of steel slag and bagasse ash waste are increasing in Ethiopia. However, the situation of using steel slag and bagasse ash, either as a resource opportunity or an environmentally friendly environment, was not studied well in Ethiopia. So, there was no specific law and regulation regarding waste of steel slag and bagasse ash management. Then these waste materials are removed from their fabricated area and transformed into another place without a proper way or no one has a specific waste accomplished place. It is easily observed that the current practices of utilizing used steel slag and bagasse ash in Ethiopia are not effective, do not result in higher value- added products, and are not environment-friendly. Therefore, due to this environmentally safe and workable, new steel slag and bagasse ash recycling techniques are needed.

1.3.Research Questions

1). What are the physical properties and chemical compositions of both steel slag dust and bagasse ash as filler material in HMA production?

2). What are the effects of blended Steel slag dust and bagasse ash used as mineral filler material on the marshal properties of HMA production?

3). What is the optimum replacement percentages of steel slag dust and bagasse ash blended with crush stone dust filler?

1.4.Objective

1.4.1.General objective

The main goal of this research study was to evaluate the possibility of steel slag dust blending with bagasse ash as a mineral filler in hot mix asphalt production.

1.4.2.Specific objectives

The specific objective of this research is:

- To know the physical properties and chemical compositions of steel slag and bagasse ash as an alternative filler in Hot Mix Asphalt.
- To investigate experimentally the effects of steel slag dust blended with bagasse ash in Hot Mix Asphalt production.

- To determine the optimum replacement percentage of blended steel slag dust and bagasse ash used as mineral filler in Hot Mix Asphalt production.

1.5.Scope of the study

This research was performed focused on selecting to evaluate the possibility of blending steel slag dust and bagasse ash as partially a substitute for natural filler material (CSD) while determining the optimum partial replacement percentage of blended steel slag dust and bagasse ash with crushed stone dust in Hot Mix Asphalt production. Besides, the study evaluated the effect of steel slag dust and bagasse ash on the marshal properties (Flow, stability, a void filled by bitumen, a void in the total mix, bulk - density, and air voids) using the materials coarse aggregate, fine aggregate, crushed stone dust passing 0.075mm sieves, steel slag dust and bagasse ash. These HMA characteristics of Marshall Properties, such as voids in mineral aggregate VMA, air void VA, VFA, Marshall Stability, flow of asphalt bituminous mixture produced and water susceptibility of the mix design, The 60/70 penetration grade of bitumen, which is the most common type of asphalt penetration grade in our country, especially in a mild climate, was used to evaluate hot mix asphalt concrete properties, and the substitute of CSD with the former blended fillers at the nominal size of mineral aggregate gradation was carried on. Lastly, an 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, followed by the determination of the TSR value of the mixes.

1.6.Significance of the Study

The significance of the research study was to determine the performance of HMA that was made with the replacement of natural filler (crushed stone dust) with the use of blended steel slag dust and bagasse ash. The emphasis of the work was based on ascertaining the performance of HMA containing steel slag dust and bagasse ash. The other possibility of this research is that it will have created an introduction for steel slag dust blended with bagasse ash to be a new filler material in a Marshall Mix design. This can use steel slag dust blended with bagasse ash as an alternative filler material from its sources, which is directly related to the concept of land safety, controlling environmental pollution and minimizing the quantity of natural filler material (crushed stone dust) in HMA production.

- ✓ Using steel slag dust and bagasse ash as mineral filler in order to improve the properties of asphalt.
- ✓ Reducing the amount of waste materials (steel slag & bagasse ash) and the area of land used for landfill.
- ✓ To create an introduction for steel slag dust blended with bagasse ash as alternative filler material in hot mix asphalt production.
- ✓ It creates a continuous way of waste management and environmental health benefit would be gained.
- ✓ Other researchers will have used the findings as a reference for further research on blended steel slag dust and bagasse ash used as filler material for HMA production.

1.7 Limitation of the research

- ✓ The viscosity test apparatus was not functional.
- ✓ The electronics asphalt mixer instrument and mix compacters also were not functional.
- ✓ The mixture done by manually (man power).

CHAPTER TWO
REVIEW OF RELATED LITERATURE

A road network providing adequate connectivity across rural to urban center, zone to zone, regional state to regional state and country to country (national territory) is typically one of the costliest items of infrastructure that any country requires. However, the construction of roads on natural soil will not accept tires route without changing its shape. Therefore, this land should be set to the desired level, compacted and built on it a strong structure. Structures built above the road pavement formation called consisting of several layers of overlay made of a suitable material of choice, work to spread the load of vehicles to the road base, providing slip resistance of road surfaces and have sufficient long life without the need for a lot of work.

The pavement is the last most common part of the road structure and which is built by using different materials like coarse aggregate, fine aggregate, crushed stone dust (filler) and bitumen Ministry of Road Transport and Highways (MORTH,2013)). The pavement will be used for all-weather by vehicles to prepare a suitable sub grade and will have sufficient total thickness and internal strength to carry the expected traffic loads; have adequate properties to prevent or minimize the penetration of internal accumulation of moisture, and have a surface that is reasonably smooth and skid resistant at the same time, as well as reasonably resistant to wear, distortion and deterioration (ERA, Pavement Design Manual, 2013).

Pavement is of three types; rigid pavement, flexible pavement and composite pavement.

Rigid pavement is a pavement structure, which distributes loads to the sub grade having, as the main load-bearing course, a Portland cement concrete slab of relatively high bending resistance. Whereas flexible pavement is a pavement consists of asphalt mixture placed over granular base layer supported by the compacted soil, the sub grade; while composite pavement is the combination of both pavement types i.e., rigid and flexible pavement. Flexible pavements are so named because the total pavement structure deflects, or flexes, under loading. It supports loads through bearing rather than flexural action, as rigid pavements do. They comprise several layers of carefully selected materials designed to gradually distribute loads from the pavement surface to the layer’s underneath. The design ensures the load transmitted to each successive layer does not exceed the layer's load-bearing capacity.

2.1.Flexible pavement structure

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

Figure 2.1. Typical Cross section of Flexible Pavement (Source, ERA,2013).

2.1.1 Sub grad

It is the supporting ground beneath a pavement structure. It is located below the base and sub-base courses. It is usually investigated to such depth as may be important to structural design and pavement life, and it may consist of materials forming the natural ground surface or exposed in excavations. In a fill section, the sub grade is the upper part of the embankment.

2.1.2 Sub-base

It is an important load-spreading layer in the completed pavement. It enables traffic stresses to be reduced to acceptable levels in the sub grade, it acts as a working platform for the construction of the upper pavement layers and it acts as a separation layer between sub grade and base course. Under special circumstances, it may also act as a filter or as a drainage layer. In wet climatic conditions, the most stringent requirements are dictated by the need to support construction traffic and paving equipment. In these circumstances, the sub-base material needs to be more tightly specified. In dry climatic conditions, in areas of good drainage, and where the road surface remains well sealed, unsaturated moisture conditions prevail and sub-base specifications may be relaxed. The selection of sub-base materials will therefore depend on the design function of the layer and the anticipated moisture regime, both in service and at construction. A sub-base is not always needed. It consists of stabilized or properly compacted granular material.

2.1.3 Base course layer

This is the layer directly beneath the surface of the HMA layer or roadway, race track, riding arena, or sporting field. It is located under the surface layer consisting of the wearing course and sometimes an extra binder course. It may be composed of screened and grinded stone, screened and grinded slag and other untreated or stabilized materials. The quality of the pavements is a layer of material in an asphalt base course, is a function of its composition, physical properties, and compaction of the material. This layer is used in areas where frost action is severe or the sub grade soil is extremely weak. Generally, consists of aggregate (either stabilized or unsterilized).

2.1.4 Surface course (Optional)

This is the top layer and the layer that comes in contact with traffic that’s why it contains superior quality materials. It may be composed of one or several different HMA sub-layers. HMA is a mixture of course and fine aggregates, filler and asphalt binder. Generally, this surface prevents the penetration of surface water to the base course; provides a smooth, well bonded surface free from loose particles resists the stresses caused by aircraft loads; and supplies a skid-resistant surface without causing undue wear on tires.

2.1.5 Asphalt binder course

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

2.1.6 Asphalt wearing course

It is the top layer of the pavement and it is directly exposed to traffic and environmental forces. Wearing course provides characteristics such as friction, smoothness, noise control, rut and shoving resistance, and drainage.

2.1.7 Asphalt concrete (bitumen mixture)

Asphalt concrete is a composite material commonly used in construction projects such as road surfaces, airports and parking lots. It consists of asphalt (used as a binder) and mineral aggregate mixed together, then are laid down in layers and compacted. Mixing of asphalt and aggregate is accomplished in one of several ways. Hot mix asphalt concrete (HMA) is produced by heating the asphalt binder to decrease its viscosity, and drying the aggregate to remove moisture from it prior to mixing. Mixing is generally performed with the aggregate at about 300 °F (roughly 150 °C) for virgin asphalt then paving and compacting will be performed while the asphalt is sufficiently hot.

2.2.Hot mix asphalt (HMA)

HMA is a mixture of course, fine aggregates, fillers and asphalt binder. HMA, as the name suggests, is mixed, placed and compacted at higher temperature. Hot mix asphalt mix design is the process of determining appropriate proportion of the materials that would give long-lasting performance paving mixture during its service life. It is a mixture of binder, aggregate, and air in different relative proportions that determine the physical properties of the mix and, ultimately, how the mix will perform as a finished pavement. Many different, and sometimes conflicting, performance demands are placed up on the asphalt mixtures, and this makes it a complex material. Thus, the design of asphalt paving mixes is largely a matter of selecting and proportioning the ingredient materials to optimize all desired properties in the finished paved road (Zemichael, 2007).

According to U.S Department of Transportation HMA pavement mix types include:

- ✓ Dense-graded mixes**:** **-** are referred to by their nominal maximum aggregate size and can further be classified as either fine- graded or coarse-graded. Fine-graded mixes have finer and sand-sized particles than coarse-graded mixes. It is suitable for all pavement layers and for all traffic conditions. It offers good compressive strength. When properly designed and constructed, a dense-graded mix is relatively impermeable.
- ✓ Open-graded mixes: - are produced with relatively uniform-sized aggregate typified by an absence of intermediate-sized particles. Mixes typical of this structure are the permeable friction coarse and asphalt-treated permeable bases.
- ✓ Stone matrix asphalt, sometimes called stone mastic asphalt: - is a gap-graded HMA originally developed in Europe to maximize rutting resistance and durability in heavy traffic road. It has a high coarse aggregate content that interlocks to form a stone skeleton that resists permanent deformation. The stone skeleton is filled with mastic of bitumen and filler to which fibers are added to provide adequate stability of bitumen and to prevent drainage of binder during transport and placement.

- ✓ Gap-graded mixes: - use an aggregate gradation with particles ranging from coarse to fine with some intermediate sizes missing or present in small amounts. These mixes are also typified by stone-on-stone contact and can be more permeable than dense-graded mixes or highly impermeable.

2.2.1. Desirable Properties of Hot Mix Asphalt (HMA)

Hot mix asphalt (HMA) is a generic term that includes many different types of mixtures of aggregate and asphalt cement (binder) produced at elevated temperatures in an asphalt plant. It's known by many different names: HMA, asphaltic concrete, plant mix, bituminous mix, bituminous concrete, and many others. The main objective in the design of HMA mixture is to determine a cost-effective proportion of ingredients in the mixture and the mix design seeks to achieve a set of properties in the final HMA product. Some of the properties of asphalt mixes are describe as below in detail individually (Wayne et al., 2006).

- ➢ Skid Resistance: - This is a concern for surface mixtures that must have sufficient resistance to skidding, particularly under wet weather conditions. Aggregate properties such as texture, shape, size, and resistance to polish are all factors related to skid resistance.
- ➢ Workability: - Mixes that can be adequately compacted under laboratory conditions may not be easily compacted in the field. Adjustments may need to be made to the mix design to ensure the mix can be properly placed in the field without sacrificing performance. HMA is a mixture that contains aggregate and bitumen fastened in to a strong mixture.
- ➢ Stability: - The mix must provide sufficient stability under traffic loading through its service life. The stability of a mixture under traffic load is the amount of resistance to deformation.
- ➢ Fatigue resistance: - The mix, as a paved road, must resist cracking effects that may induce due to repeated traffic loading over time. The cracking of mixes under repeated traffic loading over time is referred to as fatigue cracking.
- ➢ Durability: - The mix must contain sufficient asphalt cement to ensure an adequate film thickness around the aggregate particles. This helps to minimize the hardening and aging of the asphalt binder during both production and while in service.
- ➢ Air voids content: - There must be sufficient voids in the total compacted mixture to allow for a slight amount of additional compaction under traffic loading and a slight amount of

asphalt expansion due to temperature increases without flushing, bleeding, and loss of stability.

- Resistance to moisture damage (Stripping): - Loss of adhesion between the aggregate surface and the asphalt binder is often related to properties of the aggregates. The assumption on the part of the mix designer should be that moisture will eventually find its way into the pavement structure; therefore, mixtures used at any level within the pavement structure should be designed to resist stripping.

2.3.Asphalt binder (Bitumen)

Bitumen is a category of organic liquids which are highly viscous, black, sticky and wholly soluble in carbon disulfide. Bitumen molecules can contain thousands of carbon atoms. This makes bitumen one of the most complex molecules found in nature.

Asphalt binder (bitumen) which holds aggregates together in HMA is the thick, heavy residue remaining after refining crude oil. Asphalt binder consists mostly of carbon and hydrogen, with little amounts of oxygen, sulfur, and several metals. The physical properties of the asphalt binder vary considerably with temperature. At high temperature, asphalt binder will become fluid with a low consistency similar to that of oil. At room temperature, most asphalt binders should have the consistency of soft rubber. At sub-zero temperatures, asphalt binder can become very brittle. Many asphalt binders will contain small percentages of polymer to improve their physical properties; these materials are called polymer modified binders. Most of asphalt binder specification was designed to control changes in consistency with temperature (Transportation Research Board Committee, 2011).

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. At subzero temperatures, asphalt binder can become very brittle. Many asphalt binders will contain small percentages of polymer to improve their physical properties; these materials are called polymer modified binders.

Generally, there are two sources of asphalt and these are: -

I. Natural asphalt is obtained from nature in that it is found in so-called “asphalt lakes” around the world.

II. II. Petroleum asphalt is obtained during the refinery process of heavy crude oils. Asphalt used for road construction is mainly produced from the refinery process. Different type ‘s grades of asphalt can be produced by using various operations.

2.3.1. Gradation specification for asphalt binder

An aggregate's particle size distribution, or gradation, is one of its most influential characteristics. In hot-mix asphalt, gradation helps to determine almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, and resistance to moisture damage. This makes gradation the primary factor in the asphalt mix design.

Table 2.1.Shows Particle Size Distribution for wearing Coarse for Nominal Size 19 mm (Source, ERA, 2002)

Sieve No.	Sieve Size (mm)	Percentage by Weight Passing	
		Minimum	Maximum
I"	25	100	100
¾	19	90	100
½	12.5	71	88
¾	9.5	56	80
No.4	4.75	35	65
No.8	2.36	23	49
No.16	1.18	15	37
No.30	0.6	10	28
No.50	0.3	5	19
No.100	0.15	4	13
No.200	0.075	2	8
Bitumen content (%)		4	10

2.3.2. Specification for binder course

Specifications for the mechanical properties of asphalt binder course are reviewed on different manuals such as ASTM, AASHTO, and Ethiopian Road Authority (ERA). The following table summarizes the specifications of Ethiopian Road Authority (ERA) local project specification on mechanical properties of binder course.

Table 2.2.Indicates Specification on mechanical properties of binder course (Source, ERA, 2013)

Total Traffic (106 ESA)	< 1.5		1.5 - 10.0		> 10.0	
Traffic Class	T1, T2, T3		T4, T5, T6		T7, T8	
	Min	Max	Min	Max	Min	Max
No. of blows of marshal compaction	2*35		2*50		2*75	
Stability (KN)	3.5	-	6.0	-	8.0	-
Flows(mm)	2		2		2	3.5
Percent air void	3	5	3	5	3	5
Percent void field with asphalt	70	80	65	78	65	75
Percent VMA (for 4% air voids and Nom. Max, Particle size of 19mm)	13	-	13	-	13	

2.4.Mineral filler

A filler material is components that often used in asphaltic pavement serve as fulfill the cavities in the mixture. Filler material consists of fine powder used in bituminous mixes for road pavement. Filler, as one of the components in asphalt mixtures, plays an effective role in their properties and behavior, especially regarding binding and aggregate interlocking effects (Asmael, 2010).

Filler is important to strengthen the structure of the road to be built. Practically filler material role in increasing the viscosity of the bitumen and reduce its concentration on temperature. In addition, the filler material also works in the hardened bitumen layer and fills the cavities found in the mixture. It should be inert material which passes 75-micron sieve and must have properties such as cleanliness and purity, fineness and affinity for bitumen. The material used as filler in cement for road construction is fine and add more to its nature as binder. It is not only meant to fill empty cavities have even helped bitumen to reinforce structure component bonding on road and hence ensuring stability and produce specifications in aggregate grading.

The composition of the filler material used in the mix shall have certain limitation because if the rate is too high filler material will cause brittle and crack pavement to be weak and easily melt when the weather is warm. In general, high filler content in mixture will lower the optimum bitumen but increases the density and stability. The use of filler will enhance the strength and durability of asphalt mix. Some of the studies have been made on the use of different types of fillers in various types of paving mixes.

From thus studies: -

(Zulkati A. et al, 2012) Studied the filler exerts a significant effect on the characteristics and performance of asphalt concrete mixture. Besides, good packing of the coarse aggregates, fine aggregates, and filler provides a strong backbone for the mixture. Mineral filler materials in hot mix asphalt are an important component of the mixture as the design and performance of hot mix asphalt concrete. (Anderson DA, 1987) Identified that filler as one of the components of asphalt concrete mixture it plays a significant role in the characteristics and performance of the asphalt mixture. Mineral fillers were generally treated as being suspended in the asphalt binder without particle–particle contact and contributed to the toughening and stiffening of the asphalt binder (Remisova, 2015). Over the years, several types of researches and studies have shown the high effect of fillers properties on the bituminous mastic performances. From a structural point of view, the presence of filler within the aggregate's mixture enhances the reduction of inter-granular voids.

Type of filler material that often used is Portland cement, limestone, fly ash, Pond ash, steel slag, Stone waste, Saw dust ash, Rice husk ash, Sewage sludge ash, Ceramic dust, Brick dust, Marble dust, Glass powder, Coal waste, and sugarcane bagasse ash etc. The effect of filler material on pavement bituminous mixture based on type and rate such as the effect of durability and deformation, potential impact, and impact value on Marshall Testing.

2.5.Effect of mineral filler on hot mixes Asphalt

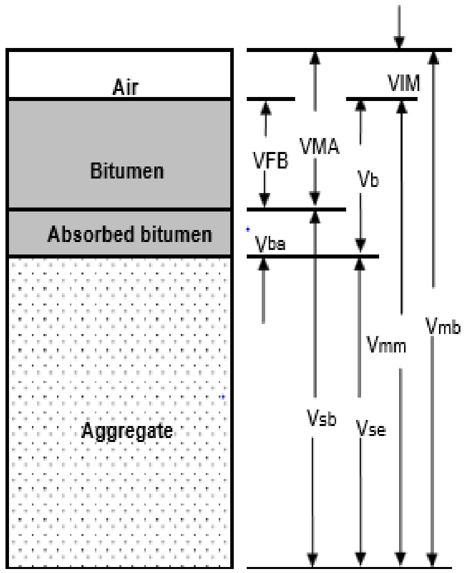
The mineral filler can greatly affect the properties of a mixture such as strength, plasticity, voids, resistance to the action of water, and resistance to the forces of weathering. The proper use of Filler can improve the asphalt paving mixture through increased density, stability, durability, and skid resistance. Various researches are conducted on the effect of filler in hot mix asphalt from thus: (Ishai, 1996,) Studied the filler plays a major role in the properties and behavior of bituminous paving mixture. Other researchers called (Yong -Raku Kim and Dallas N. Little, 2003) studied that the mineral filler increase stiffens of the asphalt mortar matrix and improving the rutting resistance of pavements. The mineral filler also helps to reduce the amount of asphalt consumes in the mix during construction, which improves the durability of the mix by maintaining the amount of asphalt initially used in the mix.

(Anderson DA, 1987) Investigated filler in an asphalt-concrete mixture, whether artificial or natural may stiffen the asphalt concrete, extend the asphalt cement, and affect the workability and compaction characteristics of the mix. (Zulkati A. et al., 2012). Studied the workability of mixing during the operation and compaction of the asphalt-concrete mixture is the consequential property of asphalt-filler mastic also affected by filler materials. The filler provides better resistance to micro cracking so that it can increase the fatigue life of the asphalt-concrete mixture.

Another researcher (Ahmed and Othman, 2006) Proved the use of waste cement dust as filler on the asphalt concrete mixture enhances the mechanical properties of the mix, and the laboratory results indicate that the cement dust can replace limestone powder in the asphalt paving mixture. Generally, the mineral filler can greatly affect the properties of a mixture such as strength, plasticity, voids, resistance to the action of water, and resistance to the forces of weathering. On the other hand, an excessive quantity of filler tends to increase brittleness and proclivity to cracking, and deficiency of filler tends to increase void content, lower stability, and soften the mix, which leads to shoving, and rutting of the pavement (Eltaher & Ratnasamy, 2016).

2.5.1. Volumetric properties of HMA Mixes

For convenience, mix components are blended in proportion by mass and expressed as percentages of the complete mix. The volume of the mix is affected by; The proportions of the different aggregates and filler, the specific gravity of the different materials, where porous aggregate is present, the amount of asphalt binder absorbed, and the amount of non-absorbed asphalt binder (ERA,2013). Fundamentally, mix design is meant to determine the volume of bitumen binder and aggregates necessary to produce a mixture with the desired properties (Roberts et al., 1996). Since weight measurements are typically much easier, are taken and then converted to volume by using specific gravities. The important volumetric properties of bituminous mixtures that are to be considered include the theoretical maximum specific gravity (Gmm), the bulk specific gravity (Gmb), percentage of voids in total mix (VTM)), percentage void in mineral aggregate (VMA) and percentage voids filled with asphalt (VFA), and Effective asphalt content (Pbe).



Vba = Volume of absorbed bitumen

VIM = Volume of air voids

VFA = Volume of voids filled with bitumen

Vsb = Volume mineral aggregate (by bulk specific gravity)

Vse = Volume of mineral aggregate (by effective specific gravity)

VMA = Volume of voids in mineral aggregate

Vmm = Void less volume of HMA mix

Vmb = Bulk volume of compacted mix

Vb = Volume of bitumen

Figure 2-2 Representation of volumes in a compacted HMA specimen (Source, ERA,2013).

Theoretical maximum specific gravity (Gmm)

Theoretical maximum specific gravity is the ratio of the weight in air of a unit volume of the un-compacted bituminous paving mixture at a stated temperature to the weight of an equal volume of gas-free distilled water a stated temperature. The maximum specific gravity (Gmm) at different asphalt contents was measured to calculate air voids.

Bulk specific gravity of compacted specimen (Gmb)

The bulk specific gravity of a mixture refers to the specific gravity of a specimen of compacted mixture, including the volume of air voids within the mixture. It is equivalent to the mass of a given specimen in grams, divided by its total volume in a cubic centimeter (Asphalt Institute, 1997). The standard procedure for determining the bulk specific gravity of compacted asphalt concrete involves weighing the specimen in air and in water.

Effective Bitumen Content (Pbe)

This governs the performance of the mix. It is the portion of bitumen that remains as a coating on the outside of the aggregate particles. Any bitumen that is absorbed into the aggregate particles does not play a part in the performance characteristics of the mix but has the effect of changing the specific gravity of the aggregate (ERA,2013).

Air Voids (Va)

Air void is the total volume of the air between or inside the coated aggregate particles throughout a compacted paving mixture after mixing with binder, and it's a percentage of total volume of the asphaltic mixture (Ahimed Suliman Bader Ali et al ,2016). This the total volume of air, expressed as a percentage of the bulk volume of the compacted mixture, which is distributed throughout a compacted paving mixture and is located between the coated aggregate particles (ERA,2013). According to (Asphalt Institute, 2003), The air voids, Va, in the total compacted paving mixture consists of the small air spaces between the coated aggregates particles (See Figure 2.2).

Voids in Mineral Aggregates (VMA)

This is the volume of void space between the aggregate particles of a compacted paving mixture. It is the sum of VIM and Pbe expressed as a percent of the total volume of the sample (ERA,2013). 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 compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the sample (See Figure 2.2).

Voids Filled with asphalt (VFA)

This is the portion of the volume of void space between the aggregate particles (VMA) that is occupied by the effective bitumen (ERA,2013). According to Asphalt Institute 2003, the percentage portion of the volume of inter-granular Void space between the aggregate particles that is occupied by the effective asphalt. The voids filled asphalt, VFA is the percentage of the integral void space between the aggregate particles (VMA) that are filled with asphalt. The purpose for the VFA is to avoid less durable HMA resulting from thin films of binder on the aggregate particles in light traffic situations (D.B. Ghile,2006).

2.5.2. Moisture Susceptibility of Hot Mix Asphalt

One of the desirable properties of bituminous mixtures is that the resistance to moisture induced damages. The presence of water in asphalt pavement is unavoidable. Several sources can lead to the presence of water in the pavement. Water can infiltrate the pavement from the surface via cracks in the surface of the pavement, via the interconnectivity of the air-void system or cracks, from the bottom due to an increase in the ground water level, or from the sides (Asres, 2013). However, water weakens the structure to a point where the mix can no longer sustain the traffic it was designed to support and finally fails under the repeated loading. Moisture is a primary cause of failure of asphalt mix because its presence could lead to its loss of structural strength and durability. The resistance to moisture damage under the presence of moisture in the mixture is a complex matter, and the degree mainly depends on the properties of each ingredient materials in the mixture, type and use of the mix, environment, traffic, construction practice, and the use of anti-strip additives (Zemichael, 2007). According to (Little et al, 2003), moisture damage is defined as the loss of strength and durability in asphalt mixtures due to the effects of moisture. Among these factors, aggregate response to asphalt cement under water is primarily responsible for this phenomenon, although some asphalt cement is more subjected to stripping than others.

2.6.Industrial Waste materials used as a mineral filler in hot mix asphalt

Recent research works in the field of highway engineering and construction materials focuses more on the search for cheaper and locally available materials, agricultural and industrial wastes, for use in construction industry. The use of different industrial and agricultural wastes has become a common practice in the construction industry. Fly ash, sugarcane bagasse ash, coconut husk ash and rice husk can be sited as an example for agricultural part and for industrial parts are Basic-oxygen-furnace (BOF) slag, Electric-arc-furnace (EAF) slag, Ladle slag (open hearth process), and etc. Those by-products are increasingly playing a part in road construction and concrete technology, hence minimizing the problem of resource depletion, environmental degradation and energy consumption. This research focuses on the replacement of natural filer by bended of bagasse ash and fine steel slag in hot mix asphalt.

2.6.1. Steel slag

The recycling of industrial waste slag is the core content of sustainable development. Steel slag is an industrial waste produced, as a byproduct during the steel manufacturing process. Steel slag, different form blast furnace slag, is also the inevitable byproduct, which is 15–20% of the production of crude steel in steel making process. The large amount of steel slag was always disposed as waste, which results in the waste of resource, environmental pollution, and even ecological destruction. Now, there is no specific regulation of the use of steel slag as aggregates and mineral filler in HMA production/concrete (Ajay Dahake on 20, February, 2017).

It is obtained either by melting scrap with a high electric current in an Electric arc furnace (EAF) or by processing hot molted metal, scrap, and fluxes with lime in Basis Oxygen Furnace (BOF) (C. Shi,2004). Steel slag has been used to construct pavements for nearly one hundred years. Since it was discovered that the residue from the manufacture of steel could be crushed and processed into a product that looked like crushed rock, researches were started to investigate the usefulness of this “waste” product. The history of slag uses in road building dates back to the time of the Roman Empire, some 2000 years ago, when broken slag from the crude iron-making forges of that era was used in base construction (D.W Lewis, 1982).

Electric-arc furnaces use high electric power, instead of gaseous fuels, to generate the heat needed for melting steel scrap and converting it into high-quality steel. The electric- arc furnace steel manufacturing process is independent of the production from a blast furnace since the main source for it is steel scrap with some pig iron. The electric-arc furnace steel manufacturing process begins with the charging of different types of steel scrap to the furnace. As the melting process progresses, a pool of liquid steel is generated at the bottom of the furnace. Lime or dolomite is charged to the furnace together with the scrap or is blown into the furnace when melting proceeds. Once the desired chemical composition of the steel is achieved, the electric-arc furnace is tilted, and the slag and steel are tapped out of the furnace into separate ladles. The slag produced during the process is called Electric-Arc Furnace (EAF) slag (Manso et al., 2006).

After completion of the primary steel manufacturing operation, steel produced by the basic oxygen furnace or electric arc furnace processes can be further refined to generate the necessary chemical composition. This Refining processes is known as secondary steelmaking operation. Refining processes are familiar in the fabrication of high-grade steels. Based on the class of the desired steel, molten steel generated in the basic oxygen furnace and electric arc furnace process goes through some or all of the above-mentioned refining processes. In secondary steelmaking operation the slag generated is called Ladle slag (Barra et al., 2002).

The use of steel slag as an aggregate substitute to natural aggregates is considered a standard practice in many countries. The incorporation of steel slag as an HMA aggregate has been evaluated extensively in many parts of the world, but not yet in Ethiopia. Resulted that the mechanical properties of steel slag concrete are acceptable, though slightly lower flexural strength than that of conventional concrete (Chunlin L, Kunpeng Z, Depeng C.,2011). Using fine steel slag aggregate with scrap tire particles, both the mechanical strength and the volume stability of scrap tire particle modified steel slag concrete were significantly increased (Ajay Dahake on 20 February 2017).

However, SS obtained from basic oxygen furnaces (BOF) and electric arc furnaces (EAF) but basic oxygen furnaces (BOF) is less commonly used in highway applications due to their volumetric instability in the presence of moisture. The expansion of free lime (CaO) and free periclase (MgO), as well as the conversion of dicalcium silicate (C2S) and the oxidation of iron and carbonation of CaO and Mg silicates results in the volumetric instability of steel slags CaO lime can fully hydrate in a few days when immersed in water. This behavior is not favorable, particularly when steel slag is used in rigid matrices (Deniz et al. 2010).

2.6.1.1. Production of Steel Slag

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. Slags are named based on the furnaces from which they are generated. Figure 2.1 shows a flow chart for the iron and steel making processes and the types of slag generated from each process.

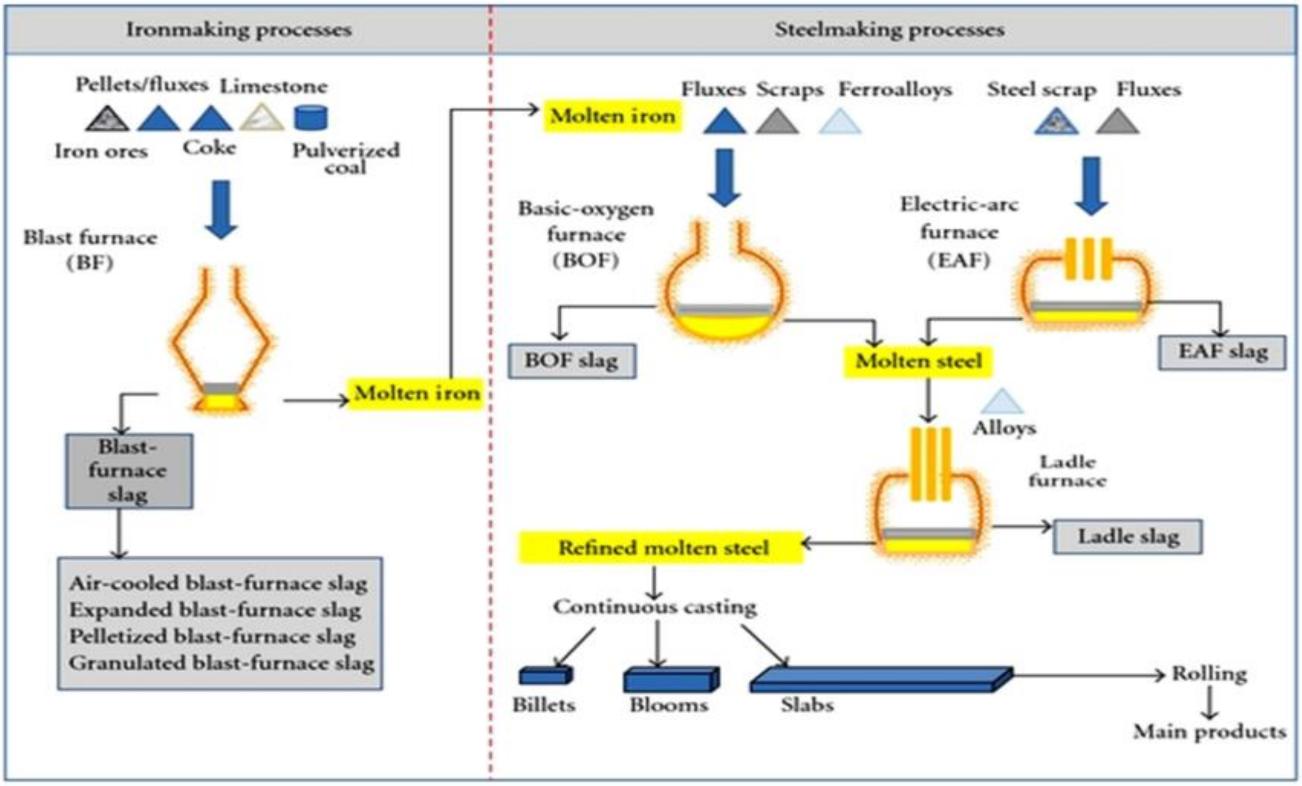


Figure 2.2. Flowchart of iron and steel making processes (Source, Energy Manager Training (EMT), "Iron and steel process," July 2008) (Source: Advances in Civil Engineering, Research Article ID: 463638, Volume 2011).

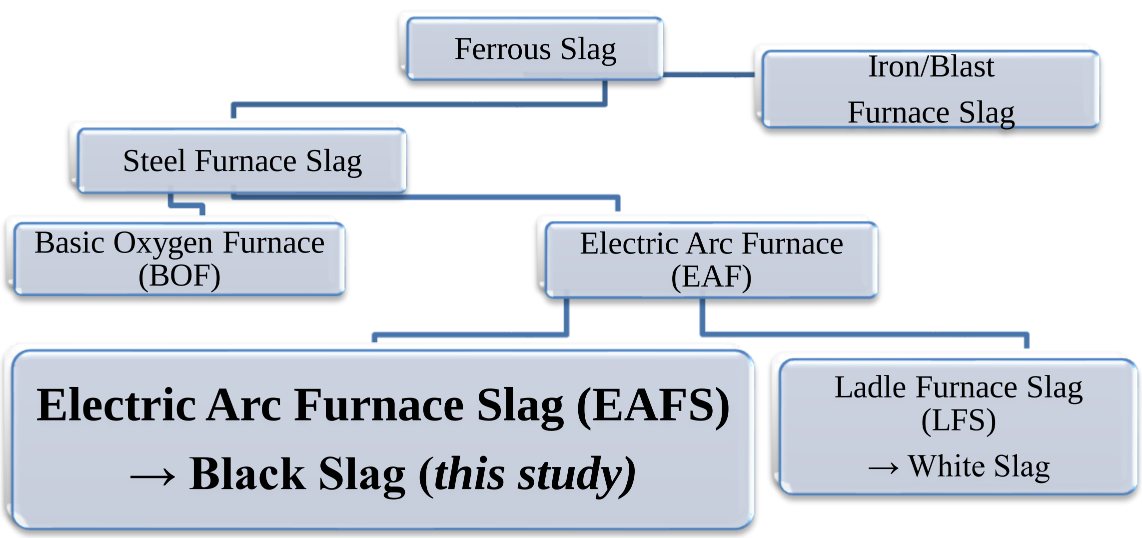


Figure 2.3. Production of (EAFS) in steel-making process (Abebe Tadie,2014).

2.6.1.2. Availability of steel slag

Steel slag is a by-product produced during the conversion of iron ore or scrap iron in the basic oxygen, electric arc, and open-hearth steelmaking processes to steel which is available as a construction aggregate in significant quantities across the world. Consumption of steel slag in developed countries is over 60% whereas it is merely around 20% in developing countries (C. Heidrich et al, 2017).

Annually estimated amount of waste steel slag production in the world is from 170-250 million ton (USGS, 2018). The rapid growth of steel production over the world, steel slag, as a by-product of steel production, now has been produced quite fast. Global Slag production was 250 Mt from 1.6 billion tons of steel production in 2014 and Asia alone contributes 60% of steel slag production. Steel and steel slag annual output of 2010 in China reached to 626.7 million tons and 90 million tons respectively (Ren Q, 2012). But now the total amount of steel slag produced in China is around 1 billion tons. However, such a waste of steel slag could lead to not only the loss of money but also lots of environmental pollution (Chenget al., 2012; Yi et al., 2012; Sheen et al., 2020) However, the current utilization rate of steel slag in china is only 22%, far behind the developed countries like USA, Japan, German and France, of which the rates have been close to 100%. In these developed countries, 50% of slag has been used for the road project directly, with the remaining part for sintering and iron-making recycling in plant (GAO JT Et Al, 2011).

The amount of deposited steel slag in china has been accumulated to more than 300 million tons, which leads to the occupation of farm land and pollution of groundwater and soil (Meng HD,2000). Production of Steel slag in India is 17.263 million tons per year (Indian Minerals Yearbook 2018). Approximately 21 million tons of SS are produced annually in the United States, and only 10-15% of this slag is reused. The remainder is either stockpiled or placed in landfills (USGS, 2014). In Germany, about 400,000 tons per year is used as aggregate for the stabilization of river bankers and river beds against erosion (Motz H, 2001).

2.6.1.3. Physical properties of steel slag

Generated steel slag has suitable physical properties for aggregate use including good soundness characteristics, good abrasion resistance, and high bearing strength. According to different researchers studded at the typical physical properties of the filler material of steel slag were described as the following table below.

Table 2.3.Physical properties of steel slag studied by previous researchers

Test type	Test Method (ASTM)	Test Result	Researcher's (Source)
Specific Gravity	ASTMD113	2.95	Hitesh Kumar, Feb.2020
Specific Gravity	-	3.2	Faisal I. shalabi,16-Nov.2016
Specific Gravity	ASTMD 698	3.45	Ahmet H. Aydilek, Oct.2015
Specific Gravity	ASTMC117	2.82	Mr. Henok Desalegn, Aug.2017

Table 2.4.Typical physical properties of steel slag studied by Jucke's

Properties Test Type	Test Result value	Source
Los Angeles Abrasion (ASTM C131), %(LAA)	20-25	Juckes, 2003
Sodium Sulfate Soundness Loss (ASTM C88), %	<12	
Angle of Internal Friction	40° - 50°	
Hardness (measured by Moh's scale of mineral)	6-7	
California Bearing Ratio (CBR)	up to 300	

2.6.1.4. Chemical composition of steel slag

Both basic oxygen furnace and electric arc furnace slags are produced at the time basic steel making operations. Calcium oxide and iron oxide are the two major chemical constituents of both basic oxygen furnace and electric arc furnace slags. The expansion of free lime (CaO) and free periclase (MgO), as well as the conversion of dicalcium silicate (C2S) and the oxidation of iron and carbonation of CaO and Mg silicates results in the volumetric instability of steel slags (Wang 2010). CaO lime can fully hydrate in a few days when immersed in water. This behavior is not favorable, particularly when steel slag is used in rigid matrices (Deniz et al. 2010).

2.6.1.5. Engineering properties of steel slag

There are large differences in the chemical, physical and mineralogical properties of steel slags. This difference is the result of the steel-making process, steel making plant, storage strategies, and particular furnaces. For this reason, the application of steel slag aggregate must be considered on a specific steel-making furnace and operating basis, with identification of the inherent variability of the slag production and the existence of potentially hydra table free magnesia and free lime (Shi, 2004). Properties of steel slag that have specific importance when they are used in asphalt concrete include durability, gradation, specific gravity, moisture content, thermal properties, absorption, and frictional properties.

2.6.1.6. Application of steel slag in highway construction

Steel slag has been used in a variety of applications in the construction industry. In particular, steel slag (SS) produced via blast furnace is used in a wide range of highway applications, such as granular base, concrete and hot mix asphalt aggregates and supplementary cementations' materials. The most common area of application of steel slag includes Asphalt Concrete Aggregate, Granular Base, and Embankment or Fill.

A). Previous Studies about application of steel slag in highway construction

(Mahieux et al, 2009). Studies the use of steel slag as an aggregate is considered a standard practice in many authorities, with applications that include its use in granular base, embankments, engineered fill, highway shoulders, and hot mix asphalt pavement

According to (Deniz et al. 2009) steel slag was reported as having excellent strength characteristics due to their angular shape and rough surface texture and it also possesses high bulk-specific gravity and exhibits good compaction behavior. The slag processor may also be required to meet moisture content requirement for instance limit the amount of moisture in the steel slag aggregate before to delivery to a hot mix asphalt plant and to adopt material handling, for instance processing and stockpiling, practices similar to those used in the conventional aggregates industry to prevent potential segregation. In addition, as previously noted, expansion due to hydration reactions should be addressed before the application of steel slag (Das et al, 2006).

(Ahmedzade and Sengoz, 2009**)** evaluated the effect of steel slag in HMA with 100% coarse aggregate (limestone) replaced by Steel slag. They observed improved fatigue resistance as the steel slag mix exhibited higher indirect tensile strength and modulus values than the coarse aggregate mix. Conducted a study on steel slag in HMA by substituting the natural aggregate at 0%, 30%, 60%, and 90% steel slag aggregate based on the total aggregate weight

(Kehagia, 2009**)** carried out a study on the skid resistance of a thin Asphalt surface using three different mixes: 100% slag mix, partial slag replacement mix, and a natural aggregate mix. Skid resistance was measured four months and one year after installation on a high traffic highway in

Greece. After one year, all the slag mixes had outperformed the natural aggregate mix. The mix with 100% slag exhibited the best skid resistance. The minimum allowable skid number on this type of roadway was 35. After one year of service, the value for the 100% slag mix section ranged from 58 to 64, whereas the section with partial slag replacement varied from 48 to 60. The natural aggregate section without steel slag displayed acceptable numbers from 40 to 57. The study showed that steel slag can improve HMA roadway conditions.

(U.S. Department of Transportation, 2019) studied Most of the physical and mechanical properties of steel slags are similar or better compared to conventional crushed stone aggregates. Steel slag has been successfully used as aggregate in wearing course hot mix asphalt and in surface treatments in the United States and internationally. Some of the mix properties that are of interest when steel slag is used in asphalt concrete mixes include stability, stripping resistance, and rutting resistance.

(Henok Desalegn,2017) The study investigates the partial replacement of CSD with Steel Slag in hot mix asphalt using Marshall Flow and Stability tests with corresponding volumetric properties. This was focus involves the partial replacement of CSD with Steel Slag in the range of 0%, 2.5%, 5%, 7.5%, and 10% contents. HMA mixtures containing 7.5% steel slag have greater rutting resistance than other tested mixtures. Therefore, the mix containing 7.5% steel slag and 92.5% CSD as filler at varying percentages of bitumen content have values which meet the standard specified in Asphalt Institute for strength criteria. Therefore, the optimum steel slag content to be partially replaced with CSD in asphalt concrete mix should be 7.5%. Also, he recommended that more testing is needed to test hot mix asphalt with Steel slag content higher than 10%.

(Arun et al., 2018) performed a comparative study of steel slag with coarse aggregate and testing its binding properties with bitumen. The Marshall properties were satisfied for 20% steel slag proportion. Economically the steel slag may be cheaper if utilized in urban roads but it would be expensive for rural roads due to the transportation charges.

2.6.1.7. Use of steel slag in hot mix asphalt

A). Previous Studies about application of steel slag in highway construction

NSA (2006) has listed uses of steel slag: -

- Steel slag is used as an ideal aggregate in hot mix asphalt (HMA) surface mixture application due to its high frictional resistance and skid resistance characteristics. The cubical nature of steel slag and its rough texture provide more resistance than round, smooth and elongated aggregates.

- It is also used in making Stone Matrix Asphalt (SMA) because the particle-to-particle contact of the aggregate does not break down during the manufacturing, lying down, or compaction process.
- It is used for the manufacture of Portland cement.
- It is used in the base application, construction of unpaved parking lots, as a shoulder material, and also in the construction of berms and embankment.
- It is also used in agriculture because it has minerals like iron, manganese, magnesium, zinc, and molybdenum which are valuable plant nutrients.
- It is environmentally friendly. During the production of cement, the CO2 emissions are reduced as slag has previously undergone the calcination process.

Xu [Xu ZK,2010] manufactured concrete arm our blocks for sea coast projects, partially replacing sand with steel slag and cement with fine slag powder, and the concrete blocks has been applied practically in East China sea coast reclamation works and Luchao port project.(Li et al,2012) prepared high strength of artificial reefs concrete with 79%granulated high furnace slag ,15% steel slag , 5% flue gas desulphurization gypsum and 1% mixture as cementitious material and steel slag grains as its fine and coarse aggregates. Approximately 60% of slag is used for road engineering in Japan and European countries, and even 98% of that is utilized as aggregates of cement and bituminous pavement in UK. More than 25 years ago in Germany test roads were built using steel slag as an aggregate for unbound and bituminous bound mixtures (Motz H, 2001).

(Ahmedzadea, 2009) investigated the in Àuences of the utilization of steel slag as a coarse aggregate on the properties of hot mix asphalt. (Asi IM,2007) observed that asphalt concrete mixes containing 30% steel slag had the highest skid number followed by Superpave, SMA (Stone Mastic Asphalt), and Marshall mixes, respectively. (Ameri et al,2012) evaluated the effectiveness of steel slag as a substitute for virgin aggregates on mechanical properties of cold mix recycling asphalt pavement. The results showed that the use of steel slag could enhance Marshall Stability, resilient modulus, tensile strength, resistance to moisture damage and resistance to permanent deformation of CIR (Cold in Place Recycling) mixes.

(Xue, 2006) found that steel slag SMA (Stone Mastic Asphalt) pavement was comparable with conventional asphalt pavement, even superior to the later in some aspects. Test road was paved on the old expressway asphalt surface as skid resistance and abrasion resistance layer with 2 km long and 24m wide. Near 2 years' service, the steel slag test road appeared excellent performance, without coming into being the rutting, cracking, and stripping, which render the asphalt pavement early damage. (Wu, 2007) also investigated the utilization of steel slag as aggregates for SMA (Stone Mastic Asphalt) mixtures. Two test sections of steel slag SMA (Stone Mastic Asphalt) mix were constructed as surface friction course on the asphalt overlay upon old cement concrete pavement of Wuhan– Huangshi expressway, and after 2 years' services, the test roads showed excellent performances. With reference to the Chinese enterprise, Bao steel built a test road with steel slag as base materials and the road presented leveled and no cracking after one-year service. Lianyuan Steel in 1997, (Zeng G, 2007) paved an asphalt pavement with steel slag as aggregates in their plants respectively. The roads were substantially leveled and observed no cracking, bump and asymmetric settlement during the service.

(Wanga et al, 2011) believed that in the steel slag treatment process, increasing the cooling rate and alkalinity of steel slag could improve the activity of cementitious phase in steel slag. The fineness of slag is also an important factor influencing the activity, and the potential cementitious property of slag fines significantly increases with their fineness.

(Qasrawi, et al, 2009) found that the compressive strength of concrete using steel slag as fine aggregates was 1.1 to 1.3 times of common concrete. (Papayianni et al, 2010) prepared a high-strength (>70MPa) concrete utilizing EAFS as aggregates.

(W. H. Chesner et al, 2002) studied Steel slag is being used in hot mix asphalt road construction for motorized vehicles for over more than four decades.

(A. S. Noureldin et al, 1990) studies one of the major advantages of using steel slag is that the quality of asphalt mix produced using locally available inexpensive or low-quality ingredients can be improved by the slag. The following figure is showing the deposit of steel slag in the world.

Figure 2.4. The deposit of steel slag in the world (sorouce-google.com).

In Ethiopia, Ethiopian Iron and Steel factory in Addis Ababa produces significant quantities of steel making slag as the major waste during the manufacture of Iron and steel. The estimated daily production of steel slag is 1.5–3 tons (Henok Desalegn, 2017) but now the estimated amount of deposited steel slag only in Ethiopian Iron and Steel factory has been accumulated to more than 548.25tons/year. This slag would normally be placed in a landfill if it was not crushed and used for construction material which may be leads to the occupation of farm land and pollution of groundwater, air and soil.

Figure 2.5. The samples of steel slag deposit on Ethiopian Iron and Steel Factory in Ethiopia (Souhce, Abebe Tadie,2014).

2.7.Bagasse Ash

The major solid wastes generated from the sugar manufacturing process include sugarcane trash, bagasse, press mud, bagasse fly ash and spent wash (Balakrishnan and Batra 2011; Partha and Sivasu-bramanian 2006; Yadav and Solomon 2006). Bagasse is a by-product from sugar industries, which is burnt to generate power required for different activities in the factory. The burning of bagasse leaves is change to bagasse ash as a waste, which has a pozzolanic property. Therefore, Meanwhile, A produced in boilers of the sugar industry can be classified as a probable pozzolanic material.

The quantities of volumes of product in sugar mills when the juice was extracted from sugarcane make it become waste product. It normally uses as a fuel to fire furnaces in the same sugar mill that produces about 8 to 10% of ashes.

(E.M.R. Fairbairn, November, 2008) Several waste and used materials from different sources are generated every day in large quantities. However, these wastes have been found to be useful in the stabilization and/or improvement of construction materials. Amongst these techniques is the use of Bagasse Ash (BA).

A. A. Murana and L. Sani, 2015, also proved that the Cement/BA mixes exhibit satisfactory trend results with an average Bitumen content of 5.5%.

(Mardhika, 2006) studied the Bagasse-ash mechanical properties (weight-density, aggregate size, fine aggregate absorption, and sand-equivalent) have fulfilled the requirements as filler in HMA mix.

(Cordeiro GC, 2008) indicated that BA would be classified as a pozzolanic material, and its reactivity depended mainly on the maximum particle size and fineness. The production of pozzolanic ash from SCBA requires the use of ultrafine grinding to transform this industrial residue in a mineral admixture, and coarser BA may be used as inert filler in the cementitious mixtures.

(Fikadu Alemu,2017) The study investigates the partial replacement of cement with bagasse ash in hot mix asphalt using Marshall Flow and Stability tests with corresponding volumetric properties. Tests on the suitability of materials used and their performance in terms of known engineering properties were carried out with bitumen content of 4.0%, 4.5%, 5.0%, 5.5% and 6.0%. This research was focus involves the partial replacement of cement with BA in the order of 0%, 10%, 20%, 30%, 40% and 50% which ninety mix specimens were produced to conduct the tests. The mix containing 20% BA and 80% OPC as filler at varying percentages of bitumen content have values which meet the standard specified in Asphalt Institute for strength criteria. Therefore, the Optimum BA content to be partially replaced with OPC in asphalt concrete mix was 20%.

(Rukzon S, 2009) was studied effects of fineness and loss on ignition (L.O.I.) of BA on compressive strength and the kinetics of the pozzolanic reaction of BA. However, BA advantages and optimum dosages resulting from chemical or physical effect are not yet clarified, and its application is limited.

(Murniati.S, Mar.2016) studded the chemical composition and physical properties of the filler material of sugarcane bagasse ash value can be described in table 2.5.

Table 2.5.Chemical composition and properties of Sugarcane Bagasse Ash (Murniati.S, Mar.2016)

Chemical Properties	Chemical composition (%)	Source
SiO2	62.43	Muriate’s, Mar.2016
Al2O3	4.38	
Foes or Fe2O3	6.98	
MgO	2.51	
SO3	2.5	
CaO	11.8	
K2O	3.53	
LOI	4.73	

Table 2.6.Physical Properties of Sugarcane Bagasse Ash (Murniati.S, Mar.2016)

Properties Test Type	Test Result value	Sources
Density (gm/cm3	2.52	Murniati.S, Mar.2016
Blaine surface area (cm2 /gm)	5140	
Particle size (μm)	28.9	
Color	Reddish grey	
Specific Gravity	2.85	A. A. Murana and L. Sani,2015

2.7.1.Use of sugarcane bagasse ash

Bagasse ash is agricultural waste product of sugarcane which can be in construction sector either by replacement method or stabilization of construction materials to improve the engineering properties of material. Recent research works in the engineering construction technology materials focuses more on the search for cheaper and locally available materials, agricultural and industrial wastes, for use in construction industry. The use of different industrial and agricultural wastes has become a common practice in the construction industry. Fly ash, sugarcane bagasse ash, coconut husk ash and rice husk can be sited as an example. Those by-products are increasingly playing a part in road construction and concrete technology, hence minimizing the problem of resource depletion, environmental degradation and energy consumption. This research focuses on the potential utilization of bagasse ash in partially replaced by mineral fillers (CSD) which was blended with steel slag dust in different proportions for hot mix asphalt production.

A). Bagasse Ash as a Soil Stabilizing and used HMA production as aggregate material

These days' sustainability plays the major role in every aspect of human activities. Many technologies came to end because they were not in harmony with the idea of sustainable development. Sustainability is concerned about the world we will be leaving behind for future generations. It focuses on the social, environmental and economic issues of human activities. Therefore, it requires every activity to be environmentally friendly, economical and safe for the social.

Bagasse ash contains large amount of silica which is the most important component of cement replacing materials. It is also found in large amount as a byproduct in sugar factories. Despite this abundance and silica content, relatively little has been done to examine the potential of this material for soil stabilization. Even though little, the conducted researches confirm the suitability of this material for soil stabilization as an admixture to lime and cement. But still its suitability as a standalone material is still questionable.

B). Bagasse Ash as an Admixture with Lime

Sabat, A.K., (2012) studied the utilization of bagasse ash and lime sludge for construction of flexible pavements in expansive soil areas. The experimental study involved compaction characteristics, unconfined compressive strength, CBR and swelling pressure. The following conclusions are drawn from the study:

The addition of bagasse ash to expansive soil decreases the MDD and increases the OMC of the expansive soil irrespective of the percentage of addition of bagasse ash. Addition of lime sludge to each expansive soil-bagasse ash mixes decreases the MDD and increases the OMC of the expansive soil irrespective of the percentage of addition of lime sludge.

Generally, the research concluded that the industrial wastes, such as bagasse ash and lime sludge can be utilized for strengthening the subgrade soil with a significant saving in cost of construction.

Ochepo, J. and Osinubi, K. J., (2013) studied the effect of comp active effort and elapse time on the strength of lime-bagasse ash stabilized expansive clay from Gombe, Nigeria. The experimental study involved unconfined compressive strength. The following conclusions are drawn from the study: The results obtained indicate that UCS values increase with lime and bagasse ash treatment, curing periods.

2.7.2.Availability of Bagasse Ash in the world

Sugarcane cultivation in the world occupies an area of 20.42 million ha and it accounts for a total production of 1333 million metric tons. India is the second-largest producer of sugarcane in the world next to Brazil. The agricultural area in India under sugarcane cultivation spans about 4.175 million hectares with an average yield of 70 tons per hectare. Fifteen countries (Brazil, India, China, Cuba, Thailand, Pakistan, Mexico, South Africa, Columbia, Australia, United States of America, Philippines, Argentina, Myanmar, and Bangladesh) contribute to 86% of area and 87.1% of sugarcane production according to World Sugarcane Production (India statistics).

Figure 2.6. The deposit of sugarcane bagasse ash in the world (source google.com).

2.7.3.Availability of Bagasse Ash in the Ethiopia

In order to assess the potential of bagasse ash production in Ethiopia, it is imperative to evaluate the sugarcane crop yield in the country. There are three state owned sugar factories functioning in the country in 2013. Their annual production capacity is about 300,000 tons, the sugarcane covering about 10,000 hectares of land. This annual production is not sufficient to the local sugar demand forcing the government to annually import 1.5 million quintals from abroad.

To avoid this shortage of sugar in the country the government plans to establish eight new sugar factories in the coming five years with a total estimated capacity of 2.250 million tons at the start of their production according to the strategic plan and covering about 225,000 hectares. Beside this the government is undertaking expansion projects on the existing factories to increase their production capacity. At the end of this expansion projects on Fincha, Methara and Wonji-Shoa sugar factories the additional total production capacity is expected to be around 365,000 tons of sugar annually.

In detail, Fincha found in the western part of the country planned to increases its production to 270,000 tons; Wonji-Shoa found 125km east of Addis Ababa plans to increase their production to 350,000 tons; Methara sugar factory found 200kms east of Addis Ababa, is also expected to increase its annual production to 190,000 tons according to the sugar development study paper.Tendaho sugar complex factory, which is set to become the country's single largest sugar processor and the biggest in East Africa, has not been opened with in the planned time and has suffered repeated setbacks due to construction delays. It is expected to have an annual production capacity of 600,000 tons and once this factory and the other facilities under construction were up and running at full capacity, that the country would no longer need to import sugar and would be able to start exporting.

As can be seen from the above discussion the sugar production in the country is boosting at a high rate, even planning to hold 2.5% of the world sugar market in the coming years according to the strategic plan. This boosting in sugar production will also result in high amount of bagasse and bagasse ash. When all the factories become fully operational, the bagasse ash from all these factories will be expected to be in thousands of tones.

As per the information from Ethiopian Sugar Corporation, all of the factories that are operating currently are now using bagasse as a fuel for boiler. Not only the current factories but the future intended projects will also operate in the same manner as this method reduces energy consumption. When all the factories start to operate with their full capacity, the respective bagasse ash that will be produced by that time will reach up to two million tons per annum. Bagasse ash of this amount can substantially contribute to both technical and environmental advantage to the local crushed stone dust production industry and reducing the rock querying used for road construction but the government should be reduced the amount of bagasse ash in each sugar factory used as constructions material because this material was deposited at the industrial area in Ethiopian. However, this bagasse ash would normally be placed in a landfill and it was not used as construction material as well as which may be leads to the occupation of farm land and pollution of groundwater, air and soil.

Table 2.7.Estimated bagasse ash potential of Ethiopia (Source, Ethiopian Sugar Corporation (Communication department), unpublished, 2016).

S.No	Sugar factories	Tone of cane per day (TCD	Annual crushing capacity (Ton)	Bagasse (Ton)	Bagasse ash (Ton)
1	Wonji Shoa	12,500	3,000,000	870,000	108,75
2	Metehara	5,000	1,200,000	348,000	43,500
3	Fincha	12,000	2,880,000	835,200	104,400
4	Tendahu	26,000	6,240,000	1,809,600	226,200
5	Beles I	12,000	2,880,000	835,200	104,400
6	Beles II	12,000	2,880,000	835,200	104,400
7	Beles III	12,000	2,880,000	835,200	104,400
8	Kuraz I	12,000	2,880,000	835,200	104,400
9	Kuraz II	12,000	2,880,000	835,200	104,400
10	Kuraz III	12,000	2,880,000	835,200	104,400
11	Kuraz IV	24,000	5,760,000	1,670,400	208,800
12	Kuraz V	24,000	5,760,000	1,670,400	208,800
13	Kesem	11,000	2,640,000	765,600	95,700
14	Arjo dedesa	8,000	1,920,000	556,800	69,600
15	Wolkayte	24,000	5,760,000	1,670,400	208,800
Total		218,500	52,440,000	15,207,60	1,900,950

As per the combined information taken from the corporation's technical office and chemical laboratory technicians in Wonji- sugar factory, the bagasse that will be extracted from the cane accounts 28-30% of the total cane production. And the bagasse ash that will be obtained from the bagasse was estimated to be 11-14% of the bagasse produced. The above calculation in the table was done using the average percentage of the range and an annual operational period of 240days. From the table it can be seen that around 2 million tons of bagasse ash per year will be disposed from the sugar industry when the intended sugar factories will start to operate with their full production capacity. The following figures, fig.1 and fig.2.10 are shows the deposit of bagasse ash, bagasse and location/places of Ethiopian - sugar factory.

Figure 2.7. Locations of Sugar Factories in Ethiopia (Source: ESC and Fikadu Alemu, 2017).

Figure 2.8. The bagasse ash deposit and taken to used sample preparation respectively (Source, Abebe Tadie,2014).

2.8. Summary

Based on the results of the previous studies reviewed, adding steel slag and bagasse ash are used in asphalt concrete, highway material, and concrete production as the fine aggregate replacement and the use of steel slag and bagasse ash as asphalt concrete and Portland cement production as fine and coarse aggregate in hot mix asphalt production. The results indicated from the studies clearly show potential benefits of using Steel slag and bagasse ash in HMA production. However, due to climate and material variations, the use of steel slag and bagasse ash in HMA must be investigated using local materials, based on local specifications.

Also, the previous study in managing steel slag, bagasse ash, crushed stone dust, controlling environmental degradation and pollution. Because, both bagasse ash and steel slag dust are containing a high percentage of silica (SiO_2), is considered as sensible pozzolanic materials. So that, the improper disposal of these materials is can created environmental problems around steel and sugar manufacturing plants area. (Pippo et al.2007) reported the economic and environmental advantages of using bagasse ash wastes and steel slag waste.

Therefore, one of aim this study is to investigate the replacement of blended of steel slag dust and bagasse ash together by partially replacement with CSD in HMA production in order to reduce natural materials and problems of economic and environmental cases. The importance of mineral fillers in the bituminous mixtures have been over looked where their effect was considered to be only filling the voids in the mixture and fulfilling the gradation criteria. However, recent researches demonstrate that they are more than just filling the voids in the aggregate particles. The study enhances and contributes significantly to the development of asphalt mix design using industrial waste materials and also provides a better alternative material for conventional mineral filler.

Generally, the combination/blending of steel slag dust and bagasse ash are still not experimented with in Ethiopia. So, this research will have studied its partially replacement of blended bagasse ash and steel slag dust used as mineral filler in hot mix asphalt production in road surface course.

CHAPTER THREE
RESEARCH MATERIAL AND METHODOLOGY

The aims of this research were performed in order to achieve the research objectives, including different tests according to different specifications or standards and mainly focused on evaluating the effect of a non-conventional filler (blending of steel slag dust and bagasse ash) in an asphalt mix as a filler that was replaced partially by a conventional filler (crushed stone dust). This chapter includes materials and material properties like aggregate physical properties, and physical properties asphalt binder including physical properties both conventional and non-conventional fillers, are measured. All tests on aggregate, asphalt binder, mixed steel slag and bagasse ash filler, and compacted specimens were conducted according to the respective ERA, AASHTO, ASTM, and BS testing standards. In addition, it has extended the discussion to the method of the research.

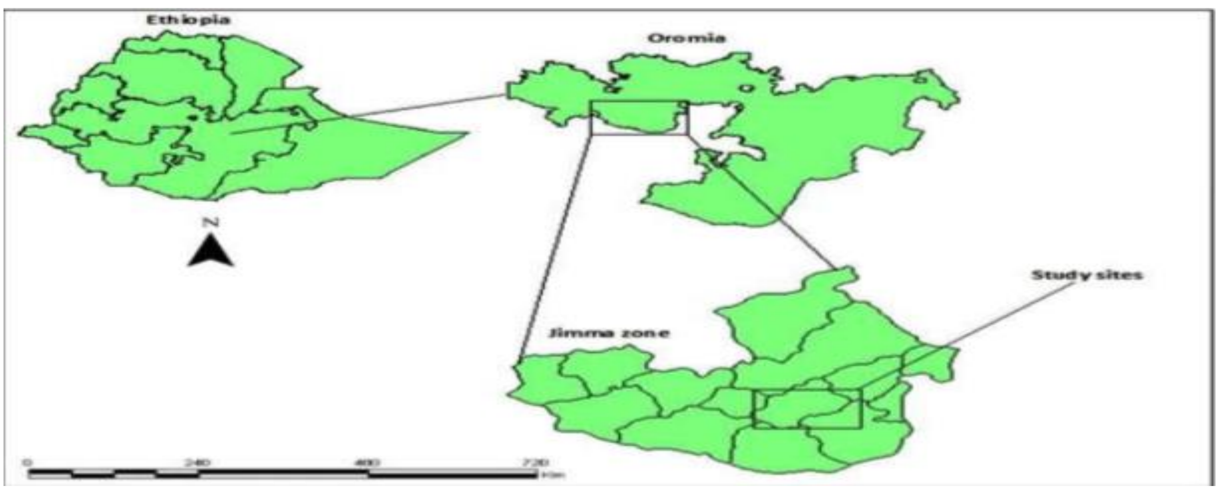


Figure 3.1. The map shows the location of study area, Source google map

3.1. Description of the study area

The study area of this research was conducted at Jima town. Jima is found in the south-western part of Ethiopia, which is located 345 km away from Addis Ababa. According to the WGS 84 coordinate reference system, Jemma is geographically located between 7° 38' 52"and 7° 43' 14"N latitude, and between 36° 48’ 00" and 36° 53’ 24" E longitude. Jima town’s topographical features can be from 1780 to 2000 m above mean sea level with average maximum and minimum temperatures in the range of 25–30 °C and it lies in the climatic zone locally known as Woyna-Dega. Based on historical accounts, Jima town was founded in 1837 E.C by the king of Abba Jifar (Source, Jima City Google website.com and Haile Zinabie,2014).

3.3 Population

The population of this study included the basic materials in the production of hot mix asphalt, which were aggregate (coarse, intermediate, and fine), bitumen, crushed stone dust, steel slag dust, and bagasse ash (Source, Daniel Alelgn,2014).

3.4 Study Variable

According to this study, there were two variables; those were dependent and independent variables. Besides, the dependent variables of this research were more related to the general aim of the study because of the property of HMA using the combination of steel slag dust and bagasse ash as a partial replacement of conventional filler. Whereas, the independent variables of the study were properties of vital materials in the production of HMA such as aggregates, asphalt binder/bitumen, fillers including conventional (CSD) and non-conventional (bagasse ash and steel slag dust), Marshall Properties of mixtures (Stability, Flow, VA, VMA, VFA, and Bulk density), and weight replacement of conventional filler.

3.5 Materials

In this research work used materials that were obtained from them source for performing is;

- Crushed Stone Dust (filler
- Bagasse Ash
- Steel Slag Dust
- Bitumen
- Aggregates

3.6 Methods

The methods that were used for making steel slag dust and bagasse ash as mineral filler materials in hot mixed asphalt were as follows:

The collected steel slag and bagasse ash were cleaned, crushed, and milled until they reached the required size for making them into dust. After that, it sieved them with a 0.075mm sieve size and blended them into different amounts.

The percentage rate that was used to replace crushed stone dust with blended bagasse ash and steel slag dust was 10% (by weight of optimum filler content) until the maximum potential of blended bagasse ash and steel slag dust could be replaced with crushed stone dust by the trial-and-error method. The 10% interval was chosen because the sampling method for this study is purposeful. The percentage replacement rates were as follows:

- 10 % blended bagasse ash and steel slag dust (by weight of OFC) mix with 90% of Crushed Stone dust (by weight of OFC).
- 20% blended bagasse ash and steel slag dust (by weight of OFC) mix with 80% of Crushed Stone dust (by weight of OFC).
- 30% blended bagasse ash and steel slag dust (by weight of OFC) mix with 70% of Crushed Stone dust (OFC). It was extending through this method trial- and- error up to the maximum potential rate of blended bagasse ash and steel slag dust that replaced Crushed stone dust fillers on the basis of standard specifications of Marshall Stability Criteria.

Figure 3.2. The process of cleaning /crushing, milling and sieving of steel slag dust and bagasse ash fillers from the source to in the laboratory (Source, Dejene Dereje,2014).

3.7 Research Design

This research was conducted using an experimental laboratory research design. In order to carry out the studies of the research effectively, a well-ordered design is formed step by step for a fruitful result. After organizing a literature review of various previously published research results, the study examines the use of steel slag dust and bagasse ash as filler materials in the design of asphalt mixes. The first step was data collection from materials used for the research design and then the quality of the materials was tested in the laboratory using AASHTO, ASTM and BS standards.

determining the optimum bitumen content and the optimum filler content by using NAPA (National Asphalt Pavement Association) criteria.

After the Marshall Mix was run for different levels of filler and bitumen to determine the OBC and OFC of the control mix, the Marshall Mix design was then run for the different levels of filler and bitumen to determine the right mix for the project. The Marshall Standard specimens were obtained by applying 75 impacts to each side according to ASTM D-1559 with five different bitumen contents (4.5%, 4.5,5%, 5.5% and 6.5%) by weight of the total mix and three different conventional fillers produced content called crushed stone dust (4.5%, 5.5% and 6.5%). From this, Marshall Samples were prepared in each filler content of 15 samples and each of them was weighted with a weight of 1200g. After preparing the HMA blends, the Marshall Stability and flow value were determined. The optimal bitumen content (OBC) and the optimal filler content were then determined from the results obtained from the samples. After determining both the optimum filler content and the optimum bitumen content, it prepares non-conventional fillers for partial replacement, mixing using the same Marshall Mix design process as conventional.

The prepared Marshall Mix design substitutes a 10% interval blended steel slag dust and bagasse ash but this interval also divided into five ratios, which means 10% of blended steel slag dust and bagasse ash (10%bagasse ash and 0%steel slag dust, 0%bagasse ash and 10%steel slag dust, 5%bagasse ash and 5%steel slag dust, 7.5%bagasse ash and 2.5%steel slag dust, and 2.5%bagasse ash and 7.5%steel slag dust) 20% blended of (20%bagasse ash and 0%steel slag dust, 0%bagasse ash and 20%steel slag dust, 10%bagasse ash and 10%steel slag dust, 15%bagasse ash and 5%steel slag dust, and 5%bagasse ash and 15%steel slag dust) and 30% blended of (30%bagasse ash and 0%steel slag dust,0%bagasse ash and 30%steel slag dust, 15%bagasse ash and 15%steel slag dust, 22.5%bagasse ash and 7.5%steel slag dust, and 7.5%bagasse ash and 22.5%steel slag dust) rate interval of non-conventional filler by weight of optimal crushed stone dust filler and at optimal bitumen content. from the mixtures, the possibility of using this mineral filler on HMA and the optimal proportion of mixed bagasse ash and steel slag dust is studied. Finally, at optimum replacement percentage the effect of mixed bagasse ash and steel slag dust on the moisture susceptibility of asphalt mixes was evaluated.

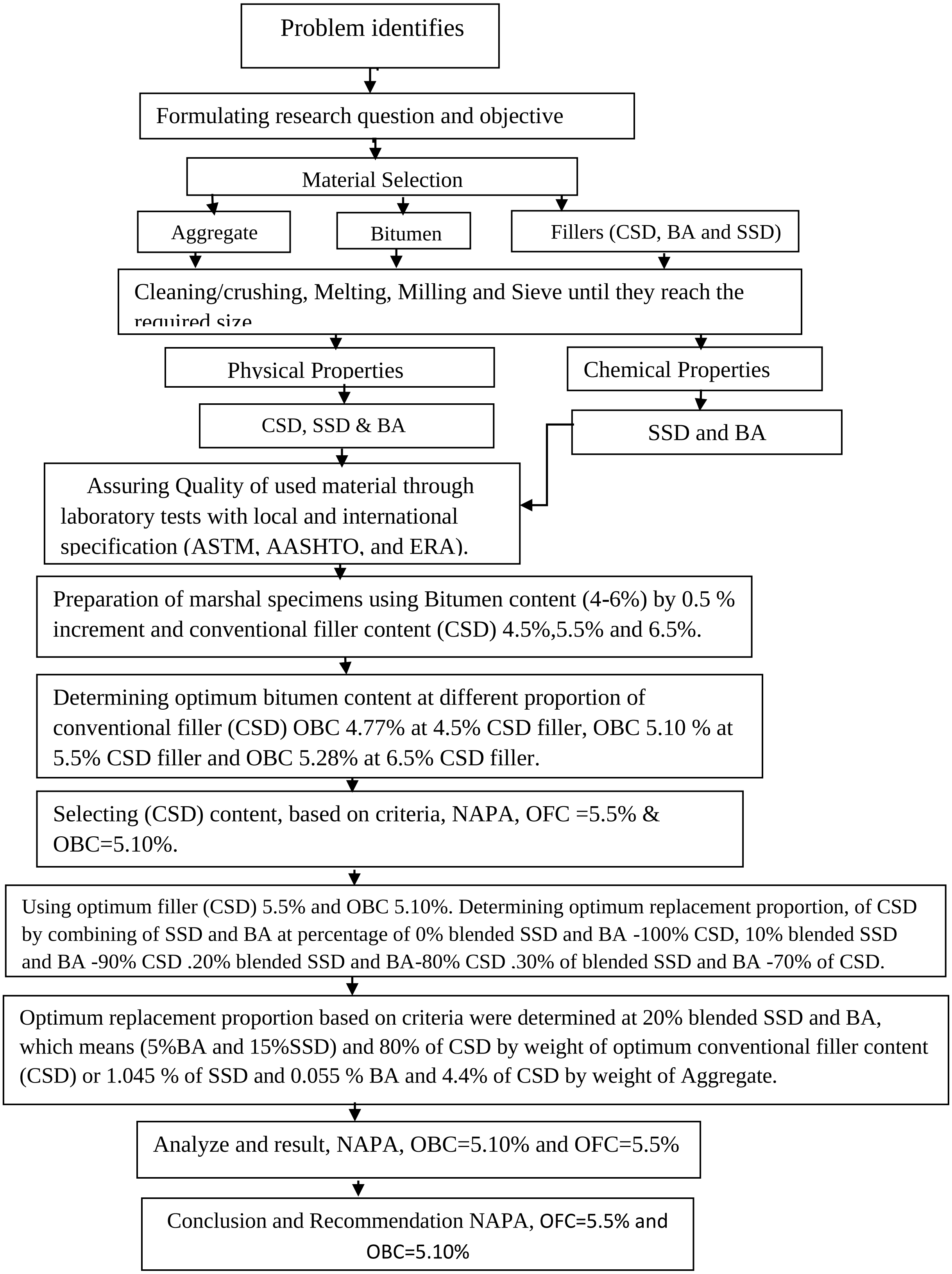


Chart-3.1 indicates the methods of laboratory preparation of asphalt mixture and its result.

3.8 Data collection method

To conduct this research, various types of data were collected. This data is primary and secondary. Primary data includes coarse and fine aggregates, bitumen, crushed stone dust, steel slag dust and bagasse ash. The conventional materials were collected from another source, and steel slag and bagasse ash, after identifying the larger availabilities, were collected and dusted in the laboratory. Laboratory tests were performed to verify the quality of the material based on each standard. The secondary data were obtained from standard manuals, literature and various sources of material used for this research.

3.9 Sampling techniques and size

3.9.1 Sampling techniques

The sampling technique used for this study was directed sampling, which is a non-probability method. This sampling technique was proposed on the basis of the intention to carry out laboratory tests on the materials required for the design, such as coarse and fine aggregates, fillers and bitumen, in order to investigate the possible use of mixed bagasse ash and steel slag dust as a substitute for the conventionally used crushed stone dust filler in hot mix asphalt. This sampling technique is freely distributed and used to help researchers select a unit sample from a population.

3.9.2 Sampling size

Sampling is the most important step to ensure quality materials are used. The materials selected for this study were collected from various sources. The 60/70 penetration grade asphalt cement crushed stone dust filler and aggregates were sourced from Ethiopian Road Construction Corporation (ERCC) quarry and crusher site in local area of Deneba in Jima zone with various sizes of 14-25mm, 6-14mm, 3-6mm and 0-3mm. The main reason for using 60/70 grade asphalt is based on the climatic conditions and its performance in the past, since the common type of asphalt widely used in most road projects in our country roads. Bagasse ash was collected from the Wonji Sugar Factory, as was steel slag from the Ethiopian Iron and Steel Works at Akaki-Beseka in Addis Ababa. Since a sample is only a small part of the total material; the importance of the sample being representative of the material being supplied cannot be overstated and the sample should be prepared to specification. In conducting this research, meet the Marshall property design requirements for all laboratory work. With this, a total of one hundred two (102) HMA samples were prepared, forty-five (45) HMA samples were prepared to determine the optimum bitumen content and optimum filler content, forty-five (45) samples to determine the optimum replacement percentage of mixed bagasse ash and Steel slag dust to be added in and the remaining twelve (12) samples were prepared to evaluate the effect of mixed bagasse ash and steel slag dust filler on the moisture susceptibility of asphalt mixtures.

3.9. Data processing and analysis

The research was initially determining the physical properties and characteristics of aggregate, bitumen and fill material through laboratory testing. Sample material preparation was use performing to determine the optimal bitumen and filler content based on the Marshall Properties and volumetric properties of each sample. The results of the laboratory tests were analyzed using Excel, drawing different types of graphs and tables. A key aspect of the analysis was then a comparison of the test results to standard specifications for surface materials according to the respective ERA, AASHTO and ASTM standards. Finally, the results of the analysis were available in accordance with the research goals.

3.10. Data quality assurance

A pre-test of the available tools was conducted prior to the start of the main data collection period, and data were collected after the main investigators became aware of how to collect relevant data. Samples were collected from appropriate sources. Standard formats were used to record test results to avoid data loss.

3.11. Ethical Consideration

Prior to the data collection, an official letter was written by the Jima Institute of Technology and sent to the Ethiopian Steel and Iron Factory Akaki-Kaliti and Wonji-Sugar Factory established in Addis Ababa to obtain the relevant data/samples and perform the necessary tests and Jima Civil Technical Department (Highway Stream) of the laboratory department to conduct the relevant tests.

3.12. Laboratory work

3.12.1. Preparation of Marshall Samples and Procedure

In conducting this research, the laboratory work consisted of determining the optimum bitumen and filler content using the Marshal method. To proceed with the Marshall blend, material testing is performed according to the Marshall method of blend design (ASTM D1559). Based on the three types of fillers (4.5%, 5.5% and 6.5%) were selected and five different bitumen contents (4-6%) with 0.5% weight gain of the mix were used. Using these 45 HMA samples were prepared in a first attempt to determine the optimal filler and bitumen content. According to the types of fillers, crushed stone dust, marble flour, cement and lime, etc. are basic conventional fillers, but in this study, crushed stone dust was used as the conventional paving mix filler. Then the mix design was carried out by laboratory tests using a different percentage of conventional filler and bitumen/asphalt binder. Laboratory tests were used to determine Marshal Stability (KN), Flow value (mm) and the volumetric properties of asphalt mixtures such as bulk density (gm/cm^3), VMA (%), VA (%) and VFA (%).

The optimum bitumen content was determined from these results. In addition, the maximum stability and lower flow values were used to determine the optimum filler content from Stability vs. Bitumen Content (%), Flow Value vs. Bitumen Content (%), Bulk Density vs. Bitumen Content (%), VMA (%) vs. Bitumen Content (%) and VFA (%) Vs Bitumen Content (%) plotted and taken as the average value of bitumen content corresponding to maximum stability, maximum bulk density, and 4% air voids. After determining the optimum bitumen and optimum filler content, the remaining test was continued, replacing the optimum filler content with varying proportions of a mixture of bagasse ash and steel slag dust, starting with (0–30%) 10% by weight of the optimal filler content (CSD) through Trial -and -error method based on optimal bitumen content. A comparison was then made to examine the effect of non-conventional filler (blended bagasse ash and steel slag dust) in HMA and the result was evaluated against the ERA standard specification for binder course material.

3.13. Material preparation and Test

3.13.1. Mineral aggregate tests and preparation

Aggregates (mineral aggregates) are hard, inert materials such as sand, gravel, crushed stone, slag or rock flour. Aggregate is the main component of HMA and the quality and physical properties of this material have a major impact on the mix performance. Accordingly, aggregate gradation, shape, surface finish, water absorption, solidity, resistance to crushing and impact loads have a major impact on the shear strength properties of hot mix asphalt. AASHTO, ASTM and BS standards are used for road construction test methods for dense graded asphalt. The mineral aggregates used in the research were subjected to various tests to determine their physical properties and their suitability for road construction, various tests were carried out and the results are presented in Chapter 4. Some of the tests were performed on mineral fillers to demonstrate physical properties believed to be of significant value in evaluating mineral fillers and were determined in the following table.

Table 3.1. Described the Marshal Mix design tests, test methods, and standard specifications (Source, ERA,2013, AASHTO and ASTM).

Test	Test Description	Test methods	Standard and specification
Aggregate Test	Sieve Analysis	AASHTO T -27	Ethiopian Road Authority,2013.
	Specific gravity of coarse Aggregate, %	AASHTO T 85	
	Specific gravity of fine Aggregate, %	AASHTO T 84	
	Plasticity Index	AASHTO T 89	
	Aggregate Impact Value, %	BS 812, Part 112	
	Flakiness Index %	BS812-part 105	
	Los Angles abrasion, %	AASHTO T 96	
	Aggregate Crushing Value	BS 812 Part 110	
	Water absorption, %	BS 812, Part 2	

Based on the list of methods in the table above and in relation to method selection for this study, laboratory tests were used. It is very common to use crushed stone as mineral fillers on top of the filler before they are used in road construction to determine their physical properties, whether or not they can meet specification limits. When designing paving compounds, many properties of fillers are required. According to the AASHTO-T95 standard, the mineral filler need not be plastic and the plastic index is less than four.

3.13.2.Physical properties of mineral filler

Mineral fillers include finely divided mineral materials such as rock dust, slag dust, hydrated lime, hydraulic cement, fly ash, and other suitable mineral materials. Mineral fillers are by-products of stone crushing processes, showing the possibility of including them in hot mix asphalt construction (Eltaher, 2016). Mineral filler made from rock dust, slag dust, loess and similar materials shall be substantially free from organic contaminants. According to the AASHTO T100/ASTMD854 standard, the mineral filler does not have to be plastic and the plastic index, since it is greater than four (>4) ASTM D4318. Aggregate that passes through the #200 (0.075 mm) sieve is referred to as filler. It used to fill the voids, stiffen the binder and provide permeability (Mohanty, 2013). The fillers used for the current study were non-conventional fillers, namely bagasse ash and steel slag dust and conventional filler, crushed rock dust (CSD), and both fillers passed 100% through the #200 sieve. Laboratory tests were conducted to evaluate the physical properties of the crushed stone dust filler, which consisted of grading parameters, plasticity index and apparent specific gravity.

In addition, the laboratory tests were carried out on mineral fillers to show the physical properties such as bagasse ash, steel slag dust and crushed stone dust. Plastic index for both bagasse ash and steel slag dust, but specific gravity for bagasse ash, steel slag and crushed stone dust. These laboratory tests were evaluated using the AASHTO and ASTM standard specification, and the test was used prior to their use in road construction to determine their physical properties, whether or not they could meet the specification limits.

3.13.3.Asphalt binder selection and test

Asphalt binder is the most commonly used material in road construction today due to its high technical performances such as elasticity, adhesion and water resistance. According to ASHTO, paving bitumen had three important properties or characteristics; these are consistency (commonly referred to as viscosity), purity and safety. These physical properties were determined by established AASHTO standard methods. Also, a series of tests included penetration, specific gravity; Softening point and ductility were performed for the basic characterization properties of penetrating grade asphalt. However, the bituminous binder used in this study had a 60/70 penetration rating. Reason, based on Manual Series2 (1997), the annual air temperature is greater than or equal to 24 °C, the asphalt quality is 60/70 penetration. in other words, 60/70 penetration grade bitumen is generally recommended for HMA in hot climates (ERA, 2013).

Since asphalt binders have different physical properties depending on the temperature, i.e., at high temperature it becomes liquid, has a low consistency similar to oil, and at room temperature, most asphalt binders should have the consistency of soft rubber. At sub-zero temperatures, asphalt binder can become very brittle. Therefore, most asphalt binder specifications have been developed to control changes in consistency with temperature (Transportation Research Board Committee, 2011). So, it was suitable for Ethiopia and widely used. This bituminous binder was used in the preparation of mixes in this research which were a partial replacement of mixed bagasse ash and steel slag dust as filler in hot mix asphalt. Subjected to research and various laboratory tests to determine physical properties. These tests are shown in Table 3.2 below. The test results of bitumen are detailed in Appendix B and summarized in chapter four of the work.

3.2 Described physical properties of bitumen test (Source, ERA,2013, AASHTO and ASTM)

Test	Test Description	Unit	Test methods	Standard and specification
Bitumen Test	Penetration	1/10mm	AASHTO T -27	Ethiopian Road Authority,2013
	Specific gravity	Kg/cm^3	AASHTO T 85	
	Ductility	cm	AASHTO T 89	
	Flash point (°C)	C°	ASTM D 92	
	Softening point	C°	BS 812, Part 112	

3.14. Marshal Mix design

The Marshall Mix design method hypothesis was originally formulated by Bruce Marshall, formerly of the Mississippi Highway Department, and by the U.S. Improved Army Corps of Engineers. The Marshall Process is only applicable to hot mix asphalt using penetration, viscosity or PG (penetration grade) rated asphalt binder or cement and containing aggregate with a maximum size of 25.0 mm (1 inch) or less.

The purpose of the Marshal Procedure is to determine the optimum asphalt content for a given aggregate mix. In addition, it provides information on the properties of the resulting pavement mix, including density and voids content, to be used during pavement construction. The Marshall method uses standard test specimens with a height of 63.5 mm and an inner diameter of 101.6 mm. A series of samples, each containing the same aggregate mixture but varying in asphalt content from 4% to 6% with a 0.5% increase, were prepared using a special process to heat, mix and compact the asphalt aggregate mixtures and separate sufficient Material prepared to produce 5 (filler rates) 15 (samples for five bitumen and three samples for each bitumen) + 5 (filler rates) 3 (samples for OBC and three samples for each OBC) = 90 samples of approximately 1200g each.

The Marshall test methods have been standardized by ASTM and published as ASTM D1559. The test procedure begins with the preparation of the test specimen. Several materials were required for the production of asphalt specimens. Since the main objective of the study was to investigate the effect of mixed steel slag dust and bagasse ash as a mineral filler (CSD) and in relation to the overall asphalt mixture parameters, it was important to evaluate not only the mixture of steel slag dust and bagasse ash, but also various aggregate and binder sources.

The raw material used in this study, the crushed stone of coarse aggregate, fine aggregate and asphalt cement with a penetration grade of 60/70.Therefore, the Marshal Mix design was created using a special process of heating, mixing and compacting the asphalt aggregate mixtures. Therefore, aggregates are the first oven-dried constant weight at 110 ± 5°C and each should be placed in a separate container. Before mixing with bituminous binder 1200 g blended aggregates was dried in oven with a temperature of 165°C (which is more than 150°C) for a minimum of 16 hours and the 60/70 penetration grade asphalt were heated to a temperature of 160°C (135-170°C) (Asphalt institute manual 7th edition,2014).

Also, the Standard Marshall Molds were heated in an oven for a minimum of 8 hours before mixing. After checking the temperature, bitumen was added with a specified amount i.e., 4.0, 4.5, 5.0, 5.5, 6.0 percent by weight of total mix and added to the pre-heated aggregate and mixed thoroughly at desired temperature at 170°C (140-170°C for 60/70 bitumen grade ERA,2013). Mix until all of the aggregate is thoroughly coated. ASTM D6926 suggests mixing for approximately 60 seconds for single specimen batches and approximately 120 seconds for multiple specimen batches (Asphalt institute manual 7th edition,2014).

The weight percentage of the asphalt content for all mixes was taken in relation to the total weight of the mix. The mixture was then placed in the preheated mold and compacted using 75 blows on both sides of the sample with the standard Marshall hammer as specified in ASTM D1559. After compression, the sample was allowed to cool and removed from the mold using an extrusion press. Following the Marshal procedure, all compacted test specimens were subjected to unit weight determination, void analysis, and stability and flow tests after 24 hours. Charts were then generated to determine the values of each respective sample made using different levels of filler.

3.15.1 Gradation of course and fine aggregates

Aggregate grain size distribution or grading is one of the most important properties of aggregates (Othman, kareen, 2021). It affecting the quality of hot mix asphalt including stiffness, stability, durability, permeability, workability, fatigue resistance, skid resistance and resistance to moisture damage and according to (Shamim Zafar, 2012). The coarse and fine aggregate particles were separated into different sieve sizes and proportioned to obtain the desired ASTM 3515 grading for bituminous mixtures. Aggregate grading is usually expressed as a percentage (by weight) of the total sample that passes through each sieve. Available aggregates, coarse aggregate (14-20 mm), medium aggregate (6-14 mm and 3-6 mm), fine aggregate (0-3 mm) and mineral filler (passage 0.075 mm (No. 200) sieve), were reviewed integrated in order to get the right gradation within the allowable limits according to ASTM 3515 standard specifications.

In order to get the overall gradation within the specification limit and to get the correct gradation, the proportioning was done using mathematical trial-and-error methods and it is also desirable to plot the graph. However, the first attempt may not always meet the specified limits. In such cases, other combinations must be tried until a satisfactory one is obtained. In this study, three grades were produced by varying the amount of crushed stone filler commonly used. The first grade was made with 4.5% CSD (by weight of the aggregate), the second grade was made with 5.5% CSD (by weight of the aggregate) and the third grade was made with 6.5% CSD (based on the weight of the aggregate) using targeted sampling techniques.

3.15.2 Preparation of HMA specimen

Before starting the mixing procedures, it is necessary to prepare suitable and sufficient materials for the whole work. Aggregates are the first oven dried constant weight at 110 ± 5°C and each should be placed in a separate container. In determining the design asphalt grade for selected aggregates using the Marshall method, a series of test specimens were prepared for a range of different asphalt grades. The basic materials were needed to prepare HMA samples. Fully mixed aggregate, filler, bitumen, flat-bottomed metal marshal mold with flat bottom metal (base plate), oven, collar, balance (Scale), furnace, compactor, filter paper and pan are the main materials used for the preparation of the HMA samples. The preparation of Marshall Specimen was the serial task of the experimental procedure according to standards.

The blended mixtures were placed in the preheated mold and compacted using a Marshall Compaction hammer with a 4.5 kg hammer weight, falling freely from a height of 457 mm, covering each side of the sample with filter paper and giving 75 blows to each side of the sample standard Marshall hammer applied there to as specified in ASTM D1559. After 75 blows on each side of the sample, the filter papers were removed from each side of the sample and the samples were put to cool for 24 hours. And the compacted specimens were removed from the molds after 24 hours using specimen extractor as shown in Fig. 3.2 below.

Figure 3.3. Extraction of mold using extractor (Source, Dejenie Dereje,2014)

The specimens were weighted in dry air, weighted in water and saturated surface dry weight and height of the specimen were noted on the prepared sheet as shown below in the Figure 3.4, and the bulk specific gravity of compacted specimens was determined according to the test procedure specified by ASTM 2726. After determination of the bulk specific gravity, bring the specimen to the desired temperature by immersing them in the water bath for 30 minutes at 60°C as shown below in Figure 3.4.

A) B) C)

Figure 3.4. The letter in fig shows A) weighed dry in air, B) weighed in water C) Saturated surface dry weight of the sample at 60°C for 30 ± 5 minutes (Source, Dejenie Dereje,2014)

The Figure 3.4 shows the measured sample height, air dry weighed, water weighed saturated surface dry matter and immersed in a 60°C water bath for 30 ± 5 minutes to prepare for Marshall Stability and flow determination. Thereafter, Marshall Stability and flow were tested after the sample was immersed in a water bath at 60°C for 30 minutes according to ASTM D1559 and observed. Then they were removed from the water bath and quickly placed in the Marshall Stability and Flow Tester machine as shown in the image below.

The flow meter or the deflection gauge is put on and adjusted to zero. The load is applied via the Marshall test setup. Maintaining a constant strain rate of 50.8 mm per minute until the maximum load (failure) is reached. The load resistance and the corresponding strain (flow) readings were carefully noted. Volumetric analysis was made for each series of test specimens after the completion of the stability and flow tests. The measured Marshall Stability value is corrected by means of a conversion factor. Note that the conversion was made on the basis of measured volume.

Figure 3.5. Removal of the specimen from the immersed water bath and measuring of Stability and flow by using Marshall Tester machine (Source, Dejenie Dereje,2014).

In this research, laboratory work was performed to determine the optimum asphalt grade and filler using the Marshal's method. To proceed with the Marshal Mix, material tests were performed according to ASTMD1559 and five different bitumen contents (4 - 6%) with 0.5% increments are used. Depending on the type of mineral fill material in this study, traditional fill material was an inert fill material such as crushed stone dust, steel slag dust and bagasse ash, etc. Therefore, crushed stone dust is used as a conventional filling material.

According to ASTM, inert filler material was used as filler in HMA to determine the optimal bitumen content and optimal filler content, using conventional filler (crushed stone). Using a different percentage of conventional filler and bitumen/asphalt binder, mix design was carried out through laboratory testing. This is how laboratory tests determine stability (KN), flow value (mm), unit weight (gm/cc), VMA (%), VIM (%) and VFA (%). The optimum bitumen content was determined from these results. In addition, the maximum stability and flow value are used to determine the optimum filler content.

After determining the optimum bitumen content, the remaining test using the optimum bitumen content and filler was replaced with different percentages of mixed steel slag dust and bagasse ash in 0% (control mix), that was 100%, 90%, 80%, and 70%, crushed stone dust and 0%, 10%, 20% or 30%, and also 4,4.5,5,5.5, and 6.0% bitumen contents. Then, to study the effect of non-conventional filler steel slag dust and bagasse ash, and to check the quality and quantity of these non-conventional materials, it is best to mix them together and get relatively similar strength with conventional filler (crushed stone dust). When mix together and also qualifies the result of the test to be compared in HMA and to evaluate the result against ERA standard specification for wearing course material.

3.15.3 Determination of optimum bitumen content

It is common practice to design the mix using the Marshall Test (ASTM D1559. The total mix designs to be carried out in the Marshall test are 3 (types of filler content) × 15 (samples for five bitumen and three samples each bitumen content) 45 specimens were prepared to determine OBC and optimum filler content. Marshall Test has been used to determine the optimum binder content. According to (asphalt institute, 2003) there are two commonly used methods to select the optimum bitumen content those are method 1 NAPA (National Asphalt Pavement Association) and method-2 Asphalt Institute methods.

Determination of optimum bitumen content was used to proceed after analyzing different volumetric properties of the mix and preparation of separate graphical plot for the value of stability, flow, VFA, VMA, Air Void, Bulk specific gravity with asphalt content. Therefore, based on the following briefly discussion about the two commonly methods used to select the optimum bitumen content.

- Method 1- Asphalt Institute Method:
  1). Determine:
     a. Asphalt content at maximum stability
     b. Asphalt content at maximum density
     c. Asphalt content at the midpoint of specified air void range (4 percent typically)

2). Average the three asphalt contents selected above

3). For the average asphalt content, go to the plotted curves and determine the following properties: Stability, Flow, and Air voids, Gmb, VFA and VMA.

4). Compare values from Step 3 with criteria for acceptability given in table 3.2

- Method -2. NAPA (National Asphalt Pavement Association)

The one commonly used procedure was recommended by NAPA, these methods mainly based on the plot curves were prepared using different volumetric properties with asphalt content. Fourthly, the optimum asphalt content can be determined by the following procedures: -

1. The asphalt content which corresponds to the specification's median air void content (4 percent typically) of the specification. This is the optimum asphalt content.
2. The asphalt content is then used to determine the value for Marshall Stability, VMA, flow, bulk density and percent voids filled from each of the plots. In this sense, these marshal volumetric properties are plotting as the following versus.
   - Bitumen Content vs. Flow
   - Bitumen Content vs. Bulk Specific Gravity
   - Bitumen Content vs. Air voids (Va)
   - Bitumen Content vs. Voids Filled with Bitumen (VFB)
   - Bitumen Content vs. Voids of mineral aggregate (VMA)
   - Bitumen Content vs. Stability
3. Then, properties of the asphalt mix using optimum bitumen content such as stability, flow, bulk density and volumetric properties (i.e., VA, VMA and VFA) are obtained and checked against standard specifications range in addition, compare each of these values against the specification values for that property, and if all are within the specification range, the asphalt content at 4 percent air voids is optimum asphalt content (Asphalt Institute, 2003). If any of these properties are outside the specification range, the mixture should be redesigned.

However, the mix should not VIM at optimum bitumen content (%) be designed to optimize one particular property but should be a compromise selected to balance all of the mix properties the design criteria and the range of bitumen content over which compliance with the criteria is achieved: that the addition test results confirm that the bitumen content giving 4 percent VIM is acceptable, that a design Optimum bitumen content would minimize the risk of plastic deformation and the aggregate particle size distribution should be adjusted further away from the maximum density line to give slightly more VMA (ERA Manual, 2013).

For this study Method-2 (NAPA) was selected in order to determine the optimum asphalt content and for additional marshal mix design that is for Replacement of filler in a mix. Therefore, the Method-2 (NAPA) procedure is used to this research. Because, it is usually the most economical one that was satisfy all of the established criteria stated in NAPA.

The marshal properties of the asphalt mix, such as stability, flow, bulk density, air void in the total mix, and voids filled with bitumen were must be in the range of suggested marshal criteria for asphalt concrete mix design (ERA Pavement Design Manual, 2002). The value of marshal test and the design criteria range can be indicating in following Table 3.2.

Table 3.2. Marshall Criteria for asphalt concrete mix design (Source, ERA, Pavement Design Manual, 2002)

Mix Designation and Nominal Maximum Size of Aggregate(19mm)						
Total Traffic (10^6ESA)	<1.5		1.5-10.0		>10.0	
Traffic Class	T1, T2, T3		T4, T5, T6		T7, T8	
	Min	Max	Min	Max	Min	Max
No. of blows of Marshall Compaction hammer	2*35		2*50		2*75	
Stability (KN)	3.5	-	6	-	8	-
Flow(mm)	2	4	2	4	2	4
Air void (%)	3	5	3	5	3	5
Void filled with asphalt VFA (%)	70	80	65	78	65	75
Percent VMA (for 4% air voids and Nom. Max, Particle size of 19 mm)	13	-	13	-	13	-

3.15.4. Determination of Optimum Replacement Rate of Blended Steel Slag Dust and Bagasse Ash

After completing determination of OBC, the intended partial replacement of CSD with blended of BA and SSD was undertaken. Before determination of optimum replacement ratio of non-conventional filler, different content of conventional filler and bitumen content were used to determine the optimum filler content and bitumen content that were used for the purpose of replacement ratio with non-conventional filler (steel slag dust and bagasse ash) with different proportion 0% (control mix), 10%, 20% and 30%, by weight of optimum crushed stone dust filler. The required amount of blended steel slag dust and bagasse ash was used to replace conventionally crushed stone dust starting from 10 % interval (by weight of optimum filler content) through trial-and-error method with first trial of bitumen and added to the heated aggregate and thoroughly mixed the basis of optimum bitumen content.

After that the mixtures were prepared and the Marshall Stability properties of these replaced asphalt mix such as stability, flow, bulk density and volumetric properties (i.e.VA, VMA and VFA) were determined and checked according to the specification range and to determine the optimum replaced percentage rate (by weight of optimum filler content) of blended bagasse ash & steel slag dust. it was depending on the Marshall Test results of having maximum stability, maximum bulk density, and air voids within the standard range of specification rates.

Table 3.3. Partial replacement rates of blended steel slag dust and bagasse ash with crushed stone dust (Source, Daniel Alelgn,2014).

CSD	BA&SSD	Non-conventional filler ratio for Marshall mix design by 5.5% filler ratios (CSD) in 1200g total mix materials										Fillers
90% of CSD (4.95g)	10% of blended BA&SSD (0.55g)	Bagasse Ash (BA %)					Steel Slag Dust (SSD %)					5.50
		0	2.50	5	7.50	10	0	2.50	5	7.50	10	10
		0	0.014	0.275	0.536	0.55	0	0.014	0.275	0.536	0.55	
CSD	BA&SSD	Bagasse Ash (BA %)					Steel Slag dust (SSD %)					5.50
80% of CSD (4.4g)	20% of Blended BA&SSD (1.1g)	0	5	10	15	20	0	5	10	15	20	20
		0	0.055	0.55	1.045	1.1	0	0.055	0.55	1.045	1.1	
CSD	BA&SSD	Bagasse Ash (BA %)					Steel Slag Dust (SSD %)					5.50
70% of CSD (3.85g)	30% of blended BA&SSD (1.65g)	0	7.50	15	22.50	30	0	7.50	15	22.50	30	30
		0	0.124	0.825	1.526	1.65	0	0.124	0.825	1.526	1.65	

Generally, the following steps show the marshal specimen preparation at different percentages of blended BA and SSD with constant bitumen content. The properties of the specimen were checked with the specified range of design criteria. The optimum replacement ratio was obtained the blended BA and SSD content having maximum stability, maximum bulk density, and air void (VA) within the allowed range of specification.

The steps follow to preparing steel slag dust and bagasse ash filler samples are summarized as follows:

i. Purposive sampling technique was utilized to obtain bagasse ash and steel slag from their industrial site by crushing and grinding until it reaches the required mineral filler size.
ii. The bagasse ash and steel slag dust, which passed on number 200 sieve (0.075mm), was checked for PI test.
iii. Four percentages of bagasse ash and steel slag dust were investigated by inter changing their quantities with compare test results, which were replaced at 10 incremental percentages of 0 % (control mix) 10, 20 and 30%, by weight crushed stone dust filler with 3 samples for each percentage.
iv. The blended bagasse ash, steel slag filler and aggregate are then heated to a temperature of 165ºC (more than 150°C) befor**e** mixing with asphalt cement **(**Asphalt institute manual 7th edition,2014).
v. Asphalt was heated at 160ºC (135ºC - 170ºC) prior to mixing with aggregates.
vi. The required amount of asphalt (i.e., Optimum bitumen content) was added to the heated aggregate and mixed by desired temperature of 170ºC (140-170°C) for mixing approximately 60 seconds for single specimen batches and approximately 120 seconds for multiple specimen batches (Asphalt institute manual 7th edition,2014).
vii. Standard Marshall Molds was heated in an oven 110ºC **(**105°C - 150ºC) for a minimum of 16 hours and then the hot mix is placed in the mold and compacted with 75 blows at each face of the specimen (Asphalt institute manual 7th edition,2014).
viii. Specimens are prepared, compacted, and tested according to standard 75-blow Marshal Method designated as ASTM D 1559.

3.15.5. Volumetric designs of HMA Mixes

Basically, mix design is necessity to determine the volume of bitumen binder and aggregates important to produce a mixture with the desired properties. Since weight measurements are typically much easier, are taken and then converted to volume by using specific gravity. To determine the volumetric properties, several tests have been conducted according to the Marshal mix design as an air void (VA) or percentage of voids in total mix (VTM), Voids Mineral Aggregate (VMA), percentage volume of bitumen (Vb), theoretical maximum specific gravity (Gmm), the bulk specific gravity (Gmb), Effective asphalt content (Pbe) and Voids with Aggregate

(VFA). Moreover, three samples have been prepared for five bitumen content percentages ranging from 4% until 6% with 0.5% intervals. According to ASTM D 1559 compaction standard using 75 blows for each face, the bulk specific gravity was determined according to ASTM D 2726. Besides that, the stability and flow value of each test sample have been evaluated according to ASTM D 1559. Therefore, these properties indicate the performance of the mixes in the field.

I). Theoretical maximum specific gravity of loose specimen (Gmm)

Theoretical maximum specific gravity is the ratio of the weight in air of a unit volume of the un-compacted bituminous paving mixture at a stated temperature and zero air voids to the weight of an equal volume of gas-free distilled water a stated temperature. The theoretical maximum specific gravity of an asphalt concrete is essential in order to determine the volumetric properties of hot mix asphalt mixture. This (density) volumetric property is one of a good indicator of the asphalt concrete performance. The maximum specific gravity (Gmm) at different asphalt contents was measured to calculate the volumetric parameters of the HMA (air voids). The mixed sample allowed cooling down at room temperature for 24hours and the bulk specific gravity was done at 25˚c according to ASTM 2726. Apply Vacuum Pump or Water Aspirator for remove air from samples, capable of evacuating air from the vacuum container to a residual pressure of 4.0 kPa (30 mm of Hg) or less. For each sample mass in the air, mass of sample in water and mass in surface saturated sample were measured. This maximum specific gravity is determined by measuring the specific gravity after removing all of the air interrupted in the mixture by subjecting the mixture to a partial Vacuum saturation. For each sample mass in the air, mass of sample in water and mass in surface saturated sample were measured. The maximum specific gravity of the mix conducted according to ASTM D 2041 method.

Figure 3.6. Mixing and cooling down of samples for specific gravity (Source. Dejenie Dereje,2014).

The theoretical maximum specific gravity (Gmm) at various asphalt binder content was used to determine the air void percentage in the mix. Place the container with the sample and water on a mechanical agitation device and anchor it to the surface of the device. Start the agitation and immediately begin to remove air trapped in the sample by gradually increasing the vacuum pressure until the residual pressure manometer reads 3.7 ± 0.3 kPa (27.5 ± 2.5 mm of Hg). The vacuum should be achieved within 2 min. Once the vacuum is achieved, continue the vacuum and agitation for 15 minutes (15 ± 2 min) ASTM D 2041 – 00.

The experimental theoretical maximum specific gravity of a mix is defined as: -

$$G_{mm} = \frac{A}{A+B-C} \quad \text{Eq.3.1}$$

Where: -

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

A = Mass of the dry sample in air, g

B = Mass of Jar Filled with Water, g, and to calibration mark

C = Mass of Jar Filled with Water + Sample, g

II). 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 compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the sample. When VMA is too low, there is not enough room in the mixture to add sufficient asphalt binder to adequately coat the individual aggregate particles. Besides, mixes with a low VMA are more sensitive to small changes in asphalt binder content. Excessive VMA will cause unacceptably low mixture stability therefore a minimum VMA is specified and a maximum VMA may or may not be specified. The objective is to furnish enough space for asphalt binder so as to provide adequate adhesion required to bind the aggregate. The VMA are calculated based on the bulk specified gravity of the aggregates and is expressed as a percentage of the bulk volume of the compacted paving mixture.

$$VMA = \frac{100*(G_{mb} - P_S)}{G_{sb}} \quad \text{Eq.3.2}$$

Where: -

VMA=voids in the mineral aggregate.

Gmb = bulk specific gravity of total aggregates.

Gsb = bulk specific gravity of total aggregates.

Ps =aggregate content, percent by mass of total mixture.

III). Bulk specific gravity of compacted specimen (Gmb)

The bulk specific gravity of a mixture refers to the specific gravity of a specimen of compacted mixture, including the volume of air voids within the mixture. It is equivalent to the mass of a given specimen in grams, divided by its total volume in cubic centimeters (Asphalt Institute, 2003). This value, as stated at ASTM D1189 and D2726, is used to determine weight per unit volume of compacted mixture. The standard procedure for determining the bulk specific gravity of compacted asphalt concrete involves and the mixed sample allowed cooling down at room temperature for 24hours, weighing the specimen in air and in water after this the bulk specific gravity was done at 25˚c according to ASTM 2726.

The bulk specific gravity (Gmb) of a compacted mix is calculated as: -

$$G_{mb} = \frac{A}{B-C} \qquad \text{Eq.3.3}$$

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

IV). Volume of Absorbed Bitumen (P_{ba})

Volume of bitumen expressed by percentage in the mix that has been absorbed by the pore structure of the aggregate. The equation for absorbed asphalt is:

$$P_{ba} = 100 - G_b * \frac{(G_{se} - G_{sb})}{(G_{se} + G_{sb})} \qquad \text{Eq. 3.4}$$

Where: -

Pba = Absorbed bitumen by weight of aggregate,

Gb = Specific gravity of asphalt cement,

Gse = Effective specific gravity of aggregate,

Gsb = Bulk specific gravity of aggregate

V). Voids Filled with asphalt (VFA)

According to Asphalt Institute, (2003), VFA is the percentage portions 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. In other words, VFA is the percentage of the voids in mineral aggregates that contain asphalt and not the absorbed asphalt. In other way, the portion of the void in the mineral aggregate that contain asphalt binder. This represents the volume of the effective asphalt content. It can also be described as the percent of the volume of the VMA that is filled with asphalt cement. VFA is inversely related to air voids: as air voids decrease, the VFA increases.

The mathematical computing of VFA and Its relationship between with VMA has shown as below:

$$VFA = 100 * \frac{(VMA-VA)}{VMA} \qquad \text{Eq.3.5}$$

Where: -

VFA=voids filled with asphalt, percent of VMA.

VMA= voids in mineral aggregate, percent of the bulk volume.

VA = air voids in compacted mineral, percent of total volume.

VI). Air Voids (VA)

Air void is the total volume of the small pockets of air that occur between the coated aggregates particles throughout in the lasted compacted paving mixture. Its volumetrically measurement may be increased or decreased by lowering or raising the binder content; also, be increased or decreased by controlling the amount of mineral filler material passing through 0.075 sieves size (200 sieves No.) in the asphalt mixture. According to (Asphalt Institute, 2008), when the finer mineral filler added to the asphalt mixture the lower, the air voids. As result, the air void may be changed by varying the aggregate gradation in the asphalt mixture. However, a certain amount of air voids in a mixture is extremely important and closely related to stability and durability. In other word, this is used to reduce the pavement from asphalt filer (flushing, shoving, and rutting).

According to (Asphalt Institute, 2003), the air voids, VA, in the total compacted paving mixture consists of the small air spaces between the coated aggregates particles. The total volume of the small pockets of air between the coated aggregates particles throughout a compacted paving mixture, expressed as percent of the bulk volume of the compacted paving mixture. The voids in a compacted mixture are obtained in accordance with ASTM D3203- 94 standard test method. The void in a compacted mixture is obtained as the following mathematical expression (way).

$$VA = 100 * \frac{(G_{mm} - G_{mb})}{G_{mm}} \quad \text{Eq.3.6}$$

Where: -

VA = air voids in compacted mixtures.

Gmm= maximum specific gravity of paving mixture.

Gmb =bulk specific gravity of compacted mixture.

The further volumetric analysis such as specific gravity, maximum theoretical specific gravity, air voids, voids in mineral aggregates and voids filled with asphalt, determined from each mix type, have been discussed in Chapter 4.

VII). Moisture Susceptibility of Mixtures

Moisture is a key factor in the deterioration of asphalt pavement. Factors that influence moisture damage include aggregate, asphalt binder, type of mix, weather and environmental effects, and pavement subsurface drainage. This part of the research evaluates the moisture damage for the mix composed of aggregate, asphalt binder and blending of bagasse ash with steel slag using indirect tensile strength. The indirect tensile strength test is a performance test which is often used to evaluate the moisture susceptibility of a bituminous mixture at 7%VIM and it greater than 79% (ERA,2013). Moisture Susceptibility is a primary cause of distress in HMA pavements. It is due to the adhesive and cohesive failure of asphalt mixture and it will shorten pavement life. Moisture damaged is typically addressed with laboratory tests as a part of the mixture design process where the main point of the test is determined the potential for the material to experience moisture related damage, known as Moisture Susceptibility test.

The moisture sensitivity tests to identify the HMA mixture's ability to resist water damage and determines the degree of moisture damage. Moisture-sensitive mixtures need to be identified during the course of the mixture design process which fulfills the specified minimum standard. The test followed as AASHTO T283. The laboratory testing procedures currently available for compacted Hot Mix Asphalt (HMA) to test the moisture sensitivity were primarily developed to determine the degree of resistance to moisture damage by a particular combination of asphalt and aggregate. These moisture sensitivity tests evaluate the effect of moisture damage in laboratory by measuring the relative change of a single parameter before and after conditioning (i.e., Tensile Strength Ratio, Resilient Modulus Ratio). (M.K. Shamsuddin [1] *, M.E. Abdullah[2] and S.M. Rhasbudin Shah 3, 2010)

The laboratory testing procedures has two sets of compacted samples with (100 mm diameter and 75 mm long) were subjected to a tensile strength ratio test, they are conducted by preparing six Marshall Specimen for each mix at optimum asphalt content of CSD, BA and SSD fillers by different percentage mixing. For each six samples are then divided into two groups of three specimens as control and the other three specimens are conditional test, the control group was stored at room temperature for four hours. The conditional test group were immersed in water at 60^0C for 24 hours and then moved to a water bath at 25°C for two hours. The indirect tensile strength test is used to determine the tensile properties of the hot mix asphalt, which can be further related to the moisture susceptibility.

The tensile strength ratio (TSR) result from the tensile strength test commonly used to evaluate the moisture sensitivity of the asphalt mixes. Then tensile strength ratio is calculated accordance with ASTM D-4867, which should be a minimum of 0.8 or 80% as adopted by (ASTM D-4867. Therefore, in this thesis work, tensile strength ratio test used to determine the moisture induced damage properties of the asphalt mixture and witnessed in Figure 3.8.

a) b) c) d) e)

Figure 3.7. Then the figure details were explained TSR preparation process (Source, Dejenie Dereje,2014).

a. Fig.-3.8a indicates the Mixing asphalt mixtures for prepared Specimens and used for moisture susceptibility test.
b. Fig.-3.8b indicates Specimens were cool down, extracted from the mold, weighed dry in the air and measure the height.

c. Fig.-3.8c indicates Specimens were immersed in water at 60^0C for 24 hours.

d. Fig.-3.8d indicates specimens were moved to a water bath at 25^0C for two hours.

e. Fig.-3.8e indicates moisture susceptibility test for tensile strength ratio (TSR).

The tensile strength ratio (TSR) result from the tensile strength test commonly used to evaluate the moisture sensitivity of the asphalt mixes. The tensile strength ratio (TSR), which is the ratio of the average split tensile strength of the conditioned (wet or S2) sample over the average split tensile strength of the control (dry or S1) sample, is satisfy the specific recommended requirement (TSR ≥ 0.80) AASHTO T283 or (TSR > 80%) ASTM D – 4867.A higher TSR value typically indicates that the mixture will perform well with a good resistance to moisture damage. The higher the TSR value, the lesser will be the strength reduction by the water soaking condition, or the more water resistant it will be.

On this research, a destructive test (a test that destroys the sample) used to evaluate the tensile strength test of the HMA mixtures. Therefore, the unconditioned and conditioned properties will have to measure on two different sets of samples having very close air void. When steel loading strips are used, the load applied at a constant rate of movement of the testing machine head of 50 mm per minute. The maximum load value recorded and placed into the equation below in order to calculate tensile strength. The tensile strength result calculated as follow:

Tensile Strength Ratio;

$$TSR = \frac{ITS1\ value\ of\ conditioned\ specimen}{ITS2\ value\ of\ unconditioned\ specimen} * 100\%$$

Where: -

- ✓ ITS1= indirect tensile strength of unconditioned or dry subset
- ✓ ITS2 = average indirect tensile strength of conditioned subset

$$S_t = \frac{2000P}{\pi DT}$$

Where: -

t= specimen thickness (mm)
St= tensile strength (Kpa)
P=maximum load (N)
D= specimen diameter (mm)

CHAPTER - FOUR
RESULT AND DISCUSSION

4.1. General

Widely this chapter includes the analysis of results and discussion of the main part of the thesis that obtained from the laboratory test. In the result section from the point of objectives of the research, there were various tests done and all results were discussed and analyzed in different categories but before going to the preparation of specimen the quality of used materials were tested based on the specification. After checking the quality of materials, the next steps are performed, such as preparation of the specimen, taking different tests, and recording test results.

Firstly, three different asphalt concrete samples were prepared at three different serials with different bitumen content (4% - 6%) by 0.5% increment and using crushed stone dust (CSD) in different proportions (4.5%, 5.5% and 6.5% by weight of aggregates) as mineral filler and the results are analyzed to determine the optimum bitumen content (OBC) and optimum filler content (OFC) for asphalt mix.

Next to this, conventional filler (crushed stone dust) was replaced by non-conventional filler (blended bagasse ash and steel slag dust) and which performed by using the optimum bitumen and filler content. There are two ways of filler replacement these are whether by weigh to volume, Basic HMA weight-volume relationships are important to understand for both mix design and construction purposes. Fundamentally, mix design is meant to determine the volume of asphalt binder and aggregates necessary to produce a mixture with the desired properties. However, since weight measurements are typically much easier, they are typically taken, and then they converted to volume by using specific gravities (Khalil Tabatabaie1*,2019).

Therefore, the HMA components in Marshall procedure is designed on weight bases. The proportions of aggregate and asphalt are determined as a result of compromising the specifications and the experiment result. Bitumen content was select to optimize mix characteristics such as density, stability, flow. Converting mix components based on weights into volume proportions require specific gravity measurements of these components. In the volumetric mix design process, the amount of binder in the mix is expressed as effective binder volume (VBE). This normalizes the binder content for different aggregate specific gravity values. If the aggregate specific gravity is high, the mix designer may over asphalt the mix if the binder content is judged only by weight bases. The effective binder volume is the portion of the binder not absorbed into the aggregate (Khalil Tabatabaie1*,2019). Then the replacement of filler was performed in a different percent 0 % (control mix), 10%, 20 %, and 30% by 10% (by weight OFC) interval incremental replacement rate and Marshall Samples prepared by using the obtained OBC. After that Marshall Test was conducted on the produced samples, the results are analyzed, and from the result, optimum replacement ratio was determined based on the result of the control mix.

4.2. Material Properties Test

4.2.1. Physical properties of Aggregates Test Result

Aggregates for HMA are usually classified by size as coarse aggregates, fine aggregates, or mineral fillers. ASTM defines coarse aggregates as particles retains on No.4 (4.75 mm) sieve, fine aggregate as that passing a No.4 sieve (4.75 mm) and mineral filler as material with at least 70 percent passing the No. 200 (75 micrometer) sieve. 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.

Therefore, in order to obtain a good quality asphalt mix design, it is must to study the aggregate properties properly. Therefore, the investigating of the physical properties of aggregate is a core test to use the material in road construction; from this point of view, a different laboratory test was conducted on aggregate, including sieve analysis, specific gravity, aggregate crushing value, Flakiness index, Aggregate impact value, and Los Angles Abrasion Test was performed. The design of aggregate proportion is the output of trials based on specified values quoted in the ERA Manual of specifications or international standards. Therefore, the adopted aggregate was found suitable for preparing the HMA design. The output of the quality tests of aggregate materials that satisfy the specification of the physical properties of aggregates and aggregates laboratory results are presented (summarizes) in the following Table 4.1.

Table 4.1. Physical properties of aggregate and required specifications (ERA,2013).

Test	Test method	Test result				Specification
		25-13mm	13-6mm	3-6mm	3-0mm	
Bulk dry S. G	AASHTO T85-95	2.615	2.622	2.624	2.634	
Bulk SSD S. G		2.664	2.674	2.675	2.686	
Apparent S. G		2.749	2.765	2.767	2.779	
Water absorption	BS 812-part 2	1.863	1.967	1.978	1.986	<2
Flakiness index	BS 812 part 108	25				<45
Aggregate Crushing Value (ACV) %	BS 812 part 110	15.90				<25
Aggregate impact Value (AIV) %		7.682				<25
LOS Angeles Abrasion (LAA) %	AASHTO T85-95	16				<30

4.3. Physical Properties of Conventional and Non -Conventional Filler Test Result

The fillers that used for this study are non-conventional namely; bagasse ash (BA) and steel slag dust (SSD) and conventional filler is crushed stone dust (CSD). Laboratory tests have been conducted in order to evaluate the physical properties of each type of fillers, which consist of the gradation parameters, plasticity index and apparent specific gravity.

This test was conducted according to ASTM D-854 using water pycnometer method. The Table-4.2 shows all types of filler are passing through sieve #30, #50 and #200, which satisfies the standards specified in ASTM D242. According to Test Method D 4318 the plastic index of Bagasse ash, Steel slag dust and crushed stone dust were not greater than four (<4). Therefore, bagasse ash, Steel slag dust and crushed stone dust are non-plastic (NP), because they satisfy the standard of ASTM D242. If the specific gravity of the individual unblended aggregates differs by more than 0.2 then the specified masses of the different aggregates in the blend must be adjust so that the volumetric properties of the plant mix are correct (ERA, 2013 and Asphalt Institute, 1994). Therefore, the apparent specific gravity of bagasse ash, steel slag dust and crushed stone dust were less than 0.2 differences then they satisfy the standards. It occurred because of difference in absorption capacity of the materials that depend on their porosity. Moreover, it is noticeable that the higher absorption capacity material has lower specific gravity and higher surface area. Some of various tests that were performed on each type of fillers to show the physical characteristics and desirable for use the road construction various tests were conducted and the results are presented in the next section.

4.4. Physical properties of mineral filler

Mineral fillers contain finely divided mineral matter such as rock dust, slag dust, hydrated lime hydraulic cement, fly ash, and Aggregate that passing through No. 200 sieve (0.075 mm) classifieds under as filler. Mineral fillers are by-products of stone crushing procedures, manifesting the feasibility of including them in the design of hot mix asphalt (Eltaher, 2016). Mineral Filler prepared from rock dust, slag dust, loess, and similar materials shall be essentially free from organic impurities and have a plasticity index not greater than four (AASHTO T95). It fills the voids, stiffens the binder and offers permeability (Mohanty, 2013).

The fillers that used for the current study are non-conventional filler namely; bagasse ash and steel slag dust and conventional filler crushed stone dust (CSD) and whose apparent specific gravity has been found to be, 2.856, 2.876 and 2.921, respectively, and both fillers passing 100% through No. 200 sieve (0.075 mm). Laboratory tests were performed on mineral filler to show the physical properties, such as plastic index for both bagasse ash and steel slag dust but specific gravity for bagasse ash, steel slag and crushed stone dust and gradation parameters were determined as specification limits. With respect to the methodological choice for this study, laboratory test was use before using them in any road construction in order to determine their physical properties whether they can meet or not the specification limits.

Table 4.2. Apparent Specific Gravity of conventional and non -conventional Filler

Sieve No.	% Of passing			ASTM D242
	Bagasse ash	Steel slag dust	Crushed stone dust	
No.30	100	100	100	100
No.50	100	100	100	95-100
No.200	100	100	100	70-100
Plastic index	NP	NP	NP	<4
Apparent specific gravity	2.856	2.876	2.921	-

4.5. Chemical properties of BA and SSD Test Result

The chemical compositions of aggregate fillers are specified in terms of oxides, unrelated to whether such oxides are present in the sample. It is the chemical properties of aggregate fillers that undergo chemical action. It plays an important role in HMA performances as asphalt cement resists stripping off the asphalt films in the presence of water. Various literatures, however, shows that it has little effect on the suitability and performance of aggregate fillers, except for the adhesion of asphalt binder to the aggregate.

The chemical composition of bagasse ash and steel slag dust was determined by using the complete silicate test which was prepare in the Geological Survey of Ethiopia at the Department of Geochemical Laboratory Staff. According to the specified ASTM D618 standard, materials which contain a combined ingredient weight of silica, aluminum, and iron oxides over 70% by weight of fraction can be deduced to be class N and F. Therefore, the combined ingredients of both bagasse ash and steel slag dust were $SiO_2 + Al_2O_3 + Fe_2O_3$ = 82.62% and 76.94%, respectively. It may be observed from Table 4.3 that the minimum requirement of oxides as per ASTM C618, i.e., the sum of silica, alumina, and iron oxide content should be greater than 70%, for natural pozzolana is satisfied. Hence, they can partially replace flay ash and cement be used as mineral filler in HMA design. 100% of the bagasse ash and steel slag dust passed through a 0.075 mm sieve, which is almost the same size as flay ash, cement and signifies that both bagasse ash and steel slag dust were suitable for HMA. The chemical composition of BA and SSD is illustrated in the Table 4.3.

Table 4.3. Chemical compositions of SSD and BA by using complete silicate analysis

Sample Chemical Composition (Weight %)								
Oxide	SiO2	Al_2O_3	FeO_3	MgO	CaO	K_2O	Na_2O	MnO
SSD%	52.14	16.96	13.52	2.00	4.48	0.88	<0.01	0.16
BA %	61.26	9.60	6.08	1.08	3.72	12.20	2.88	11.04

4.6. Asphalt binder Test Result

A series of bitumen quality tests were conducted before the mix design started. However, the test results for the performance of this study, including ductility, flash point, penetration, softening point, and specific gravity, were conducted for the basic characterization of properties of penetration grade asphalt. The result of the bitumen quality test met the standard specification of selected bitumen of 60/70 penetration grade according to the ERA pavement design manual standard specification. A bituminous binder with a penetration of 60/70 was use in the preparation of the mixtures, as it is widely used and suitable for areas with a hot climate such as Ethiopia.

The annual air temperature is greater than or equal to 24°C, and the asphalt grade is 60/70 penetration, according to Manual Series-2 (1997). The test results obtained are compared with those specified by the relevant codes to identify the suitability or otherwise of the tested materials for HMA pavement design. According to test results shown in Table 4.4, the 60/70 penetration grade bitumen was fallen within the allowable boundary that is specified in ERA Manual code, 2013.Therefore; the material can be used in the preparation of an HMA mix design. The laboratory test results of bitumen were done by AASHTO/ASTM method and for each test type results were compared with specifications of ERA, 2013.The test results indicated that all the test types were satisfied the standard requirements. The test results are shown in Table-4.4, which complies with the requirements of ERA Specification.

Table 4.4. Bitumen quality test result

	Test method	Test No.	Test Temp. (C)	Time of test (S)	Test load (g)	Reading date (0.1mm) 1st time	2nd time	3rd time	Average (0.1mm)
Penetration at 25˚c	AASHTO T49/ASTM D70	1	25	5	100	63.83	61.88	60.78	62.16
		2	25	5	100	68.32	67.54	62.86	66.24
		3	25	5	100	63.59	65.98	67.94	65.84
Average penetration									64.75
Ductility at 25˚c	Test method	Test No.	Test temp.	Speed cm/mm			Ductility (cm)		Average (cm)
	AASHTO T51/ASTM D113	1	25	5			89		86.33
		2	25	5			86		
		3	25	5			84		
Softening point at 25˚c	Test method	Test No.	Test temp. when starting to heating (C°)			Record of liquid temp. in breaker 4min	5min	6min	Softening pt. (C°)
	AASHTO T53/ASTM D36	1	24					6min	45.85
		2	24				5min		49.35
Average (C°)									47.6
Flash point ˚c	ASTM D 92								287.9
Bitumen Specific Gravity at 25˚c					Test Method ASTM D 70				1.03

4.7. Sieve Analysis and Gradation of mix design

The particle size distribution of aggregate is one of the most influential characteristics in determining how the HMA mixture performs as a pavement material. In the same way, the gradation of aggregates is one of the most important factors for the marshal mix design of the HMA mixture. To produce identical controlled gradation, aggregates were sieved and recombined in a laboratory to meet the selected gradation, which satisfied ASTM specifications for asphalt binder course gradation for mix designation. The coarse and fine aggregate particles were separated into different sieve sizes and proportioned to get the desired gradation for bituminous mixtures of ASTM 3515 used for 19 mm nominal maximum aggregate size (NMAS) or the nominal maximum aggregate size (NMAS) and the maximum aggregate size (MAS) were found to be 19.0 mm and 25.0 mm, respectively.

Table 4.5. Asphalt paving mixture specification ASTM D3515

		Mix Designation and Nominal Maximum Size of Aggregate				
Sieve Size		1 1/2in (37.5mm)	1in (25.0mm)	¾ in (19.00mm)	½in (12.5mm)	3/8 in (9.5mm)
2”	50mm	100	…..	…..	…..	…..
1 ½”	37.5mm	90 to 100	100	…..	…..	…..
1”	25.00mm	…..	90 to 100	100	…..	…..
¾”	19.0mm	56 to 80	…..	90 to 100	100	…..
½”	12.5mm	…..	56 to 80	…..	90 to 100	100
3/8”	9.5mm	…..	…..	56 to 80	…..	90 to 100
No. 4	4.75mm	23 to 53	29 to 59	35 to 65	44 to 74	55 to 85
No. 8	2.36mm	15 to 41	19 to 45	23 to 49	28 to 58	32 to 67
No. 16	1.18mm	…..	…..	…..	…..	……
No. 30	0.6mm	….	…..	…..	…..	…..
No. 50	0.3mm	4 to 16	5 to 7	5 to 19	5 to 21	7 to 23
No. 100	0.15mm	…..	…..	…..	…..	…..
No. 200	0.075mm	0 to 5	1to 7	2 to 8	2 to 10	2 to 10
Bitumen, Weight % of Total Mixture		3to8	3to9	4 to 10	4 to 10	5 to 12

Source: Asphalt institution of Hot Mix Asphalt Pavement Manual, series No.22, 2nd edition.

4.8. Blending Proportion of Aggregate

Aggregate grain size distribution, or gradation, is one property of aggregates that influences the quality of hot mix asphalt. Therefore, it is needed to determine the aggregate blending proportion by using the weight of the contents of each sieve following the sieve analysis and calculating the percentage passing through each sieve by a mathematical trial method that suggests different trial proportions for aggregate materials from the whole gradation. The aggregate materials, coarse aggregate (13-25 mm), intermediate aggregate (6-13 mm and 3-6 mm), fine aggregate (0-3 mm), and filler (kept on pan or passed 0.075 sieve size), were combined in order to determine the proper gradation within the allowable limits according to ASTM specifications using the mathematical trial method. If the calculated gradation is within the permitted limits, no further adjustments need to be made; if not, the proportions must be changed, and the calculations repeated. Therefore, the mix type and blending proportions of the different aggregate sizes to produce the desired combined gradation for different filler content of the asphalt binder course can be shown in the following Table.

Table 4.6. Blending Proportion of Aggregate

Mix Type						
Filler content (%)	Coarse Aggregate (CA)	Intermediate Aggregate (IA1)	Intermediate Aggregate (IA2)	Fine Aggregate (FA)	Filler	Combined 100%
	13-25mm	6-13mm	3-6mm	0-3mm	CSD	
4.5	25.0%	31.6%	15.9%	26.62%	0.88%	100%
5.5	25.0%	31.6%	15.9%	26.00%	1.5%	100%
6.5	25.0%	31.6%	15.9%	25.46%	2.04%	100%

Table 4.6 shows the blending proportions of the three fillers for the Marshall Mixture preparation. Figure 4.1 through 4.3 shows aggregate gradation curves without blended bagasse ash and steel slag dust with 19 mm maximum aggregate nominal size for three different percentages of fillers (4.5%, 5.5% and 6.5%) by weight of total mix added to the mix of the prepared aggregate gradation. All the three aggregate gradation curves drawn in Figure 4.1 through 4.3 were prepared based on the standard specification of ASTM D3515 limits and the color that used to indicate the upper limit, lower limit, the proposed gradation, and middle value for the three Varying percentage of crushed stone dust fillers (4.5%, 5.5% and 6.5%), are green, blue, pink, and broken black respectively.

The proposed gradation is between the upper and lower limits of ASTM specification as shown in the figure above. Therefore, the proposed gradation meets the standard specification requirements. Corresponding to the three levels of traditional mineral filler levels or the three types of grading based on three different percentages of fillers (4.5%, 5.5% and 6.5% by weight of the total mixture), the combined grading of the aggregates and the specification criteria for asphalt binder course are summarized in the following Table 4.7.

Table 4.7. Final proportion of each aggregate material in asphalt binder course

Sieve size, mm	Aggregate Gradation for different filler content			ASTM D3515 Specification
	4.5%	5.5%	6.5%	
25	100	100	100	100
19	93.21	93.67	94.25	90-100
12.5	79.44	81.67	78.83	71-88
9.5	69.58	72.08	67.25	65-80
4.75	49.67	53.92	48.50	35-65
2.36	35.83	40.33	35.50	23-49
1.18	26.00	27.67	25.42	15-37
0.60	18.83	20.50	18.42	10-28
0.30	12.33	14.33	11.92	5-19
0.15	9.50	10.33	9.33	4-13
0.075	4.5	5.5	6.5	2-8

Table 4.7 shows the final proportion of each aggregate material in asphalt binder course and the proposed aggregate gradation curves are shown in fig 4.1 to 4.3 based on ASTM specification for asphalt binder coarse specification. The final proportion of each aggregate material in the asphalt binder and the proposed aggregate gradation curve are found to satisfy the ASTM specification for asphalt binder course gradation. Figures 4.1 to 4.3 show the three types of gradations based on three varying percentages of filler (4.5.0%, 5.5%, and 6.5%) with a 25mm maximum aggregate size were designed from percent passing.

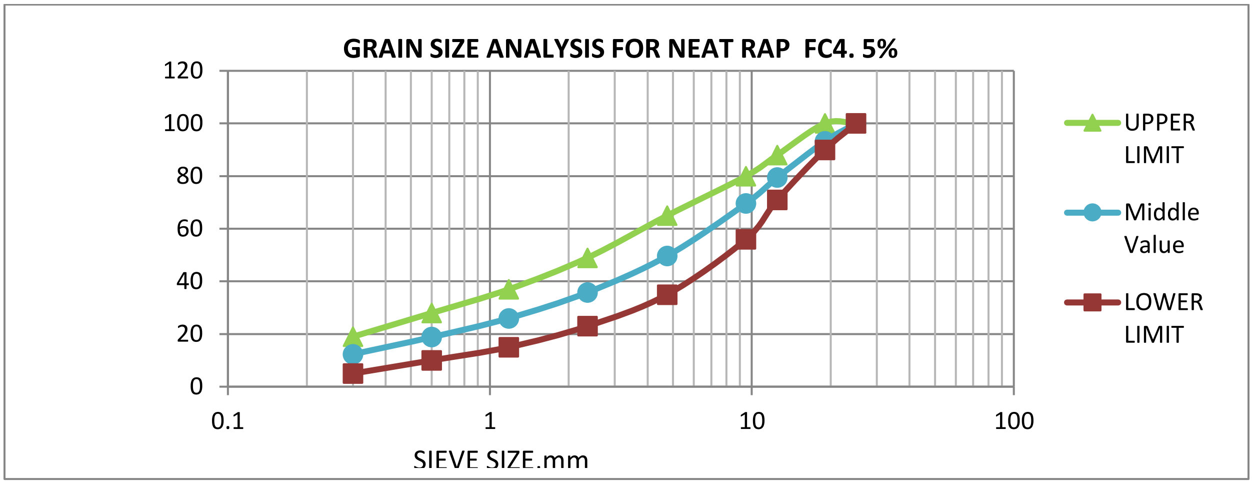


Figure 4.1. Gradation curve for 4. 5% CSD

Figure 4.1 shows the gradation curve created based on the standard specification of ASTM D3515 limits. The aggregates used in this grade were selected from each size according to their limiting ranges, and the crushed stone filler was 4.5% (based on the weight of the aggregates). According to the above, the overall gradation chart shows three different color lines. The green line shows the upper limit of the ASTM specification; the red line shows the lower limit of the ASTM specification; and the blue line shows middle value manufactured grade of 4.5 percent crushed stone dust filler. The grade prepared is between the upper and lower limits of the ASTM specification as shown in Fig.4.1. Therefore, the gradation produced meets the specification requirement.

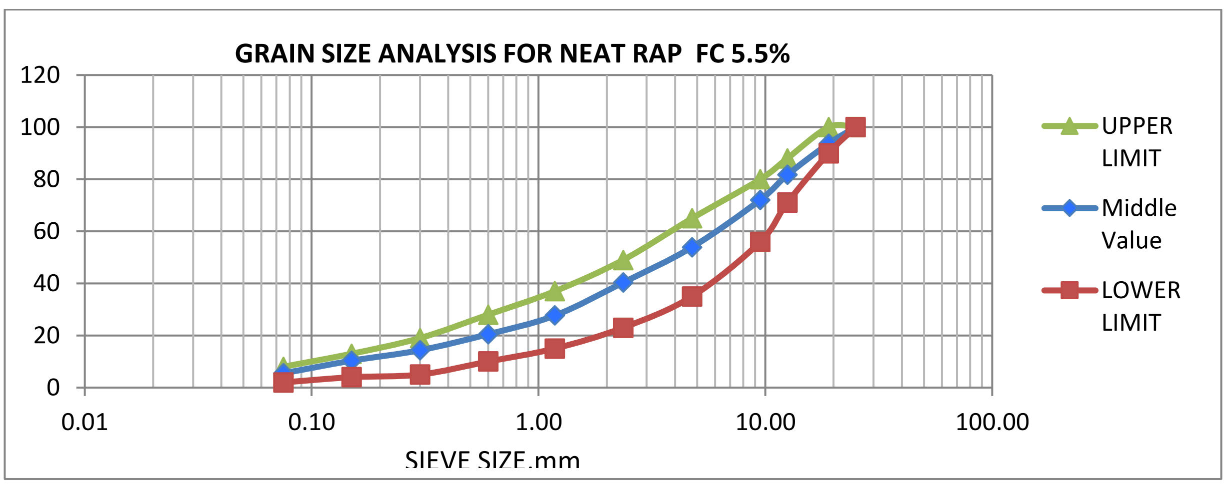


Figure 4.2. Gradation curve for 5.5% CSD

Fig.4.2 shows the gradation curve created based on the standard specification of ASTM D3515 limits. The aggregates used in this grade were selected from each size according to their limiting ranges and the crushed stone filler was 5.5% (based on the weight of the aggregates). According to the above, the overall gradation chart shows three different color lines. The green line represents the upper limit of the ASTM specification while the red line represents the lower limit. The blue line shows the middle value, the manufactured grade of 5.5% crushed stone dust filler. The grade prepared is between the upper and lower limits of the ASTM specification as shown in Fig.4.2. Therefore, the gradation produced meets the specification requirement.

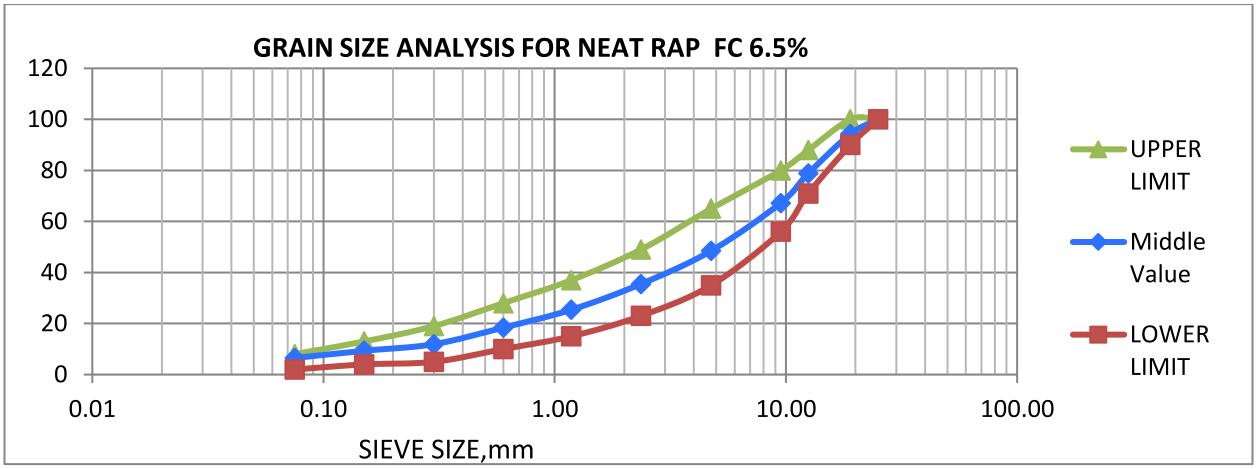


Figure 4.3. Gradation curve for 6.5% CSD

Fig. 4.3 shows the gradation curve created based on the standard specification of ASTM D3515 limits. The aggregates used in this grade were selected from each size according to their limiting ranges and the crushed stone filler was 6.5% (based on the weight of the aggregates). According to the above, the overall gradation chart shows three different color lines. The green line shows the upper limit of the ASTM specification, the red line shows the lower limit of the ASTM specification, and the blue line shows the grade of 6.5% crushed stone dust filler prepared with middle value. The grade prepared is between the upper and lower limits of the ASTMD3515 specification as shown in Figure 4.3. Therefore, the gradation produced meets the specification requirement.

4.9 Marshall Test Results and Discussion

The Marshall Properties of the laboratory work results of asphalt mix design have been obtained and analyzed in order to achieve the study objectives of the research, which includes studying the effect of crushed stone dust with other different filler contents on the Marshall Properties of asphalt mix.

The test results of Marshall Properties of specimens prepared with varying amounts of conventional filler at 4.5%, 5.5% and 6.5% of crushed stone dust as filler by weight of aggregate with varying bitumen contents In this manner, a total of 45 samples, each of which weighed 1200 grams, were prepared using five different bitumen contents (4.0, 4.5, 5.0, 5.5, and 6.0% by weight of total mix) in order to determine the optimum filler and optimum bitumen content from those prepared specimens and the results of material tests. The table below shows the properties of the mixture at various levels of asphalt content for mixing with different conventional filler content (CSD). Additional detailed information has been presented in Appendix E. According to the ERA Pavement Design Manual, 2002, the Asphalt Institute uses five-mix design criteria recommended for the Marshall Mix design method.

Maximum Marshall Stability; Range of Acceptable Marshall Flow; Range of Acceptable Air Voids; Range of Percentage of Voids Filled with Asphalt (VFA); and Minimum amount of VMA are the criteria. In this regard, Marshall Mix Design criteria for Heavy Traffic have standard volumetric property limits from those included. The minimum stability must be 8 KN at 60^0C, the flow value must be ranged between 2 to 4 mm, the percentage of air voids must be ranged between 3 to 5%, the VFA must be ranged between 65 to 75%, and the minimum VMA related to 4% air voids and the nominal maximum particle size of 19 mm must be 13%.

Table 4.8. Marshall Test result for Mixes with 4.5% CSD filler and different bitumen content and it adjusted by using adjusting factors based on specimen thickness.

Asphalt content by wt. total mix, %	Sample No.	ρA (g/cm3)	Air Voids (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4	1	2.209	11.0	18.3	39.7	8.3	2.30
	2	2.192	11.7	18.9	38.1	6.7	2.08
	3	2.198	11.5	38.7	38.7	7.3	2.02
	Average	**2.200**	**11.4**	**18.6**	**38.9**	**7.4**	**2.13**
4.5	1	2.357	4.3	13.3	67.5	8.5	2.70
	2	2.322	5.7	14.5	60.8	8.3	3.20
	3	2.353	4.5	13.4	66.7	8.3	3.00
	Average	**2.344**	**4.8**	**13.7**	**65.0**	**8.4**	**2.97**
5	1	2.358	3.5	13.7	74.4	9.0	3.85
	2	2.344	4.1	14.2	71.4	9.5	3.70
	3	2.348	3.9	14.0	72.2	9.4	3.50
	Average	**2.350**	**3.8**	**14.0**	**72.6**	**9.3**	**3.68**
5.5	1	2.371	2.0	13.6	85.4	8.5	3.82
	2	2.353	2.8	14.3	80.7	8.7	4.02
	3	2.348	3.0	14.5	79.5	8.4	3.78
	Average	**2.357**	**2.6**	**14.2**	**81.9**	**8.5**	**3.87**
6	1	2.364	2.1	14.4	85.4	7.1	4.01
	2	2.338	3.2	15.3	79.3	7.8	4.13
	3	2.342	3.0	15.2	80.2	7.7	4.20
	Average	**2.348**	**2.8**	**14.9**	**81.6**	**7.5**	**4.11**

Table 4.8 indicates the Marshall Property laboratory test results of a mix gradation that was prepared with 4.5% conventional filler (CSD) (by weight of aggregates) and determines relationships between the corresponding values of marshal properties such as stability, flow value, air void, voids in mineral aggregate, voids filled with asphalt and unit weight by using five different bitumen contents (by weight of total mix).In addition, the figure 4.4 shows that the relationships between the different marshals' properties have different bitumen content.

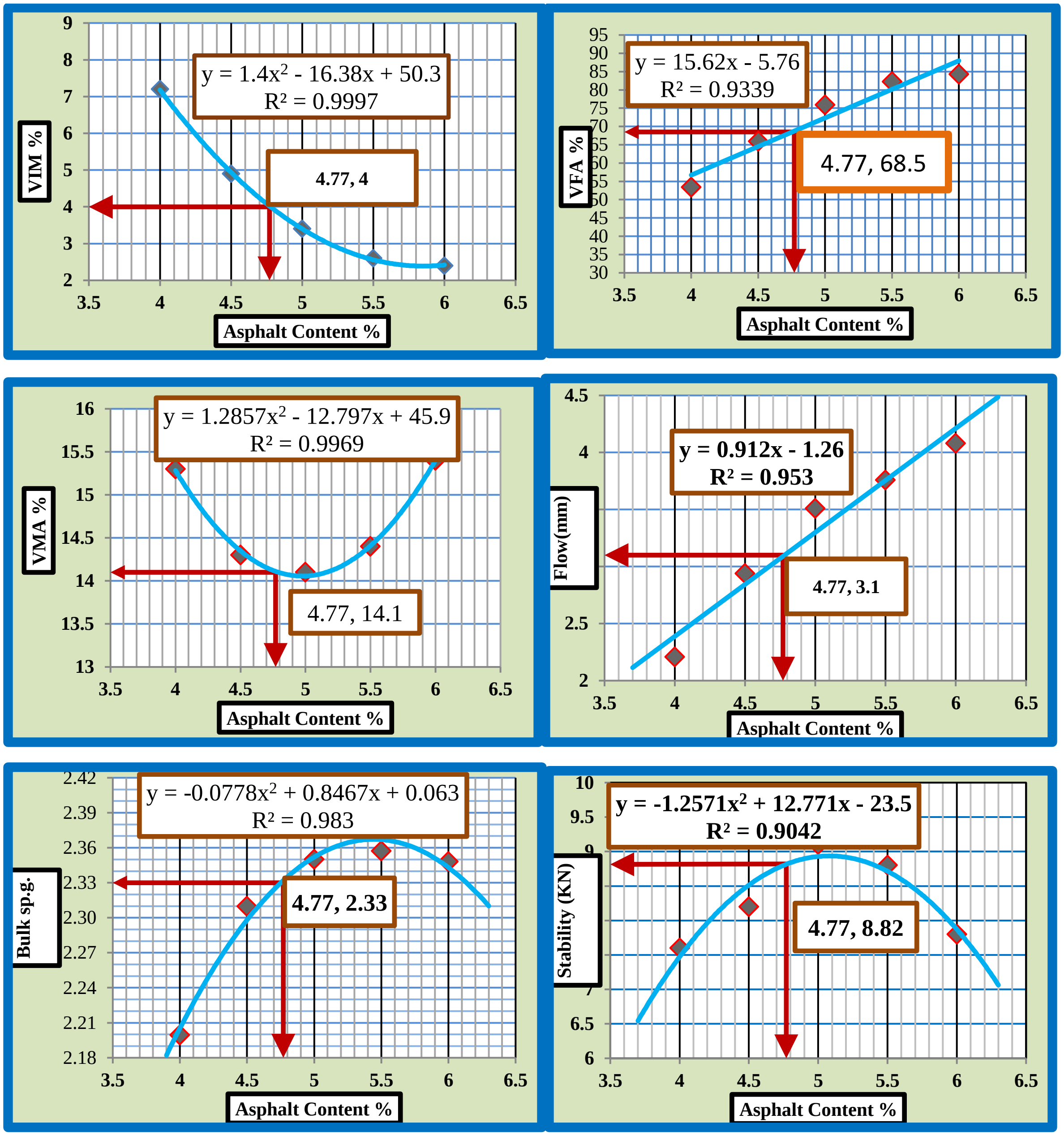


Figure 4.4. OBC and the properties of mixtures with 4.5 % CSD filler

A Fig.4.4 showed that the relationships between binder content and the marshal properties of mixtures with 4.5% conventional filler (CSD) were maintained. According to Fig.4.4 the unit weight for total mix and the value of stability increase as the value of asphalt content increases up to a maximum and then gradually decrease as shown in the figure above. The value of voids filled with asphalt (VFA) and flow increases with an increase in asphalt content, whereas the percent of voids in mineral aggregates (VMA) decreases to the minimum value and then increases with an increase in asphalt content. The NAPA mix design method requires the mix to have 4% air voids at the optimum binder content (OBC). By using this method, as shown in the figure above, the optimum binder content (OBC) is equal to 4.77% by weight of the total mix.

Table 4.9. Marshall Test result for Mixes with 5.5% CSD filler and different bitumen content and it adjusted by using adjusting factors based on specimen thickness.

Asphalt content by wt. total mix, %	Sample No.	ρA (g/cm3)	Air Voids (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4	1	2.129	7.6	17.6	56.8	7.4	2.21
	2	2.138	7.2	17.2	58.1	7.2	2.19
	3	2.138	7.2	58.2	58.2	8.2	2.88
	Average	2.135	7.3	17.3	57.7	7.6	2.43
4.5	1	2.165	6.5	16.6	61.0	8.9	2.90
	2	2.200	5.0	15.3	67.4	8.5	2.86
	3	2.175	6.1	16.2	62.7	8.5	2.97
	Average	2.180	5.8	16.1	63.7	8.6	2.91
5	1	2.255	3.8	13.6	72.4	9.9	3.75
	2	2.230	4.8	14.6	66.9	10.0	3.84
	3	2.257	3.7	13.5	73.0	9.6	3.69
	Average	2.247	4.1	13.9	70.8	9.8	3.76
5.5	1	2.282	3.0	13.0	77.4	9.3	3.81
	2	2.282	2.9	13.0	77.5	9.6	3.92
	3	2.261	3.9	13.9	72.2	9.0	3.85
	Average	2.275	3.3	13.3	75.7	9.3	3.86
6	1	2.315	2.1	12.3	82.6	8.3	3.98
	2	2.290	3.2	13.2	76.0	8.7	3.97
	3	2.319	2.0	12.1	83.9	7.4	3.92
	Average	2.308	2.4	12.5	80.8	8.2	3.96

Table 4.11 indicates the Marshall Property of laboratory test results for a gradation that was prepared by using 5.5% crushed stone dust filler (by weight of aggregates) and the corresponding values of marshal properties such as stability, flow value, air void, voids in mineral aggregate, voids filled with asphalt, and unit weight at different bitumen content. Also, Fig.4.5 shows the relationships between the different marshal properties and different bitumen content.

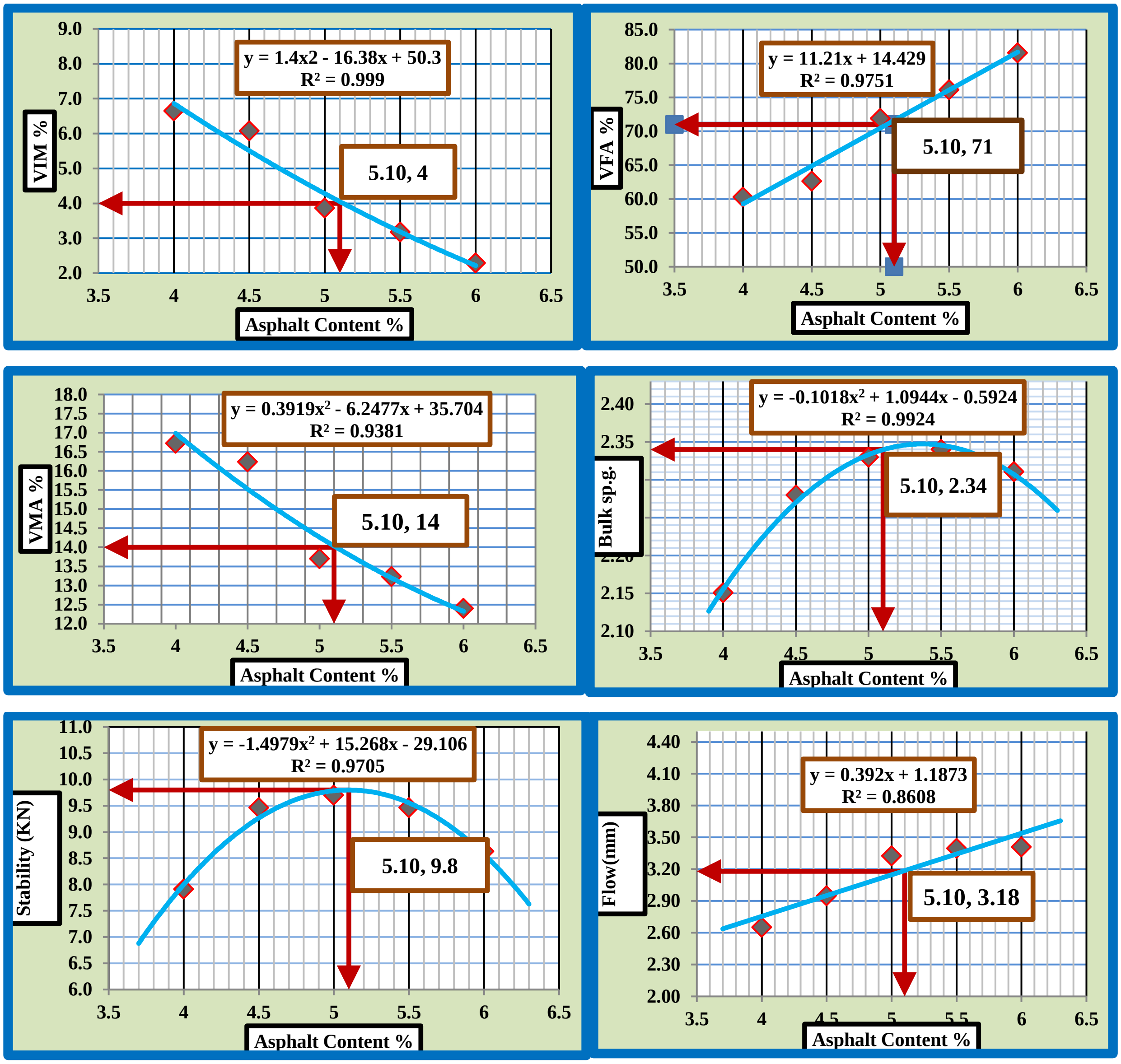


Figure 4.5. OBC and the properties of mixtures with 5.5 % CSD filler

The relationships between binder content and the properties of mixtures containing 5.5% conventional filler (CSD) are depicted in Fig.4.5. From the above relation, the optimum binder content of the mix is determined at 5.10%, based on the median air void content (4%) of the specification. The results showed a 5.5% crushed stone dust filler content that was similar to the previous curve of 4.5% crushed stone dust filler. The detailed properties of the mixture at optimum bitumen content are shown above in Table 4.9.

Table 4.10. Marshall Test result for Mixes with 6.5 % CSD filler and different bitumen content and it adjusted by using adjusting factors based on specimen thickness.

Asphalt content by wt. total mix, %	**Sample No.**	**ρA (g/cm3)**	**Air Voids (%)**	**VMA (%)**	**VFA (%)**	**Stability (KN)**	**Flow (mm)**
4	1	2.284	7.9	16.1	51.1	9.1	2.08
	2	2.299	7.3	15.5	53.3	8.4	2.02
	3	2.303	7.1	53.9	53.9	8.1	2.01
	Average	2.295	7.4	15.7	52.8	8.5	2.04
4.5	1	2.323	5.8	15.1	61.9	8.9	2.35
	2	2.323	5.8	15.1	61.9	8.5	2.29
	3	2.321	5.9	15.2	61.5	8.9	2.32
	Average	2.322	5.8	15.1	61.8	8.8	2.32
5	1	2.344	4.4	14.8	70.3	9.7	2.62
	2	2.330	5.0	15.3	67.6	9.4	2.67
	3	2.342	4.5	14.9	69.8	8.9	2.58
	Average	2.339	4.6	15.0	69.2	9.3	2.62
5.5	1	2.352	3.2	15.0	78.3	8.8	2.74
	2	2.358	3.0	14.8	79.6	9.2	2.61
	3	2.354	3.2	14.9	78.8	9.0	2.68
	Average	2.355	3.1	14.9	78.9	9.0	2.68
6	1	2.357	2.7	15.2	82.2	8.5	2.48
	2	2.353	2.9	15.4	81.1	8.3	2.52
	3	2.352	2.9	15.4	81.0	8.1	2.59
	Average	2.354	2.8	15.3	81.4	8.3	2.53

Description of symbolical words these are: -Where, ρA = Bulk Density, VIM% =Air voids, VMA% =Voids Mineral Aggregates, VFA% =Percent Voids Filled with Bitumen.

Table 4.10 shows the Marshall Property laboratory test results of a mix that was prepared by using 6.5% crushed stone dust filler with five different bitumen contents (by weight of total mix) and the corresponding values of each marshal property such as stability, flow value, air void, voids in mineral aggregate, voids filled with asphalt and unit weight. Besides, the relationships between the different marshal's properties with different bitumen content can be indicated in Fig. 4.6 below.

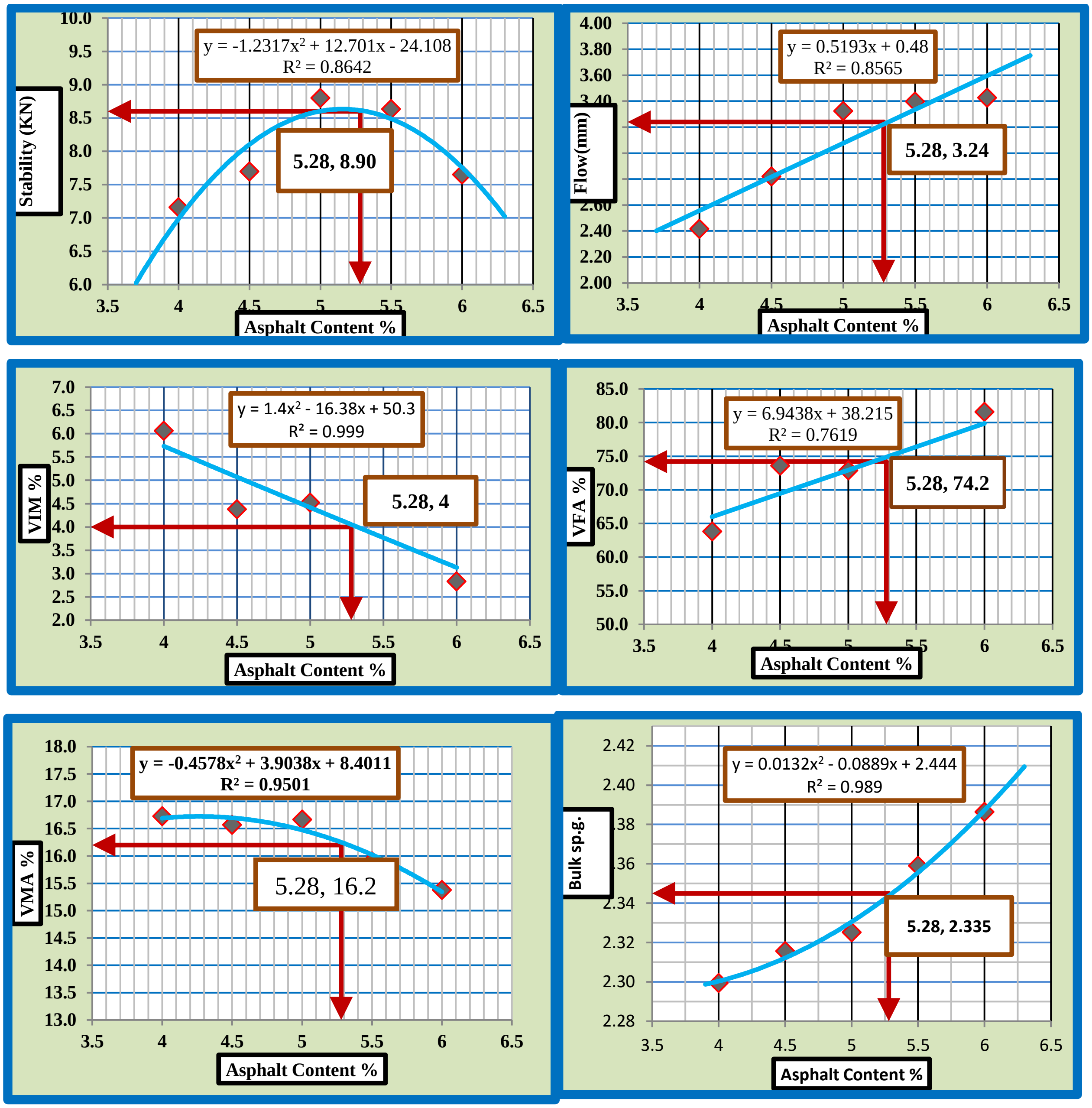


Figure 4.6. OBC and the properties of mixtures with 6.5 % CSD filler.

Fig. 4.6 shows that the relationships between binder content and the properties of mixtures with 6.5% CSD are different, and the curves of the relationships between the binder and the properties of the mixture are like the previous conventional filler content. Also, the optimum bitumen content of the mix was determined at 5.28%, based on the median air void content (4%) of the specification. The detailed information on the properties of the mixture at the optimum bitumen content has been shown in Fig.4.6 above and listed in Table 4.12.

4.10 Optimum Bitumen Content (OBC)

According to this study, the National Asphalt Pavement Association (NAPA) determined the optimum asphalt content. Depending on the method previously stated, (NAPA) stated that the optimum asphalt content determined by plotting curves of the five percentages of bitumen content (4, 4.5, 5, 5.5, and 6%) corresponds to the median air void (4%). In this sense, the aggregates are examined to determine the best percentage of bitumen for the aggregates, and the asphalt content from the bitumen content corresponds to the median air void (4%) of the specification by the plotting curve.

After finding this asphalt content, the values of Marshall Stability, flow, VMA, VFA, and bulk specific gravity are determined from those plotting curves. Each value is compared to the specified value for that property, but if all values are within the specified range, the asphalt content at 4% air-void is the optimum bitumen content (Asphalt Institute, 2003). Based on the above explanation, the determined procedures of the value of the optimum bitumen content at 4% air void was 4.77%, 5.10%, and 5.28% (by weight of total mix) for 4.5%, 5.5%, and 6.50% conventional filler (CSD) respectively. The properties of mixtures at their optimum bitumen content for mixes with 4.5%, 5.5%, and 6.5% of crushed stone dust filler can be summarized and illustrated in the following Tables, respectively.

Table 4.11. Summary of Marshal Test results at 4.5% CSD filler and 4.77% OBC

Mix property		ERA Spec. Limit		Asphalt this test value shows Inst.spec. limit		Remark
		Lower	Upper	Lower	Upper	
Asphalt content %	4.77					Satisfies
Air void %	4	3	5	3	5	-
VFA %	68.5	65	75	65	75	-
VMA %	14.1	Min.-13		Min.-13		-
Stability (KN)	8.82	Min.8		Min.8		-
Flow (mm)	3.1	2	3.5	2	4.0	-
Bulk Specific Gravity (gm/cc)	2.33	-	-	-	-	-

Table 4.11 describes the asphalt content corresponding to the standard specification criteria and the marshal results of mix located with their values obtained from the plot curve. Based on this, the marshal results for mix properties such as stability, flow, VMA, VFA, and specific gravity at 4.5% crushed stone dust filler and 4.77% OBC fully fill or satisfy ERA, Pavement Design Manual,

2013, and Asphalt Institute, 2003 Specification. Therefore, it shows that the mix at 4.5% crushed stone dust filler satisfied the criteria with 4.77% of OBC.

Table 4.12. Summary of Marshal Test results at 5.5% CSD filler and 5.10 % OBC.

Mix property		ERA Spec. Limit		Asphalt Inst.spec. limit		Remark
		Lower	Upper	Lower	Upper	
Asphalt content %	5.10					Satisfies
Air void %	4	3	5	3	5	-
VFA %	71.0	65	75	65	75	-
VMA %	14.0	Min.-13		Min.-13		-
Stability (KN)	9.80	Min.8		Min.8		-
Flow (mm)	3.18	2	3.5	2	4.0	-
Bulk Specific Gravity (gm/cc)	2.34	-	-	-	-	

Table 4.12 shows the marshal values of mix and bitumen content corresponding to the standard specification criteria and locates the values of mix properties obtained from the plot curve. Based on this, the marshal results for mix properties such as stability, flow, VMA, VFA, and bulk specific gravity at 5.5% crushed stone dust filler and 5.10% OBC full fill or satisfy ERA, Pavement Design Manual, 2013, and Asphalt Institute, 2003 Specification. It is thus shown that the mixture with 5.5% crushed stone filler meets the criteria with 5.10% OBC.

Table 4.13. Summary of Marshal Test results at 6.5 % CSD filler and 5.28 % OBC

Mix property		ERA Spec. Limit		Asphalt Inst.spec. limit		Remark
		Lower	Upper	Lower	Upper	
Asphalt content %	5.28					Satisfied
Air void %	4	3	5	3	5	-
VFA %	74.2	65	75	65	75	-
VMA %	16.2	Min.-13		Min.-13		-
Stability (KN)	8.90	Min.8		Min.8		-
Flow (mm)	3.24	2	3.5	2	4.0	-
Bulk Specific Gravity (gm/cc)	2.335	-	-	-	-	

Table 4.13 shows that the asphalt content corresponds to the standard specification criteria and locates the marshal results of mix properties with their values obtained from the plot curve. Based on this, the marshal results for mix properties such as stability, flow, VMA, VFA, and specific gravity at 6.5% crushed stone dust filler and 5.28% OBC meet or exceed ERA, Pavement Design Manual, 2002, and Asphalt Institute, 2003 specifications, as do the previously marshal results at 4.5% crushed stone dust filler with 4.77% OBC and 5.5% crushed stone dust filler with 5.10%

OBC. In addition, the values of marshal mix properties were described in the table and shows the maximum values from the used percentage of conventional filler (CSD) were (4.5%, 5.5%, 6.5%), and a total of 45 specimens were prepared at each percentage of conventional filler by using five different bitumen content.

4.11 Comparison of OBC at Percentage mix proportion of Crushed Stone Dust filler (CSD)

The comparison of optimum bitumen content (OBC) at Percentage of mix proportion by weight of optimum crushed stone dust filler of 4.5%, 5.5 %, 6.5% and compare the three results of marshal and volumetric properties of asphalt mix respectively. These marshal and volumetric properties of asphalt mix results are summarized and select the OBC from the three Percentage of Conventional filler although those test results could be showed in the following table. Therefore, the marshal stability result is greater than the minimum requirement value of 9.8 KN. Summary of marshal properties at different percentage of conventional filler (CSD).

Table 4.14. Comparison summary of Marshal Test results at 4.5,5.5, and 6.5 % CSD filler and 4.77,5.10, 5.28 % OBC.

Mix property	% Of CSD Filler content			Specification			
	4.5	5.5	6.5	ERA spec. limit		Asphalt Inst.limit	
Asphalt content %	4.77	5.10	5.28	4	10	4	10
Air void %	4	4	4	3	5	3	5
VFA %	68.5	71.0	74.2	65	75	65	75
VMA %	14.1	14.0	16.2	Min.13		Min.13	
Stability (KN)	8.82	9.80	8.90	Min.8		Min.8	
Flow (mm)	3.1	3.18	3.24	2	3.5	2	4.0
BSG (gm/cc)	2.33	2.34	2.335				

Based on the value of crushed stone dust filler content (4.5%, 5.5%, and 6.5%), the optimum bitumen content was 4.77%, 5.10%, and 5.28%, respectively. For the three-filler contents, the Marshall Stability and Flow are 8.82KN, 9.80KN, and 8.90KN, and 3.1mm, 3.18mm, and 3.24mm, respectively. In addition, the volumetric properties of the three-filler contents satisfied the specification ranges of the ERA pavement design manual. According to the results described in Table 14 above, the bitumen content of all the three percentages of crushed stone dust fillers was within the range of the specification, and comparing all the mixtures, it shows that at 5.5% crushed stone dust filler with 5.10% bitumen content (by weight of total mix), it shows higher stability than all other mixtures. Therefore, the result of 5.5% crushed stone dust filler and 5.10% bitumen content is considered the optimum bitumen content and optimal filler content based on Maximum Marshall Stability. From this finalization, determined the optimum bitumen content and optimum filler content of the mix design, which was then used for partial replacement of filler material with bagasse ash and steel slag dust in the mixtures of material According to this, the optimum contents of OBC and OFC were used for the replacement of the mix in this study. In addition, the chart below also shows the comparison of Marshal Properties of three different percentages of conventional filler (CSD).

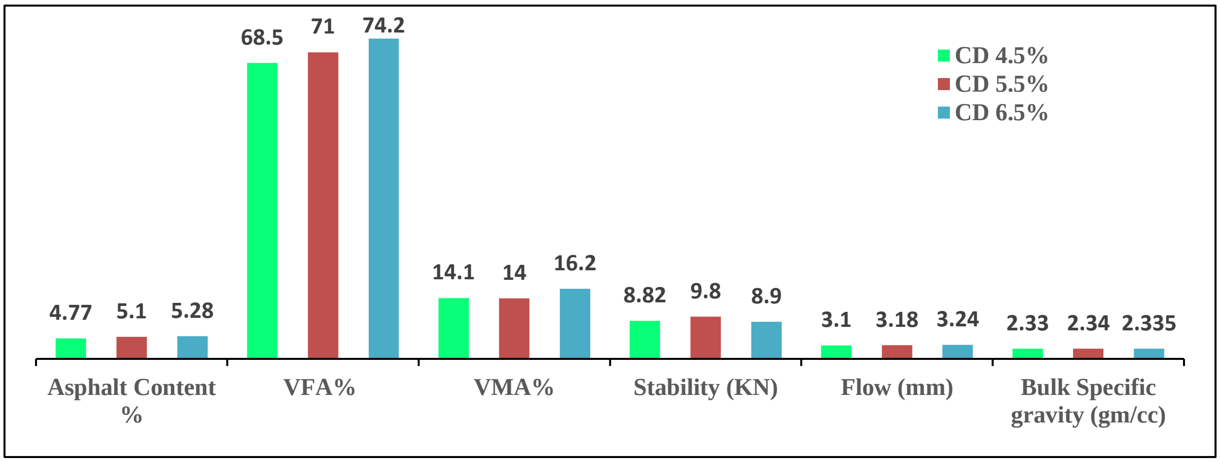


Figure 4.7. Comparison of marshal properties of three different percentages of conventional filler (CSD)

Fig. 4.7 shows the three percentages of crushed stone dust filler. As a result, all properties of the mix are within the range of specifications. It was compared and determined the optimum replacement ratio of conventional filler for determining the effect of non-conventional filler (blended bagasse ash and steel slag dust) and the optimum replacement percentage of bagasse ash and steel slag dust. In this study, the properties with higher stability from alternative filler content were selected. In this manner, the mix with higher stability was at 5.5% filler content. As a result, 5.5% conventional filler content (CSD) and the corresponding 5.10% optimum bitumen content were chosen as the optimum filler content and optimum bitumen content was used to replace conventional filler (CSD) with non-conventional filler (bagasse ash and steel slag dust). Furthermore, this result was applied to the following laboratory work: determining the optimal replacement rate and evaluating the effect of non-conventional fillers in a mixture.

4.12 Marshall Properties of Partial Replacement of mineral filler materials with blended bagasse ash and steel slag dust.

Based on the selected optimum bitumen content (OBC) and optimum filler content (CSD), they were partially replaced with different percentages of blended bagasse ash and steel slag dust. The Marshall properties (stability, flow, and volumetric properties) of a typical binder for coarse asphalt concrete were evaluated. The percentage interval of replacement rate was 10% (by weight of OFC) up to the Marshall properties' decline to fulfill the standards of the ERA pavement design manual and compared with control mix as well as with each other. According to the replacement rate of conventional filler with different percentages of non-conventional filler, which had five different substituted rates, these are 0 %(control), 10, 20, and 30%, but the substitution ratios include four different types of non-conventional and three conventional fillers for each ratio.

In this sense, for mixes prepared using the replacement rates of different filler contents and the proportion of the mixtures had different percentage ratio of materials, at 5.5% conventional filler (CSD) added to 10% non-conventional filler and divided into five different proportions (10% non-conventional filler could be separated into 0% BA and 10% SSD, 2.5% BA and 7.5% SSD, 5% BA and 5% SSD, 10% BA and 0% SSD, and 5.5% (4.5%, 5.5, and 6.5%) CSD and used the reverse of these materials ratio).

In addition, the mix design proportion also comprises coarse aggregates (14-20mm), intermediate aggregates (6-14mm) and (3-6mm), fine aggregates (0-3mm) and mineral fillers (0.075mm size) were prepared by Marshall Specimens of mixtures, and each specimen had a total weight of 1200 gm. The rest of this material has been prepared in the same way as previously used procedures but with different rates of non-conventional and conventional fillers for prepared Marshall Specimens. In addition, compare the marshal and volumetric properties of asphalt mix at different rates of blended BA and SSD with crushed stone dust filler until the replacement mix fulfills local and international specifications. The following table presents the relationship between conventional and non-conventional fillers plus shows the partial replacement of crushed stone dust filler (CSD) by blended BA and SSD filler with different percentage proportions. The table showed how to divide non-conventional fillers for combining with conventional fillers.

Table 4.15. Showed that partially replacement of CSD by blended BA and SSD at each different proportion

Sample Name	Coarse aggregate.	Intermediate aggregate.		Fine aggr.	% Of CSD (By Wt. Of aggregates)	% Of BA & SSD (by Wt. OFC).	Filler (CSD+BA and SSD)
	(13.5-25) mm	(6-13.5) mm	(3-6) mm	(0-3) mm			
Control Sample	7.61%	23.74%	18.65%	44.50%	5.5 (100%)	0 (0%)	5.50(100%)
BBASSD1	7.61%	23.74%	18.65%	44.50%	4.95 (90%)	0.55(10%)	5.50(100%)
BBASSD2	7.61%	23.74%	18.65%	44.50%	4.4 (80%)	1.1 (20%)	5.50(100%)
BBASSD3	7.61%	23.74%	18.65%	44.50%	3.85 (70%)	1.65(30%)	5.50(100%)

Table 4.15 describes that the mix design proportion comprises coarse aggregates (14-20mm) of 7.61%, intermediate aggregates (6-14mm) of 23.74%, and (3-6mm) of 18.65%, fine aggregates (0-3mm) of 44.50%, and mineral fillers (0.075mm size) of 5.5%. Totally, of 45 Marshall Specimens of mixtures were prepared. Each specimen weighs 1200 gm. four different percentage rates of replacements were prepared but three of them (means 10%,20%, and 30%). Each has five different percentage (10%bagasse ash and 0%steel slag dust, 0%bagasse ash and 10%steel slag dust, 5%bagasse ash and 5%steel slag dust, 7.5%bagasse ash and 2.5%steel slag dust, and 2.5%bagasse ash and 7.5%steel slag dust). Similarly for 20% samples were (20%bagasse ash and 0%steel slag dust, 0%bagasse ash and 20%steel slag dust, 10%bagasse ash and 10%steel slag dust, 15%bagasse ash and 5%steel slag dust, and 5%bagasse ash and 15%steel slag dust) prepared.

Finally for 30% of (30% bagasse ash and 0% steel slag dust,0% bagasse ash and 30% steel slag dust, 15% bagasse ash and 15% steel slag dust, 22.5% bagasse ash and 7.5% steel slag dust, and 7.5% bagasse ash and 22.5% steel slag dust) were prepared. Which were: 0%, 10%, 20%, and 30% (by weight of OFC) and 5.10% bitumen content (by weight of total mix, i.e., one specimen). The Marshall test was use to evaluate the specimens. The Marshall test was use to evaluate the specimens, and more details are presented in Appendix E.

Table 4.16. Marshall Properties of asphalt mixes of 10% of blended bagasse ash & steel slag dust with optimum filler content 5.5% at constant bitumen content of 5.10%.

%Of replacements rates		BA & SSD Content par. repl. by % of at 5.5 optimum filler contents	Sample No.	ρA g/cm 3	VIM %	VMA %	VFA %	Stability (KN)	Flow (mm)
0% (Control mix) CSD		5.50%	1	2.352	4.26	13.61	73.04	9.41	3.29
			2	2.350	3.70	13.72	72.06	8.74	3.28
			3	2.349	4.27	13.55	72.12	9.36	3.31
			Average	**2.350**	**4.08**	**13.63**	**72.41**	**9.17**	**3.29**
10%	0%BA &10% SSD	0%BA+0.55SSD +4.95CSD	1	2.346	4.0	13.2	69.3	9.2	2.69
			2	2.345	4.3	13.4	68.2	9.2	2.67
			3	2.344	4.3	14.4	68.0	9.2	2.69
			Average	**2.345**	**4.2**	**13.3**	**68.5**	**9.2**	**2.68**
	10%BA &0%SSD	0.55BA+0%SSD +4.95CSD	1	2.342	4.2	12.6	67.0	9.3	2.71
			2	2.340	4.1	12.6	67.4	8.4	2.69
			3	2.341	4.1	12.6	67.4	8.4	2.69
			Average	**2.341**	**4.1**	**12.6**	**67.3**	**8.7**	**2.70**
	5%BA& 5%SSD	0.275BA+0.275SSD +4.95CSD	1	2.343	4.1	13.9	70.2	9.7	2.72
			2	2.345	4.1	13.9	70.3	9.4	2.71
			3	2.342	4.5	14.2	68.4	9.4	2.73
			Average	**2.343**	**4.3**	**14.0**	**69.6**	**9.5**	**2.72**
	7.5%BA &2.5%SSD	0.53625BA+0.01375 SSD+4.95CSD	1	2.341	4.3	14.7	70.6	10.19	2.79
			2	2.343	4.4	14.7	70.1	10.09	2.80
			3	2.341	4.5	15.8	69.7	10.08	2.81
			Average	**2.342**	**4.4**	**14.7**	**70.2**	**10.12**	**2.80**
	2.5%BA &7.5%SSD	0.01375BA+0.53625 SSD+4.95CSD	1	2.345	4.5	15.4	71.1	10.32	2.82
			2	2.348	3.8	14.8	72.6	10.33	2.79
			3	2.346	4.3	15.3	73.0	10.34	2.83
			Average	**2.347**	**4.2**	**15.2**	**72.2**	**10.3**	**2.82**

Table-16 shows the laboratory test results of asphalt mixtures with different percentage replacement rates of blended bagasse ash and steel slag dust by optimum crushed stone dust filler with a constant bitumen content of 5.10%. The properties of asphalt mixtures with different percentages of replacement of 10% blended bagasse ash and steel slag dust were good in marshal stability, flow and volumetric properties. They were increased from lower replacement rates to higher. As a result, all properties of the mix were satisfied and within the range of specifications. It was compared and determined the optimum replacement ratio of non-conventional filler (blended bagasse ash and steel slag dust) and the optimum replacement percentage of bagasse ash and steel slag dust. The percentage replacement ratio of non-conventional fillers was shown in the table to increase by 2.5% from 0%–10% and inter rotated the combinations.

Table 4.17. Marshall Properties of asphalt mixes of 20% blended bagasse ash & steel slag dust with optimum filler content 5.5% at constant bitumen content of 5.10%.

% Of replacements rates		BA & SSD Content par.repl. by % of at 5.5 optimum filler contents	Sample No.	ρA g/cm3	VIM %	VMA %	VFA %	Stability (KN	Flow (mm)
0% (Control-mix) CSD		5.50%	1	2.352	4.26	13.61	73.04	9.9.41	3.29
			2	2.350	3.70	13.72	72.06	8.74	3.28
			3	2.349	4.27	13.55	72.12	9.36	3.31
			Average	**2.350**	**4.08**	**13.63**	**72.41**	**9.17**	**3.29**
20 %	0%BA & 20%SS	0%BA+1.1SSD +4.4CSD	1	2.345	4.3	15.4	68.4	10.3	3.06
			2	2.347	4.3	15.3	68.8	10.6	3.04
			3	2.348	3.8	13.5	71.2	10.9	3.06
			Average	**2.347**	**4.1**	**15.4**	**69.5**	**10.6**	**3.05**
	20%BA &0%SS D	1.1BA+0%SSD +4.4CSD	1	2.343	4.0	16.5	71.4	10.5	3.08
			2	2.346	4.3	15.8	70.0	10.7	3.06
			3	2.342	4.3	15.9	70.2	10.3	3.07
			Average	**2.344**	**4.2**	**16.0**	**70.5**	**10.5**	**3.07**
	10%BA &10%S SD	0.55BA+0.55SSD +4.45CSD	1	2.346	4.3	15.0	71.4	10.4	3.07
			2	2.347	4.0	14.7	72.9	11.3	3.05
			3	2.344	4.3	15.0	71.5	10.3	2.99
			Average	**2.346**	**4.2**	**14.9**	**72.0**	**10.7**	**3.04**
	15%BA &5%SS D	1.045 BA+0.055 SSD+4.4CSD	1	2.345	4.0	14.1	73.6	10.6	3.08
			2	2.342	4.0	13.4	73.9	10.6	3.05
			3	2.348	4.2	13.3	72.8	11.1	3.04
			Average	**2.345**	**4.1**	**14.3**	**73.4**	**10.8**	**3.06**
	5%BA& 15%SS D	0.055BA+1.045SSD +4.4CSD	1	2.350	4.3	13.70	71.6	10.9	3.08
			2	2.348	3.9	13.65	75.5	11.0	3.06
			3	2.349	3.9	13.63	75.4	11.2	3.09
			Average	**2.349**	**4.0**	**13.66**	**74.7**	**11.0**	**3.08**

Table 17 shows that the laboratory test results of asphalt mixtures with different percentage replacement rates of blended bagasse ash and steel slag dust with optimum crushed stone dust filler at constant bitumen content of 5.10%. As a result, all properties of the mix were satisfied and within the range of specifications. It was compared and determined the optimum replacement ratio of non-conventional filler (blended bagasse ash and steel slag dust). At the same time, the effect of the maximum replacement percentage of bagasse ash and steel slag dust combined with mineral filler was also determined. Then the optimum results were obtained at 5% BA and 15% SSD with optimum filler content of 5.5% and optimum bitumen content of 5.10% combinations. Therefore, the percentage replacement ratio of non-conventional fillers has been increased from 0% to 20% in 2.5% increments, but it is also repeated in the reverse of the fillers.

Table 4.18. Marshall Properties of asphalt mixes of 30% of blended bagasse ash & steel slag dust with optimum filler content 5.5% at constant bitumen content of 5.10%.

% Of replacements rates		BA & SSD Content par. repl. by % of at 5.5 optimum filler contents	Sample No.	ρA g/cm3	VIM %	VMA %	VFA %	Stability (KN)	Flow (mm)
0% (Control mix) CSD		5.50%	1	2.352	4.26	13.11	73.04	9.41	3.29
			2	2.350	3.70	13.34	72.06	8.74	3.28
			3	2.349	4.27	13.36	72.12	9.36	3.31
			Average	**2.350**	**4.08**	**13.27**	**72.41**	**9.17**	**3.29**
30%	0%BA & 30%SSD	0%BA+1.65SSD +3.85CSD	1	2.343	3.9	14.0	72.0	6.70	3.19
			2	2.345	3.6	13.7	74.0	6.70	3.18
			3	2.340	3.2	14.0	72.1	6.90	3.21
			Average	**2.343**	**3.8**	**13.9**	**72.7**	**6.70**	**3.19**
	30%BA&0%SSD	1.65BA+0%SSD +3.85CSD	1	2.336	4.6	14.0	66.9	6.60	3.15
			2	2.337	4.7	14.1	66.4	6.60	3.15
			3	2.338	4.6	13.9	67.3	6.80	3.14
			Average	**2.337**	**4.6**	**14.0**	**66.8**	**6.60**	**3.15**
	15%BA&15%SSD	0.825BA+0.825SSD+3.85CSD	1	2.338	3.6	14.3	75.2	6.80	3.24
			2	2.339	3.6	14.4	74.7	6.80	3.18
			3	2.337	3.2	14.0	77.4	6.90	3.09
			Average	**2.338**	**3.5**	**14.2**	**75.8**	**6.80**	**3.17**
	22.5% BA& 7.5%SSD	0.371BA+0.124 SSD+3.85CSD	1	2.335	2.8	14.2	80.5	6.83	3.20
			2	2.334	3.1	14.5	78.7	6.82	3.22
			3	2.332	2.7	14.1	81.2	6.80	3.21
			Average	**2.334**	**2.8**	**14.3**	**80.1**	**6.82**	**3.21**
	7.5% BA& 22.5% SSD	0.124BA+1.526SSD+3.85CSD	1	2.347	2.8	14.9	81.4	6.94	3.28
			2	2.345	2.8	14.9	81.1	6.93	3.29
			3	2.339	3.3	15.4	78.3	6.92	3.27
			Average	**2.344**	**3.0**	**15.0**	**80.3**	**6.93**	**3.28**

Table-18 shows that the laboratory test results of asphalt mixtures with different percentage replacement rates of blended bagasse ash and steel slag dust with optimum crushed stone dust filler at constant bitumen content of 5.10%. As a result, all properties of the mix were not within the range of specifications except for the blend of 0% BA & 30% SSD and 30% BA &0% SSD. The table illustrates that all test results of marshal stability, flow and volumetric properties with different proportions of both conventional and non-conventional filler content have not satisfied the specification requirement. Marshal properties were reduced from a blend of 20% BA and 0% SSD, 15% BA and 5% SSD, 22.5% BA and 7.5% SSD, 7.5% BA and 22.5% SSD, and 20% SSD and 0% BA. Based on the result, replacement of CSD filler by blended BA and SSD filler had no positive impact at 30%. Although all did not meet the requirement as per ERA specifications, generally the replacement of blended BA and SSD filler at 30% has no important effect on the mixture. The above Table 4.18-20 showed that the summary of the marshal mix results with different proportions of conventional (CSD) and non-conventional (blended of bagasse ash and steel slag dust).

The laboratory test results of asphalt mixtures with different percentage replacement rates of 10–30% of blended bagasse ash and steel slag dust with crushed stone dust filler were describe in Table 4.16–18. Whereas the effect of non-conventional filler (blended of bagasse ash and steel slag dust) on Marshal Properties was determined based on the optimum filler content (5.5%) and optimum bitumen content (5.10%) at five different percentages of non-conventional filler.

4.13 Effects of partial replacement of blended BA and SSD as mineral filler (CSD) in Hot Mix Asphalt production

The results of marshal tests on bituminous mixes prepared at various BA and SSD contents by total weight of the mix. From the test results, optimum asphalt content was determined for all respective mixtures using different amounts of filler. The above Tables 18–20 showed that the properties of mixtures at their constant asphalt content for mixes with different blends of bagasse ash and steel slag dust content were determined based on the optimum filler content (5.5%) and optimum bitumen content (5.10%) at five different percentages of blended BA and SSD 0% (control mix, 10%, 20 and 30% by weight of total mix aggregate). The effect of replacing different percentages of the conventional filler (CSD) with the blended bagasse ash and steel slag dust on marshal stability, flow, and different volumetric properties of the mixture will be discussed in the following section. However, on some diagrams there are some irregularities, which occur due to laboratory work limitations like the difficulty of having a consistent mixing temperature and minor aggregate loss at the time of mechanical mixing. The following sections analyze and discuss the results collected in the laboratory under different percentages of blended of bagasse ash and steel slag dust.

4.14 Effects of blended bagasse ash & steel slag dust (10%) content on asphalt mix properties and their relationship.

The effect of replacing different percentages of the non-conventional filler with the crushed stone dust on marshal stability, flow, and different volumetric properties of the mixture was evaluated.

The effect of non-conventional fillers (BA and SSD) on Marshal Properties was determined based on the optimum filler content (5.5%) and optimum bitumen content (5.10%) at five different percentages of blended bagasse ash and steel slag dust. In addition, at five different percentages of non-conventional filler (steel slag dust and bagasse ash), 0% control mix, 10%, 20%, and 30% by weight of conventional filler content (CSD). The mix of 0% steel slag dust and bagasse ash was used as a control mixture, which is important to evaluate the effect of steel slag dust and bagasse ash in a mixture. After completing the laboratory work and organizing the data, it carried out the analysis to assess the importance of adding bagasse ash and steel slag dust with partially optimal crushed stone dust in asphalt concrete production at constant bitumen content.

1. Effect of blended bagasse ash & steel slag dust on marshal stability and relationship

Specimen stability is the maximum load required to cause fracture of the specimen when the load is applied at a constant rate. Stability is the measure of resistance to deformation, which is influenced by the friction of aggregates between particles and cohesion. This friction depends on the different properties of the aggregates, such as surface finish, shape, absorption and structure of the aggregates. The cohesion depends on the binding ability of the bitumen, which is influenced by the bitumen type because of viscosity variations. The relationship between Marshall stability and mixed bagasse ash and steel slag dust was shown by demonstrating the following in Table 4.19 and in Fig. 4.8.

Table 4.19. Relationship between stability and replacement rate of BA and SSD

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &10%BA	10%SSD &0%BA	5%SSD &5%BA	7.5%SSD &2.5%BA	2.5%SSD &7.5%BA
Marshall Stability Value (KN)	9.17	8.7	9.2	9.5	10.3	10.12

Table 4.19 shows the laboratory test results of Marshall Stability with different replacement ratios of bagasse ash and steel slag dust as a mineral filler in Hot Mix Asphalt Concrete production, ranging from 10% BA & 0% SSD to 0% BA & 10SSD (by weight of optimum filler content). It shows that 10% CSD replacement of BA may be considered as the replacement ratio in HMA production (Mao-Chief Chi*, 2012). However, mixing CSD with different ratios of non-conventional fillers resulted in higher marshal stability than mixing BA and SSD separately with CSD. From the proportions of non-conventional fillers (BA &SSD) exchanged their rates for mixing, there were variations in the Marshall stability, which means the quantity of steel slag dust

was greater than bagasse ash. It also exceeded stability. The results show that steel slag dust mixed with crushed stone dust has higher Marshall Stability and is more effective. As a result of the dense and porous characteristics of steel slag dust (Dr. K Ganesh**, 2018), steel slag dust mix has higher Marshall Stability. The effect of blended bagasse ash & steel slag dust on the stability was shown in the following Figure.

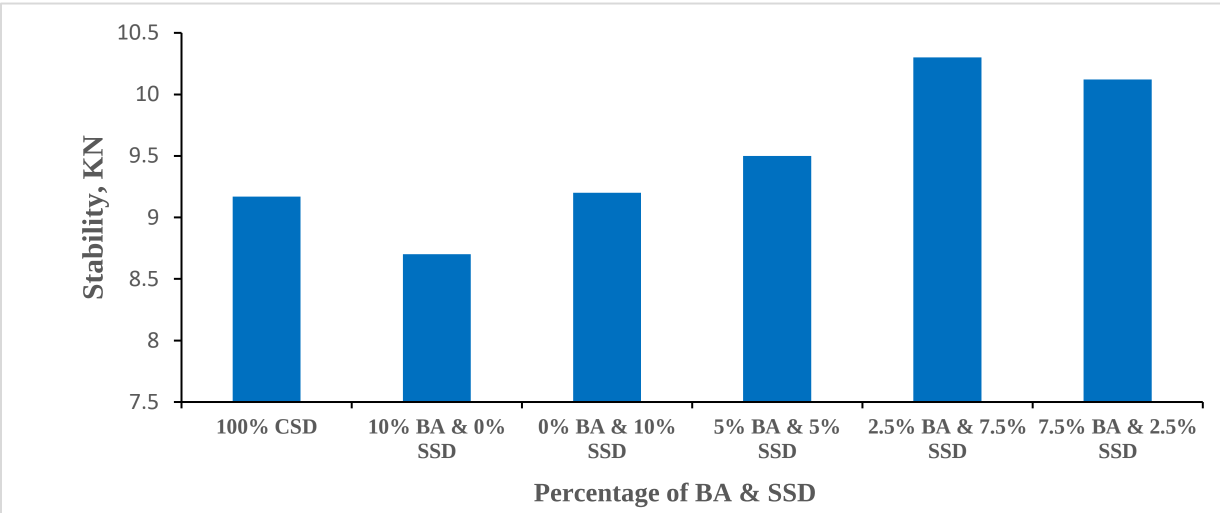


Figure 4.8. The effect of blended bagasse ash & steel slag dust on the stability of HMA

The figure shows that all stability test results with different levels of both conventional and non-conventional filler content met the specification requirements. Marshal Stability increases from 0% SSD and 10% BA up to 2.5% BA and 7.5% SSD replacement in 2.5% increments. Both the combination of BA and SSD with CSD improved marshal stability, but the mixed BA and SSD separately improved marshal stability more than the combination of BA and SSD separately. Furthermore, mixing mixed BA and SSD with CSD in different ratios improved SSD more than BA because steel slag mixed with different amounts of steel slag dust offers high stability, resisting permanent deformation (Ramirez 1992, Noureldin and Mc Daniel 1990).

Several studies have been conducted to investigate the chemical action or pozzolanic activity of BA and have concluded that BA is a pozzolan that improves performance when mixed with cement (Mao-Chieh Chi*, 2012). Based on the results, replacing CSD with mixed BA and SSD has a positive impact of 10%. Although the overall material combination should meet the requirements under ERA specifications, the substitution of mixed bagasse ash and steel slag dust up to 2.5% BA and 7.5% SSD has an important impact on the mix.

2. Effect of blended bagasse ash & steel slag dust on Marshal Flow and relationship

Flow is the total amount of deformation that occurs at the maximum load or is the vertical deformation of the sample (measured from the start of loading to the point at which stability begins to decrease) in 0.25mm. The relationship between flow and blended bagasse ash and steel slag dust is illustrated in the following Table 4.20 and in Fig 4.9.

Table 4.20. Relationship between Flow and replacement rate of blended bagasse ash & steel slag dust

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &10%BA	10%SSD &0%BA	5%SSD &5%BA	7.5%SSD &2.5BA	2.5%SSD &7.5%BA
Marshall flow Value (mm)	3.29	2.7	2.68	2.72	2.82	2.8

Table 4.20 shows the laboratory test results of flow with different exchange ratios of bagasse ash and steel slag dust as mineral fillers in the production of hot asphalt concrete, ranging from 0% SSD and 10% BA to 7.5% SS and 2.5% BA (by weight, the optimum filler content). Marshall flow was higher when CSD was blended with different ratios of non-conventional fillers than when BA and SSD were blended separately with CSD. The value of the flow had a variation when the amounts of BA and SSD were exchanged. In other words, as the amount of BA increased, the marshal flow also increased, but the amount of steel slag dust decreased. This is because the steel slag dust mix has a greater effect on marshal flow than bitumen (Liz Hunt, P.E., April 2000). Based on laboratory test results, mix flow is over 2mm and still within local and international specifications at all different levels of mixed bagasse ash and steel slag dust at a constant 5.5% filler (CSD) and at optimum bitumen content (5.10%).

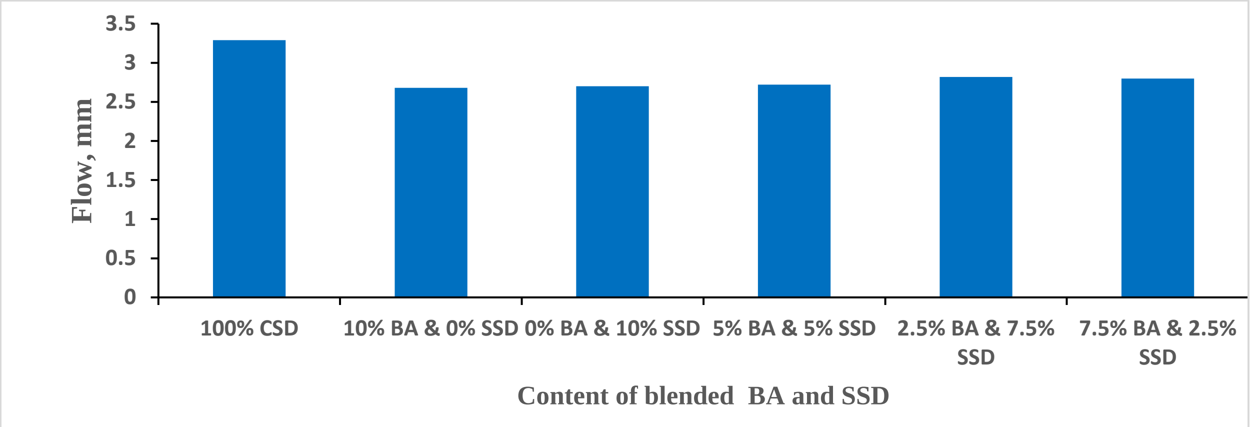


Figure 4.9. Effect of blended bagasse ash & steel slag dust on Marshal Flow of HMA

Fig 4.9 indicates the relationship between flow value and the replacement rate of crushed stone dust filler with blended bagasse ash and steel slag dust. The value indicates all the replacement percentage rates satisfy the specification requirement. As discussed above, for the relationship between flow value and the replacement rate of crushed stone dust filler with blended bagasse ash and steel slag dust, it was achieved the specification requirement up to 10% (4.95% CSD & 0.55%) blended BA &SSD percentage replacement rate.

3. Effects of blended bagasse ash & steel slag dust on Voids in mineral aggregates and relationship

The voids in the mineral aggregate (VMA) are defined as intergranular voids between the aggregate particles in a compacted paving mix. A minimum VMA is required in mixes to accommodate sufficient asphalt content to allow aggregate particles to be coated with an adequate asphalt film thickness. This creates a durable asphalt pavement mix. Table 4.21 and Figure 4.10 show the relationship between voids in mineral aggregates (VMA) and mixed bagasse ash and steel slag dust.

Table 4.21. Relationship between (VMA) and replacement rate of blended bagasse ash & steel slag dust

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &10%BA	10%SSD &0%BA	5%SSD &5%BA	7.5%SSD &2.5%BA	2.5%SSD &7.5%BA
Voids in the mineral aggregates Value (%)	13.63	12.6	13.3	14.0	15.2	14.7

Voids in mineral aggregates with different replacement ratios of blended bagasse ash and steel slag dust from 0% SSD & 10% BA up to 7.5% SS & 2.5%BA (by weight of optimum filler content) used as a mineral filler in Hot Mix Asphalt Concrete production are shown in Table 4.18. Some combinations of BA and SSD with CSD improved the voids in mineral aggregates, but the blended BA and SSD improved the voids in mineral aggregates more than the combination of BA and SSD separately. From the combination of BA and SSD with CSD individually, SSD was more effective and had a higher VMA value than BA. It can be seen from the figure that lower VMA is in mixtures with 10% BA and 0% SSD content, and hence, results in lower effective asphalt content. These mixes could be less durable than those containing 0% BA and 10% SSD content. Higher voids in mineral aggregate were obtained from mixes prepared by 2.5% BA and 7.5% SSD replacement, which resulted in higher effective asphalt content. This may be due to lower asphalt absorption of steel slag dust or bagasse ash. The general pattern of the figure is that as the replacement rate of blended BA and SSD increases, the VMA of the paving mixture also increases. Based on the laboratory results, it is indicated that the VMA of all hot mixed asphalt mixtures is within the allowable limits specified in the ERA pavement design manual. According to ERA pavement design, a manual VMA value in hot mix asphalt mixtures has to be greater than 13%.

Figure 4.10 Relationship between Voids in Mineral Aggregate and replacement proportion of blended BA and SSD (by optimum filler contents) at constant bitumen content of 5.10%.

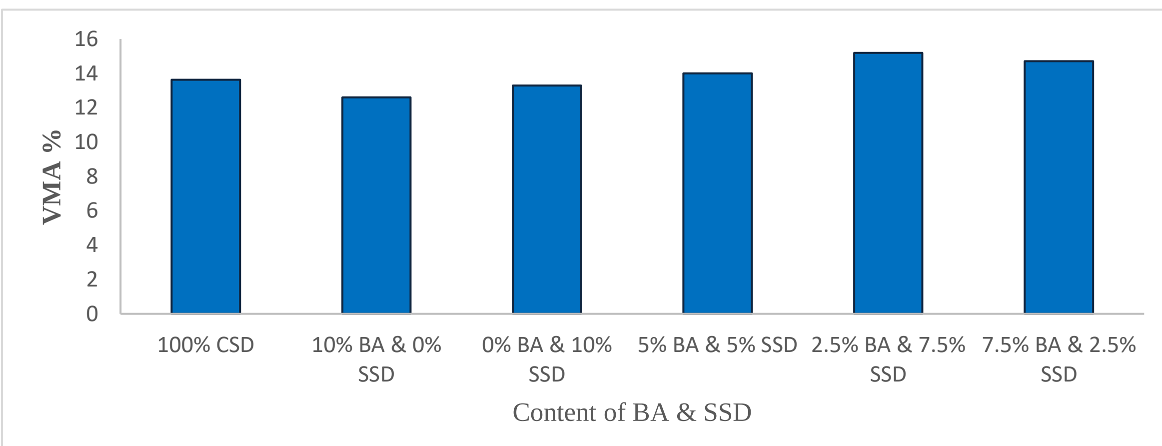


Figure 4.10. Effects of blended bagasse ash & steel slag dust on Voids in mineral aggregates

Fig. 4.10 shows the relationship between Voids in Mineral Aggregates (VMA) value and the replacement rate of crushed stone dust filler with blended bagasse ash and steel slag dust. Based on the laboratory results, though, it shows that the VMA of all hot mixed asphalt mixtures is within the allowable limits (all the percentage rates) specified in the specification criteria (the ERA, 2002). According to ERA, the 2002 VMA value in hot mix asphalt mixtures has to be greater than 13%. The above figure shows the values of the voids in mineral aggregates increase with increasing blended bagasse ash and steel slag dust content up to their maximum value. It can be seen from the figure that lower VMA was in mixtures with blended 0% SSD and 10% BA filler content and hence, lower effective asphalt content. These mixes could be less durable than those containing a higher blend of 2.5% BA and 7.5% SSD content. Higher voids in mineral aggregate were obtained from mixes prepared by 2.5% BA and 7.5% SSD replacement, which resulted in higher effective asphalt content. This may be due to the lower asphalt absorption of either steel slag dust or bagasse ash.

4. Effect of blended bagasse ash & steel slag dust on Air Voids and relationship

The air void (VA) is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, which is expressed as a percent of the bulk volume of the compacted paving mixture. The laboratory test result of Air Voids with different replacement ratio of blended bagasse ash and steel slag dust from the first laboratory test of 0% SSD &10% BA up to 7.5% SS &2.5% BA (by weight of optimum filler content of 5.5%) at optimum bitumen content of 5.10% used as a mineral filler in Hot Mix Asphalt Concrete production. The relationship between air voids (VA) and blended bagasse ash and steel slag dust is determined in the following Table 4.22 and Fig 4.11.

Table 4.22. Relationship between Air Voids (VA) and replacement rate of blended BA &SSD

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &10%BA	10%SSD &0%BA	5%SSD &5%BA	2.5%SSD &7.5BA	7.5%SSD &2.5%BA
Air Voids (%)	4.08	4.1	4.2	4.3	4.4	4.2

The effect of both filler type (bagasse ash & steel slag dust) and their content on air void of the compacted asphalt mixture shows in Figure 4.11.

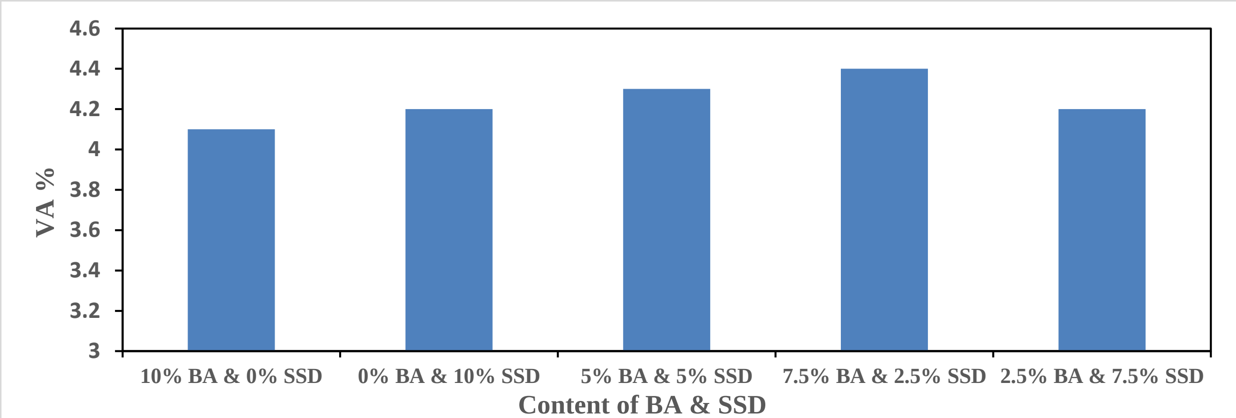


Figure 4.11. Effect of blended bagasse ash & steel slag dust on Air Voids

Fig 4.11 shows the air void content for replaced mixtures of 0% SSD &10% BA to 2.5% BA &7.5% SSD blended bagasse ash & steel slag dust (by weight of OFC). All the replacement rates satisfied the specification criteria ranges (3-5%) specified by the ERA pavement design manual, 2002. At 2.5% BA and 7.5% SSD% blended bagasse ash and steel slag dust content (by weight of OFC), the air void value is 4.2%, which is greater than the median value of international and local specifications by 0.2%.

The value of air voids is gradually the same with changing bagasse ash and steel slag dust ratios, but the replacements are similar in content. However, mixing CSD with different ratios of non-conventional fillers resulted in a lower air void than mixing BA and SSD separately with CSD. Furthermore, the combination of 10% SSD and 0% BA air void value was greater compared with 10% BA and 0% SSD. Therefore, steel slag had more effect on the air void than bagasse ash. This is due to the higher air voids in the steel slag mix.

5. Effect of blended bagasse ash & steel slag dust on Void Filled with Asphalt and relationship

The nature of the aggregates and filler used in the mixture highly influenced the void in the asphalt concrete mix. It measured void filled with asphalt as the proportion of VMAs that are occupied with asphalt binder. In this study, the laboratory test results of Voids filled with asphalt with different replacement ratios of blended bagasse ash and steel slag dust from the first combination of 10% of blended BA and SSD (by weight of optimum filler content) used as a mineral filler in hot mix asphalt concrete production and then laboratory test results can be shown in Table 4.23.

Table 4.23. Relationship between Void Filled with Asphalt and Replacement ratio of blended BA and SSD

Replacement ratio of blended BA and SSD, (%)	100%CSD	0%SSD &10%BA	10%SSD &0%BA	5%SSD &5%BA	7.5%SSD &2.5%BA	2.5%SSD &7.5%BA
Void Filled with Asphalt Value (%)	72.41	67.3	68.5	69.6	72.2	70.2

In this study, the laboratory test results of Voids filled with asphalt with different replacement ratios of blended bagasse ash and steel slag dust content ranged from 0%BA & 10%SSD up to 2.5%BA & 7.5%SSD (by weight of optimum filler content). The laboratory test results are show in the following figure. The effect of blended bagasse ash and steel slag dust content on the voids filled with asphalt properties of the mixture and the relationship between them are show in the following Figure.

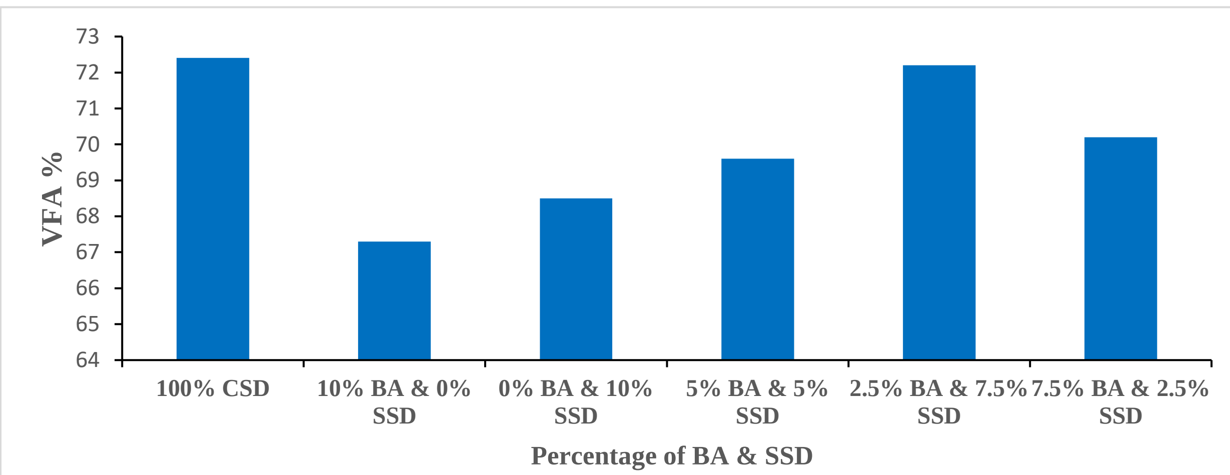


Figure 4.12. Effect of blended bagasse ash & steel slag dust on Void Filled with Asphalt

Fig, 4.12 shows the relationship between percent voids filled with asphalt (VFA) value and the replacement rate of crushed stone dust filler with blended bagasse ash and steel slag dust. However, mixing CSD with different ratios of non-conventional fillers increased the void filled with asphalt compared to mixing BA and SSD separately with CSD. The combination of BA and SSD with CSD in different ratios showed the Void Filled with Asphalt of 2.5% BA and 7.5% SSD had a lower density than the bulk density of 7.5% BA and 2.5% SSD because the quantity of SSD decreased. The value of the void filled with asphalt also decreased. As a result, steel slag had more effect and a lower void filled with asphalt than bagasse ash. The main reason is that bitumen fills fewer voids in steel slag than steel. According to the experimental results, VFA values increase with an increased replacement rate of blended bagasse ash and steel slag dust filler until it reaches a 10% replacement rate. Based on ERA pavement design, manual VFA values in hot mix asphalt production are within a range of 65% to 75%.

6. Effect of blended bagasse ash & steel slag dust on Bulk Specific Gravity and relationship

The bulk density of HMA mixes with different replacement rates of blended bagasse ash and steel slag dust is within the range of requirements. The value of the laboratory test result of the bulk-density of non-conventional fillers of bagasse ash and steel slag dust both had different values when compared to one another by different percentage rates. As a result, the effect of both filler contents on bulk density was completely different from each other. The relationship between bulk density and blended bagasse ash and steel slag dust was determined in Table 4.23 and in Figure 4.13.

Table 4.24. Relationship between Bulk –density and replacement rate of blended BA &SSD

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &10%BA	10%SSD &0%BA	5%SSD &5%BA	7.5%SSD &2.5BA	2.5%SSD &7.5%BA
Bulk specific gravity(gm/cm3)	2.35	2.341	2.345	2.343	2.347	2.342

A Table-4.23 shows that the laboratory test result of bulk-density with different replacement ratios of blended bagasse ash and steel slag dust is 10% (by weight of optimum filler content) when used as a mineral filler in hot-mix asphalt concrete production. Both the combination of BA and SSD separately with CSD improved the bulk specific gravity, but the blended BA and SSD separately improved the bulk specific gravity more than the combination of BA and SSD separately. In addition, from the mixing of blended BA and SSD with CSD in different ratios, the SSD improved better than the BA. This is because while steel slag filler content increases in the mix, since the steel slag mix has a higher marshal bulk density than BA, the marshal bulk density will increase.

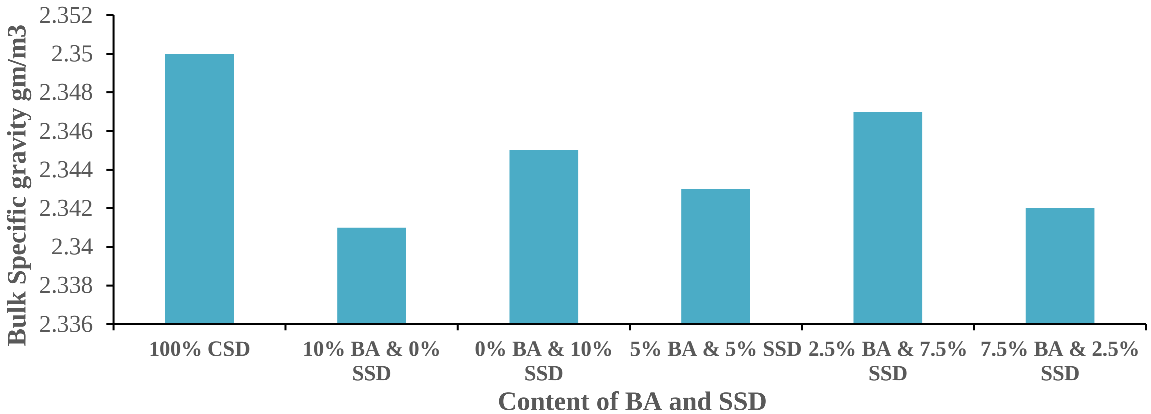


Figure 4.13. The effects and relationship between Bulk –density and replacement rate of blended BA &SSD.

Fig.13 shows the laboratory test result of the bulk-density of HMA with a different replacement rate of blended bagasse ash and steel slag dust. The bulk density was increased from 2.346 CSD to 2.356 after the addition of 0%BA and 10%SSD. However, mixing CSD with different ratios of non-conventional fillers resulted in higher bulk density than mixing BA and SSD separately with CSD.The main reason that the increments in bulk density were due to the increase of blended BA and SSD filler content in the mix was that it fills the voids while the bulk density also increases. From the combination of BA and SSD with CSD in different ratios, it was shown that the bulk density of 2.5%BA and 7.5%SSD was higher than the bulk density of 7.5%BA and 2.5%SSD As a result, because the quantity of SSD increased, the value of bulk density also increased. As a result, steel slag had more effect on bulk density than bagasse ash. As a result, of steel slag's effect on Marshall Properties, steel slag dust mix has higher marshal bulk density. This behavior is due to the dense and porous characteristics of the steel slag. In general, the bulk density increased as the blended bagasse ash and steel slag dust content increased, until it reached the maximum bulk density of 10% (2.5%BA & 7.5%SD). However, the bulk-specific gravity these replacements less than from the control mix because both BA and SSD are had lower specific gravity of CSD.

7. Summary of Properties of partially replaced of CSD mix with different percentages of blended BA & SSD in HMA production

It's noticed that all values of Marshall stability, flow and volumetric properties of HMA production at 10% of non-conventional filler mixing with 90% conventional filler at different rates content satisfy the ERA,2002 specifications. However, mixing of the CSD with different ratios of non-conventional fillers had more improved Marshall Stability, flow and volumetric properties than mixing separately BA and SSD with CSD. In addition, when compared between the combination of BA and SSD individually, the values of marshal properties have variation, i.e., steel slag dust was better than bagasse ash. Anyhow, as obviously shown above, the 10% blended bagasse ash and steel slag dust mixed with 90% optimum crushed stone dust at optimum bitumen content (5.10%) by weight of aggregates achieves both the local and international specifications requirements for all tested properties.

It implies that replacement of crushed stone dust with blended bagasse ash and steel slag dust in hot mixed asphalt does not affect the performance property of asphalt concrete because of the constant percentage of bitumen content (5.10%). Besides, the comparison of marshal and volumetric properties of asphalt mix at 0% BA &10% SS with 10% BA and 0% SS content (10% SS and 10% BA) respectively by weight of optimum crushed stone dust filler (5.5%) with optimum bitumen content (5.10%) while all marshal parameter values at 10% SS and 10% BA were to meet the standard requirements. Therefore, both BA and SSD were at 10% blend and separate can be used as mineral filler in HMA with optimum filler content (weight of 90% CSD) at optimum bitumen content (5. 10%).

4.15 Effects of blended bagasse ash & steel slag dust (20%) content on asphalt mix properties and their relationship.

Using an upgraded quantity of previously blended BA and SSD filler in the asphalt mixture has noticeable effects on the Marshall properties of HMA. The following section analyzes and discusses the results collected in the laboratory under different percentages of blended BA and SSD filler. It showed the effect of both filler type and their content on Marshall Properties mix in the tables below. Tables have clearly shown that both filler materials have characteristics of Marshall Properties, which are from 0% SSD and 20% BA up to 5% BA and 15% SSD filler content. Marshall Properties, while at a blend of 20% BA and 0% SSD filler content decreases, but it was ranged between ERA and Asphalt Institute specification limits.

The reason behind this scenario is, at lower filler content the OBC for both filler types is not enough to cover the void spaces. However, at higher filler contents, an increase in the amount of filler content in the mixture fills the voids taken together. This, subsequently, decreases the Marshall Properties in the mineral aggregate and lower space is available for air. In comparison with the two-filler types, Marshall Properties in steel slag dust mixture is slightly higher than bagasse ash mixture because steel slag dust has smaller particle size than bagasse ash, which minimizes the volume covered by a single filler aggregate, which allows extra space for Marshall Properties.

1. Effect of blended bagasse ash & steel slag dust on marshal stability and relationship

The stability of the specimen is the maximum load required to produce failure of the specimen when load is applied at a constant rate or is the measure of resistance to deformation which is influenced by inter-particle frictions of aggregates and cohesion. This friction depends on the different properties of aggregates like surface texture, shape, absorption and structure of aggregates. The cohesion depends on the turning ability of the bitumen, which is affected by bitumen grade because of variation in viscosity. The relationship between Marshall Stability and blended bagasse ash & steel slag dust is shown in the following in Table 4.24 and in Fig 4.14.

Table 4.25. Relationship between stability and replacement rate of BA and SSD

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &20%BA	20%SSD &0%BA	10%SSD &10%BA	15%SSD &5%BA	5%SSD &15%BA
Marshall Stability Value (KN)	9.17	10.5	10.6	10.7	11.0	10.08

Table 4.24 showed the laboratory test result of Marshall Stability with different replacement ratio of bagasse ash & steel slag dust from 20% BA &0% SSD up to 5% BA &15SSD (by weight of optimum filler content) used as a mineral filler in hot mix asphalt concrete production. When compared the marshal stability in the laboratory test results between non-conventional fillers (BA and SSD), mixing with CSD one by one and the mixing of blended BA and SSD with CSD in different ratios, more interesting, was the mixture of blended BA and SSD with CSD.

Besides, the Marshall stability of summation of non-conventional filler (20% BA and 0% SSD) and (0% BA 20% SSD) with conventional filler (CSD) was changed from 10.5KN to 10.6KN while the blended 15% SS &5% BA compare with blended 5% SS &15% BA mix with CSD the value of 15% SS &5% BA was exceeded from 10.8KN to 11KN. Based on this result conclude that the combination of steel slag dust mix has more effective and higher marshal stability than bagasse ash. Therefore, steel slag dust mix has higher Marshall Stability. This behavior is because of the dense and porous characteristics of the steel slag dust (Dr. K Ganesh**,2018). The effect of blended bagasse ash & steel slag dust on stability is shown in the following Figure.

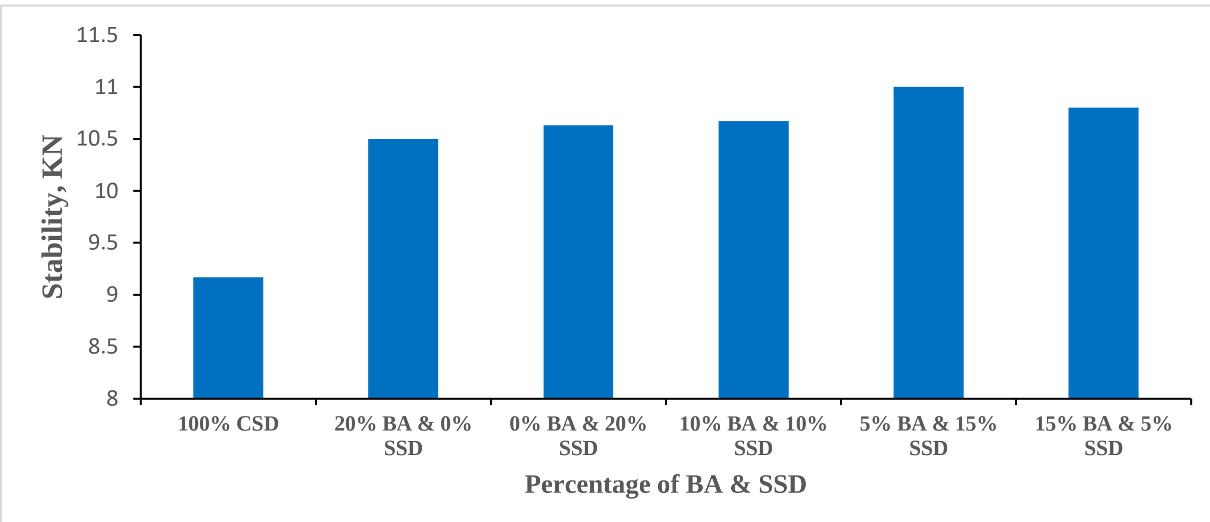


Figure 4.14. Effects of blended bagasse ash & steel slag dust (20%) on marshal stability

The Figure 4.14 showed that all test results of stability with different proportion of both conventional and non -conventional filler content has satisfied the specification requirement. Marshal Stability increases from 0% SSD &20% BA up to 5% BA & 15% SSD of replacement by 2.5% increments. All the combination of BA and SSD with CSD was improved the marshal stability but the blended BA and SSD separately improved the marshal stability than the combination of BA and SSD separately.in addition, from the mixing of blended BA and SSD with CSD in different ratios the SSD was more improved than BA. Because the production of hot mix asphalt concrete by CSD mixes with varying amounts of SSD provide high stability, which resist permanent deformation. Depended on the results the replacement of CSD partially by blended BA &SSD has a positive impact throughout 20% although, all meet the requirement as per ERA specifications. Weight of aggregates recorded at 20% replacement rate (4.4% CSD and 1.1% blended BA &SSD the maximum stability value) which was 11KN.

2. Effect of blended bagasse ash & steel slag dust on Marshal Flow and relationship

Flow is the total amount of deformation, which occurs at the maximum load or is the vertical deformation of the sample (measured from start of loading to where stability begins to decrease) in 0.25mm. The relationship between Flow and blended bagasse ash & steel slag dust is illustrated in the following Table 4.25 and in Fig 4.15.

Table 4.26. Relationship between Flow and replacement rate of blended bagasse ash & steel slag dust

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &20%BA	20%SSD &0%BA	10%SSD &10%BA	15%SSD & 5%BA	5%SSD & 15%BA
Marshall flow Value (mm)	3.29	3.07	3.05	3.04	3.08	3.06

Table 4.15 showed the laboratory test result of flow with different replacement ratio of blended bagasse ash & steel slag dust from 0% SSD &20% BA up to 22.5% SSD &7.5% BA (by weight of optimum filler content) used as a mineral filler in hot mix asphalt concrete production. The mixing of the CSD with different ratios of non-conventional fillers increased marshal flow rather than mixing of BA and SSD with CSD separately. The value of flow was a variance when the amount of BA and SSD ratios were exchanged. In another way, the amount of BA is greater than steel slag dust. The marshal flow became higher but the steel slag dust amount was in excess and the value of marshal flow was relatively lower. This, due to steel slag mix, has more effect and lower marshal flow with Bitumen (Liz Hunt, P.E. April 2000). Based on the laboratory test results, the flow of mixes is above 2 mm and still in the range between local and international specifications of all different blended bagasse ash & steel slag dust content with a constant filler of 5.5% (CSD) and at optimum bitumen content (5. 10%).

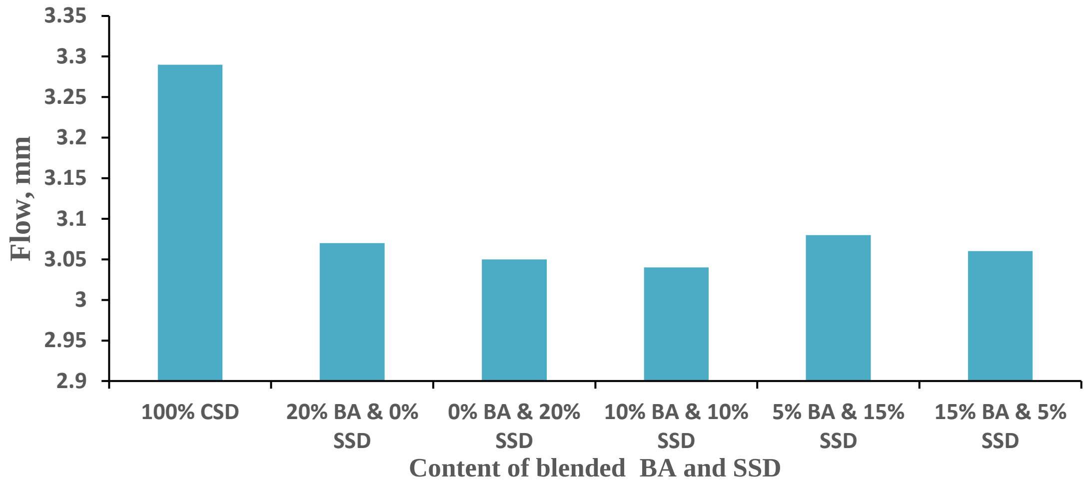


Figure 4.15. Effect of blended bagasse ash & steel slag dust (20%) on Marshal Flow

Fig 4.8 shows the relationship between flow value and the replacement rate of crushed stone dust filler with blended bagasse ash & steel slag dust. As discussed above, the relationship between flow value and the replacement rate of crushed stone dust filler with blended bagasse ash & steel slag dust. The hot mixed asphalt mixture Marshal Flow value shows all the replacement percentage rates satisfy and achieved the specification requirement. Up to 20% CSD (4.4%) and blended BA &SSD (1.1%) percentage replacement rate. Therefore, the replacement of CSD partially by blended BA &SSD results had a positive impact of 20% CSD. Although all meet the requirements as per ERA specifications, the replacement of blended bagasse ash & steel slag dust up to 5% BA & 15% SSD has an important effect on a mixture.

The maximum flow value was recorded at 20% replacement rate (4.4% CSD and 1.1% Blended BA & SSD by weight of aggregates), which was 3. 08mm.The flow value of the replacing mix is less than from the control mix. It described that the bitumen content of the control mix is not sufficient, and it has some effect on durability, and may lead to cracking of the mix. High flow values generally indicate a plastic mix that will experience permanent deformation under traffic, whereas low flow values may indicate a mix with higher-than-normal voids and insufficient asphalt for durability and one that may experience premature cracking due to mixture brittleness during the life of the pavement.

3. Effect of blended bagasse ash & steel slag dust on Voids in mineral aggregates and relationship

The voids in the mineral aggregates (VMA) are defined as inter-granular void space between the aggregate particles in a compacted paving mixture. A minimum VMA is necessary in mixtures to accommodate enough asphalt content, so that aggregate particles can be coated with adequate asphalt film thickness. This consequently results in a durable asphalt paving mixture. The relationship between voids in mineral aggregates (VMA) and blended bagasse ash & steel slag dust is shown in the following Table 4.26 and Fig 4.16.

Table 4.27. Relationship between (VMA) and replacement rate of blended bagasse ash & steel slag dust

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &20%BA	20%SSD &0%BA	10%SSD &10%BA	15%SSD& 5%BA	5%SSD &15%BA
Voids in the mineral aggregates Value (%)	13.63	16.0	15.4	14.9	13.66	14.3

Table 4.26 showed the laboratory test result of Voids in mineral aggregates with different replacement ratio of blended bagasse ash & steel slag dust from 0% SSD & 20% BA up to 5% BA & 15% SSD (by weight of optimum filler content) used as a mineral filler in hot mix asphalt concrete production. The combination of BA and SSD with CSD improved the Voids in mineral aggregates separately, but the blended BA and SSD improved more. From the combination of BA and SSD with CSD individually, SSD was more effective and had VMA value than BA. It can be seen from the figure that lower VMA is in mixtures with 5% BA &15% SSD content and, hence, the resulting decrease in the VMA value is due to partial replacement of mineral aggregates by blended BA and SSD which increases the amount of filler resulting in reduction the void spaces between the granular particles in the compacted mix.

Lower values of VMA result in fewer spaces to accommodate the required asphalt to produce a good coating and durable mix. The result shows that the minimum value of VMA was determined at 20% (5% BA & 15% SSD) replacement filler which is 13.66% but it is greater than 13.63mm of the control mixes. Therefore, we can conclude that the control mixes result more durable mixes as compared to the mixes with blended BA and SSD. All the values of the VMA satisfy the required specification. This may be due to lower asphalt absorption of steel slag dust. Based on the laboratory results, it is indicated that the VMA of all hot mix asphalt mixtures is greater than 13% and is within the allowable limits specified in the ERA pavement design manual.

Higher voids in mineral aggregate were obtained from mixes prepared by 20% BA & 0% SSD replacement, resulting in lower effective asphalt content. The maximum VMA value was recorded at a 20% (20%BA & 0% SSD) replacement rate which was 16.0%. Figure 4.16 Relationship between Voids in Mineral Aggregate and replacement proportion of blended BA and SSD (by optimum filler content) at a constant bitumen content of 5.10%.

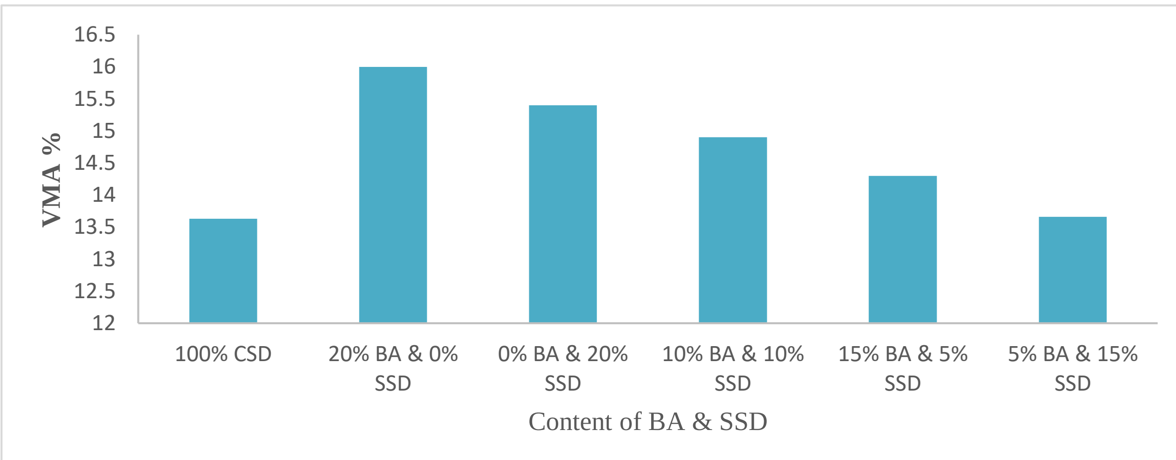


Figure 4.16. Effect of blended bagasse ash & steel slag dust (20%) on Voids in mineral aggregates

Fig.4.16 illustrates the relationship between the Voids in mineral aggregates (VMA) value and the replacement rate of crushed stone dust filler with blended bagasse ash & steel slag dust. the above figure shows, the values of the voids in mineral aggregates decrease with increased blended bagasse ash and steel slag dust content up to minimum value obtained at blended of 5% BA and 15% SSD content. The general pattern of the figure is that the replacement rate of blended BA and SSD increases and the VMA of the paving mixture also decrease. According to the laboratory results, it showed that the VMA of all hot mixed asphalt mixtures is within the allowable limits (all the percentage rates) specified in the specification criteria (the ERA, 2002).

4. Effect of blended bagasse ash & steel slag dust on Air Voids and relationship

The air voids (VA) are the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as percent of the bulk volume of the compacted paving mixture. In this study, the laboratory test result of Air Voids with different replacement ratio of blended bagasse ash & steel slag dust from 0% BA &20% SSD up to 5% BA &15% SSD at optimum bitumen content 5.10% (by weight of optimum filler content 5.5%) used as a mineral filler in Hot Mix asphalt concrete production. The relationship between air void (VA) and blended bagasse ash & steel slag dust is determined in the following Table 4.27 and Fig 4.17.

Table 4.28. Relationship between Air Voids (VA) and replacement rate of blended BA &SSD

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &10%BA	10%SSD &0%BA	10%SSD &10%BA	5%SSD &15%BA	15%SSD &5%BA
Air Voids (%)	4.08	4.2	4.1	4.2	4.1	4.0

Air voids in the mix refer to the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture. As observed in Figure 4.17 the air voids value of the bituminous mixes decreased gradually as the blended BA and SSD filler content increases, the decrease is within the range given in (ERA, pavement design manual, 2002 and Asphalt Institute, 2003) which is (3-5) %. The value of air voids percentage at 20% filler content was 4.0%, which is the median value of the specification. The effect of both filler type (bagasse ash & steel slag dust) and their content on air void of the compacted asphalt mixture.

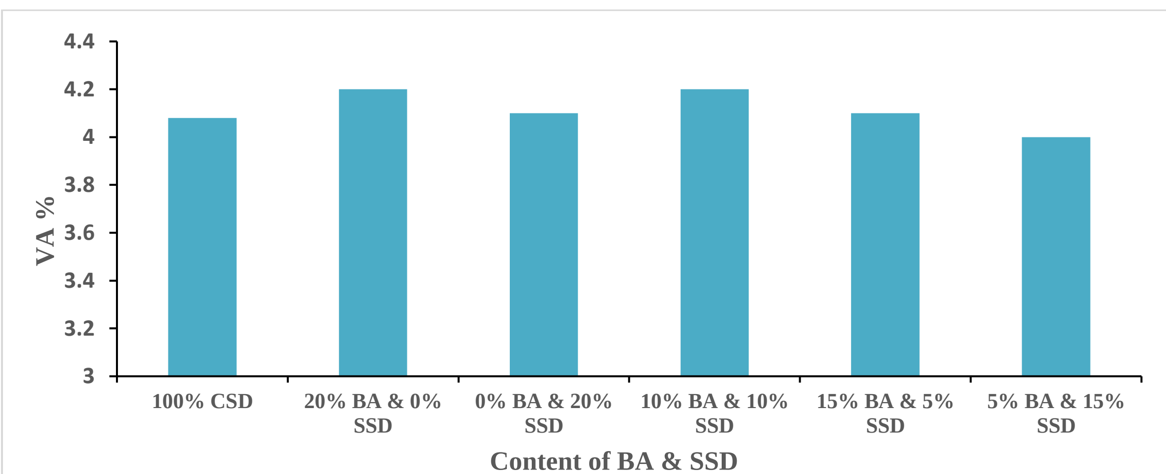


Figure 4.17. Effect of blended bagasse ash & steel slag dust (20%) on Air Voids

Fig 4.10 showed the air void content for replaced mixtures: 0% SSD &20% BA-5% BA &15% SSD blended bagasse ash & steel slag dust (by weight of OFC). All the replacement rates satisfied the specification criteria ranges (3-5%) specified by the ERA pavement design manual, 2002. At 20% (5% BA &15% SSD%) blended bagasse ash & steel slag dust content (by weight of OFC) the air void value was 4.0%, which is the median value of international and local specifications. From the figure shown, the air voids value of the bituminous mixes decreased gradually as the blended bagasse ash & steel slag dust filler content increases, the decrease is within the range given in (ERA, pavement design manual, 2002 and Asphalt Institute, 2003) which is (3-5) %.

Besides, some value of air voids is the same with changing bagasse ash & steel slag dust ratio, but the replacements had similar content. However, mixing of the CSD with different ratios of non-conventional fillers decreased air void than mixing separately BA and SSD with CSD. Furthermore, the combination of 20% SSD & 0% BA air void value was greater compared with 20% BA and 0% SSD. Therefore, steel slag dust had more effect and air void than bagasse ash. This is due to steel slag dust mix having higher air voids (Dr. K Ganesh**,2018).

5. Effect of blended bagasse ash & steel slag dust on Void Filled with Asphalt and relationship

The nature of aggregates and filler used in the mixture greatly influenced the void in asphalt. Void filled with asphalt was measure as the proportion of VMAs that was occupy with asphalt binder. In this research, the laboratory test results of Void filled in asphalt at different replacement ratio of blended bagasse ash & steel slag dust from the first combination of 20% of blended BA and SSD (by weight of optimum filler content) used as a mineral filler in hot mix asphalt concrete production, and then laboratory test results can be shown in the following table and figure.

Table 4.29. Showed that the laboratory test result of Voids filled with Asphalt with different replacement ratio of blended bagasse ash & steel slag dust content

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &20%BA	20%SSD &0%BA	10%SSD &10%BA	15%SSD &5%BA	5%SSD &15%BA
Void Filled with Asphalt Value (%)	72.41	69.5	70.5	72.0	74.7	73.4

Table 4.28 showed that the laboratory test result of Voids filled with asphalt with different replacement ratio of blended bagasse ash & steel slag dust content: 0% BA &20% SSD up to 5% BA &15% SSD (by weight of optimum filler content) used as a mineral filler in Hot Mix asphalt concrete production in the study. The result shows that the value of voids filled with asphalt increase to a value of 74.7% as the replacement percentage of blended bagasse ash & steel slag dust content increases to 20% (5% BA &15% SSD). All the VFA values of the mix with a

replacement percentage rate of (20%BA &0%SSD - 5%BA &15%SSD) fell within the standard specification (65-75). VFA represents the volume of effective bitumen content in the mixture. It is inversely related to air voids. The percent of air voids found minimum for 20% blended bagasse ash & steel slag dust filler content but the value of VFA was maximum and it has higher values than the control mix at the same bitumen content.

The effect of blended bagasse ash & steel slag dust content on the voids filled with asphalt property of the mixture and relationship were shown on the following Figure.

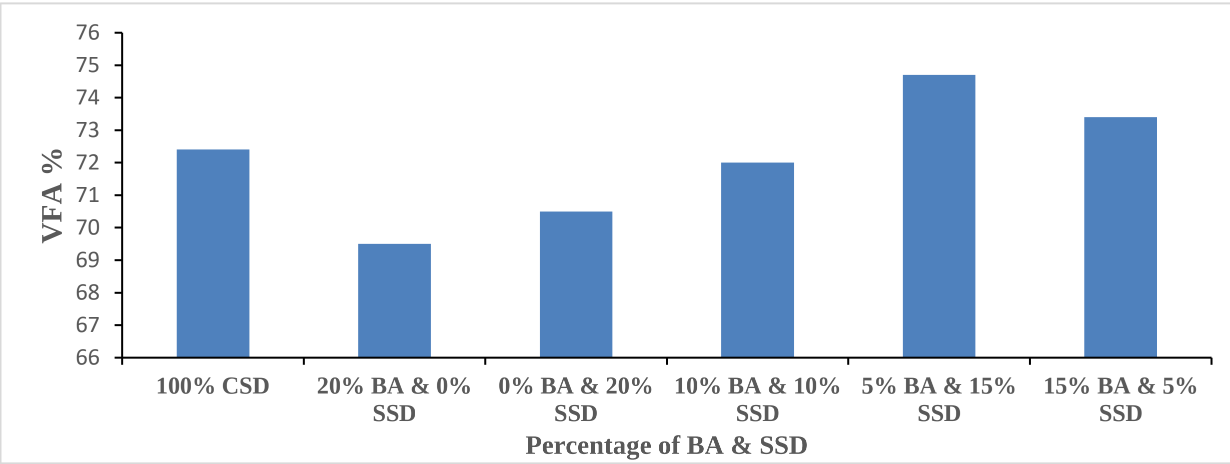


Figure 4.18. Effect of blended bagasse ash & steel slag dust (20%) on Void Filled with Asphalt

Fig. 4.18 shows the relationship between percent voids filled with asphalt (VFA) value and the replacement rate of crushed stone dust filler with blended bagasse ash & steel slag dust. The mixing of the CSD with different ratios of non-conventional fillers had increased the void filled with asphalt than mixing separately BA and SSD with CSD. Voids filled with asphalt values are greater than 65% for all blended of non-conventional fillers contents, where the Marshal Criteria for VFA is 65% -75%. This criterion is important for the durability of mixes and is related to the effective asphalt content in the mix.

If the percentage of voids filled with asphalt is lower than the limit indicated, there had been less asphalt film around the aggregate particles. Lower asphalt films are more subjected to moisture and weather effects where they can be detached from the aggregate particles and subsequently lower performance. On the other hand, if the limit is exceeded, more voids a Figure 4.18 shows the relationship between percent voids filled with asphalt (VFA) value and the replacement rate of crushed stone dust filler with blended bagasse ash & steel slag dust. The mixing of the CSD with different ratios of non-conventional fillers increased the void filled with asphalt rather than mixing separately BA and SSD with CSD. Voids filled with asphalt values are greater than 65% for all blended of non-conventional fillers contents, where the Marshal Criteria for VFA is 65% -75%. This criterion is important for the durability of mixes and is related to the effective asphalt content in the mix.

If the percentage of voids filled with asphalt is lower than the limit shown, there will be less asphalt film around the aggregate particles. Lower asphalt films are more subjected to moisture and weather effects where they can be detached from the aggregate particles and subsequently lower performance. If it exceeds the limit, it fills more voids with asphalt than required for durability. This can be explained as the asphalt film around aggregate particles is thicker and lower voids than required are left. From the combination of BA and SSD with CSD in different ratios show the Void Filled with Asphalt of 5% BA and 15% SSD was lower than the Void Filled with Asphalt of 15% BA and 5% SSD. Because the quantity of SSD decreased the value of Void Filled with Asphalt also decreased as the result, steel slag more effect and lower void filled with asphalt than bagasse ash.

The main reason is that the steel slag mix has lower voids filled with bitumen. According to the experimental results, VFA values increase with an increased replacement rate of blended bagasse ash & steel slag dust filler until it reaches a 20% (5% BA and 15% SSD) replacement rate. Based on ERA pavement design, manual VFA values in hot mix asphalt production are within a range of 65% - 75%.

5. Effect of blended bagasse ash & steel slag dust on bulk specific gravity and relationship

The bulk density of HMA mixes with different replacement rate of blended bagasse ash & steel slag dust is within the range of requirement. The value of the laboratory test result of the bulk-density of non-conventional fillers of bagasse ash & steel slag dust both had different values when compared to one another by different percentage rates. As a result, the effect of both filler content on bulk density differed completely from each other. The relationship between bulk -density and blended bagasse ash & steel slag dust was determined on the following Table and in Figure.

Table 4.30. Relationship between Bulk –density and replacement rate of blended BA &SSD

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &20%BA	20%SSD &0%BA	10%SSD &10%BA	15%SSD &5%BA	5%SSD & 15%BA
Bulk specific gravity(gm/cm3)	2.35	2.344	2.345	2.347	2.349	2.346

Table-4.29 shows that the laboratory test result of bulk-density with different replacement ratio of blended bagasse ash & steel slag dust at 20% (by weight of optimum filler content) is used as a mineral filler in hot mixed asphalt concrete production. It improved both the combination of BA and SSD separately with CSD, the bulk specific gravity, but the blended CSD with non-conventional filler in different replacement ratios improved the bulk specific gravity more. In addition, it improved the mixing of CSD in different ratios with SSD more than BA. This is because while steel slag dust filler content increases in the mix, the steel slag dust mix had higher Marshall bulk density than BA, hence increased Marshall bulk density. The steel slag dust mix had higher Marshall bulk density (Hitesh Kumar, Sudhir Varma*, 3 August 2020).

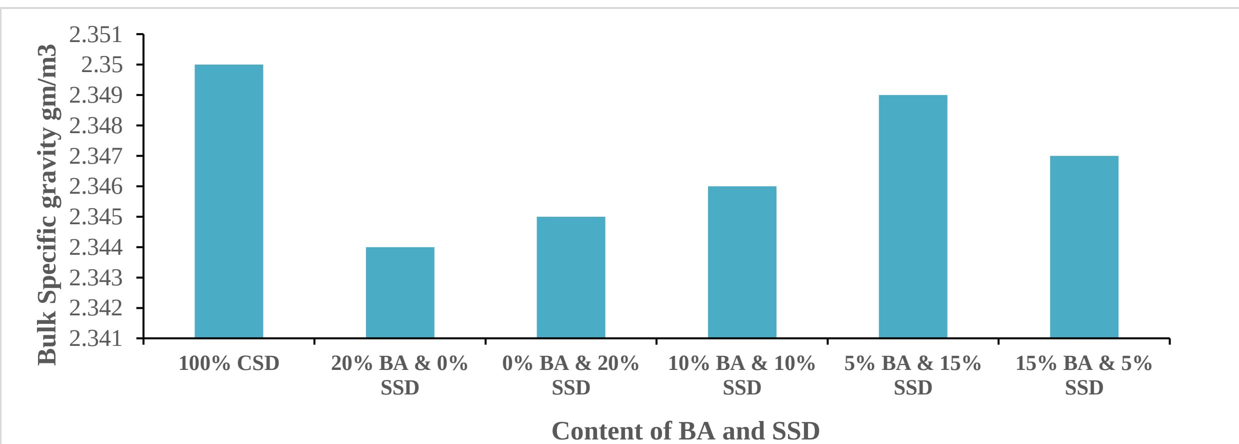


Figure 4.19. the effects and relationship between Bulk –density and replacement rate of blended BA &SSD

Fig. 4. 19 shows the laboratory test result of bulk-density of HMA with different replacement rates of blended for bagasse ash & steel slag dust. Adding 20% BA and 0% SSD decreased from 2.350 to 2.344 g/cm3 whereas the addition of 0% BA and 20% SSD improved to 2.345g/cm3. However, the mixing of the CSD with different ratios of non-conventional fillers had more increased bulk

density than mixing separately BA and SSD with CSD. Almost all Mixes with variable blended BA and SSD filler content increases showed a trend of increase in bulk density.

The main reason is that the increments in bulk density were because of the increase of blended BA and SSD filler content in the mix. Hence, it fills the void while the bulk density also increases. From the combination of BA and SSD with CSD in different ratios showed that the bulk density of 5% BA and 15% SSD was higher than the bulk density of 15% BA and 5% SSD because the quantity of SSD exceeded than BA. The steel slag dust had more effective and bulk density than bagasse ash. Therefore, the effect of steel slag dust on marshal properties has higher marshal bulk density (Dr. K Ganesh**,2018). This behavior is because of the dense and porous characteristics of the steel slag. But here, for Marshall Bulk density status, it satisfied the requirement in all percentage replacement rates.

The maximum value of bulk density was recorded at 20% replacement rate (4.4% CSD and 1.1% blended BA and SSD by weight of aggregates), which was 3.349gm/cm3. Altogether, the increases in blended bagasse ash & steel slag dust content increased the bulk density, until it reaches the maximum bulk density at 20% (5% BA &15% SSD) 3.349gm/cm3.But the bulk-density value of the replacing material is less than the bulk -density of crushed stone dust filler this due to the specific gravity of crushed stone dust greater than the both BA and SSD filler.

6. Summary of Properties of partially replaced of CSD mix with different percentages of blended BA & SSD in HMA production.

It's noticed that all values of marshal stability, flow and volumetric properties of HMA production at 20% of non-conventional filler mixing with 80% of conventional filler at different rates content satisfy the ERA,2002 specifications. However, mixing of the CSD with different ratios of non-conventional fillers had more improved Marshall Stability, flow and volumetric properties than mixing improved separately with CSD. In addition, when compared between the combination of BA and SSD individually, the values of marshal properties have a variation i.e., steel slag dust was better than bagasse ash.

Anyhow, as obviously shown above, the 20% blended bagasse ash and steel slag dust mix with 80% optimum crushed stone dust at optimum bitumen content (5.10%) by weight of aggregates achieves both the local and international specifications requirements for all tested properties. It implies that replacement of crushed stone dust with blended bagasse ash and steel slag dust in hot mixed asphalt does not affect the performance property of asphalt concrete for the constant percentage of bitumen content (5.10%). Besides, the comparison of marshal and volumetric properties of asphalt mix at 0% BA &20% SS with 20% BA and 0% SS content (10% SS and 10% BA) respectively by weight of optimum crushed stone dust filler (5.5%) with optimum bitumen content (5.10%) while all marshal parameter values at 20% SS and 20% BA were to meet the standard requirements. Therefore, both BA and SSD were at 20% blend as well as separate and can be used as a mineral filler in HMA with optimum filler content (weight of 80% CSD) at optimum bitumen content (5. 10%).

4.16 Effects of blended bagasse ash & steel slag dust (30%) content on asphalt mix Properties and their relationship

Using an upgraded quantity of previously blended BA and SSD filler in the asphalt mixture has noticeable effects on the Marshall properties of HMA. The following section analyzes and discusses the results collected in the laboratory under different percentages of blended BA and SSD filler. It showed the effect of both filler types and their content on Marshall Properties mix in the tables below. Tables have clearly shown that both filler materials are characteristics of Marshall Properties, which are from 0% SSD and 30% BA up to 7.5% BA and 22.5% SSD filler content. Marshall Properties, while at a blend of 30% BA and 0% SSD filler content decreases, does not satisfy ERA and Asphalt Institute specification limits. The reason behind this scenario is, the lower filler content the OBC for both filler types is not enough to cover the void spaces. However, at higher filler contents, an increase in the amount of filler content in the mixture fills the voids taken together. This, subsequently, decreases the Marshall Properties in the mineral aggregate and lower space is available for air. In comparison with the two-filler types, Marshall Properties in steel slag dust mixture is slightly higher than bagasse ash mixture because steel slag dust has smaller particle size than bagasse ash, which minimizes the volume covered by a single filler aggregate, which allows extra space for Marshall Properties.

1. Effect of blended bagasse ash & steel slag dust on marshal stability and relationship

The stability of the specimen is the maximum load required to produce failure of the specimen when load is applied at a constant rate or is the measure of resistance to deformation which is influenced by inter-particle frictions of aggregates and cohesion. Table 4.30 and Figure-20 show that all test results of stability with different proportions of both conventional and non-conventional filler content do not satisfy the specification requirement. As a result, the stability of mixes with the proportion of both BA and SSD filler content increases until it is blended with 20% non-conventional filler and beyond that, the stability decreases.

Table 4.31. Relationship between stability and replacement rate of BA and SSD

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &30%BA	30%SSD &0%BA	15%SSD &15%BA	22.5%SSD &7.5%BA	7.5%SSD &22.5%BA
Marshall Stability Value (KN)	9.17	6.60	6.70	6.80	6.93	6.82

As the laboratory test result shows, the addition of 30% BA alone reduced the stability by 32%, whereas the addition of 30% SSD reduced the stability by 15% from the stability obtained by CSD alone, since it does not satisfy the ERA and Asphalt pavement institute specifications. Relatively, where the content of SSD increases, the stability gradually increases to 30% BA and 0% SSD and 0% BA and 30% SSD. Therefore, steel slag dust mix has higher marshal stability; this behavior is because of the dense and porous characteristics of the steel slag dust. Therefore, it was concluded that the addition of BA and SSD up to 20% filler in an asphalt mix had an important effect on increasing the stability of the mix to reduce deformation. Besides that, the stability was reduced because of an increase in the content of BA and SSD. In this study, it decreased stability to 6.93KN when 30% of non-conventional filler (7.5% BA and 22.5% SSD) was added to the CSD. The effect of blended bagasse ash & steel slag dust on the stability was shown in the following Figure.

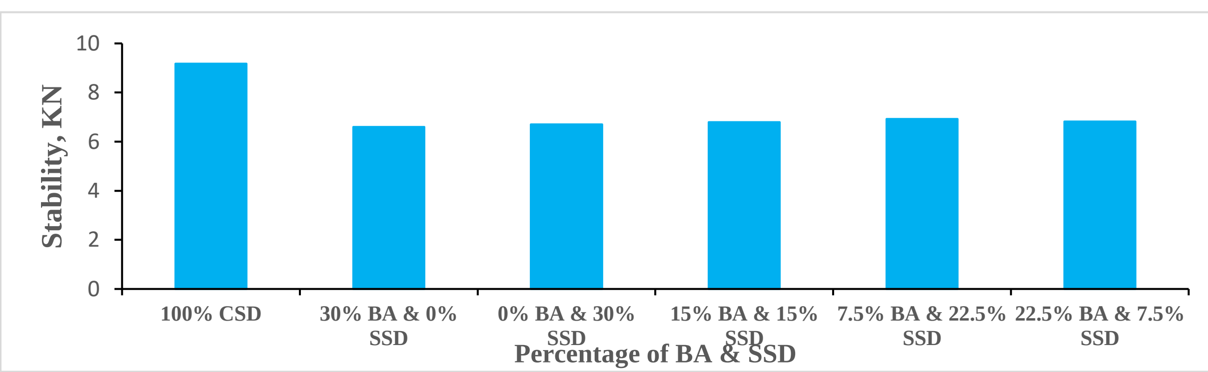


Figure 4.20. Effects of blended bagasse ash & steel slag dust (30%) content on asphalt mix Properties

The effect of blending bagasse ash & steel slag dust on stability is shown in the following Figure 4.20. The figure showed that all test results of stability with different proportions of both conventional and non-conventional filler content satisfied the specification requirement. Marshal Stability increases from 0% SSD &30% BA up to 7.5% BA &22.5% SSD of replacement by 2.5% increments. It improved both the combination of BA and SSD with CSD for Marshall stability, but the blended BA and SSD better improved Marshall stability rather than the combination of BA and SSD separately. In addition, from the mixing of blended BA and SSD with CSD, in different ratios the SSD was more improved than barbecues. Steel slag mixed with varying amounts of steel slag aggregate provides high stability, which provides permanent deformation (Ramirez 1992). Based on the result, replacement of CSD by blended BA &SSD has a positive impact of 30%. Although all meet the requirements as per ERA specifications, the replacement of blended bagasse ash & steel slag dust up to 7.5% BA &22.5% SSD has an important effect on mixture stability.

2. Effect of blended bagasse ash & steel slag dust on Marshal Flow and relationship

Flow is the total amount of deformation which occurs at the maximum load or the vertical deformation of the sample (measured from the start of loading to where stability decreases) at 0.25mm. Table 4.31 and Figure 4.21 illustrate the relationship between flow and blended bagasse ash & steel slag dust.

Table 4.32. Relationship between Flow and replacement rate of blended bagasse ash & steel slag dust

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD& 30%BA	30%SSD &0%BA	15%SSD &15%BA	22.5%SSD &7.5BA	7.5%SSD &22.5%BA
Marshall flow Value (mm)	3.29	3.19	3.15	3.17	3.28	3.21

Table 4.31 shows the laboratory test result of flow with different replacement ratio of bagasse ash & steel slag dust from 0% SSD &30% BA up to 7.5% SS &2.5% BA (by weight of optimum filler content) used as a mineral filler in Hot Mix asphalt concrete production. The mixing of the CSD with different ratios of non-conventional fillers increased marshal flow rather than mixing separately BA and SSD with CSD.

Just the value of flow is exchanged when the amount of BA and SSD exchanges, other the amount of BA increases the marshal flow also increased but steel slag dust amount was decreases. This is because having the steel slag mix has more effect and lower marshal flow with Bitumen (Liz Hunt, P.E. April 2000). Based on the laboratory test results, the flow of mixes is above 2mm and still in the range of local and international specifications at all different blended bagasse ash & steel slag dust content with a constant filler of 5.5% (CSD) and at optimum bitumen content (5. 10%).

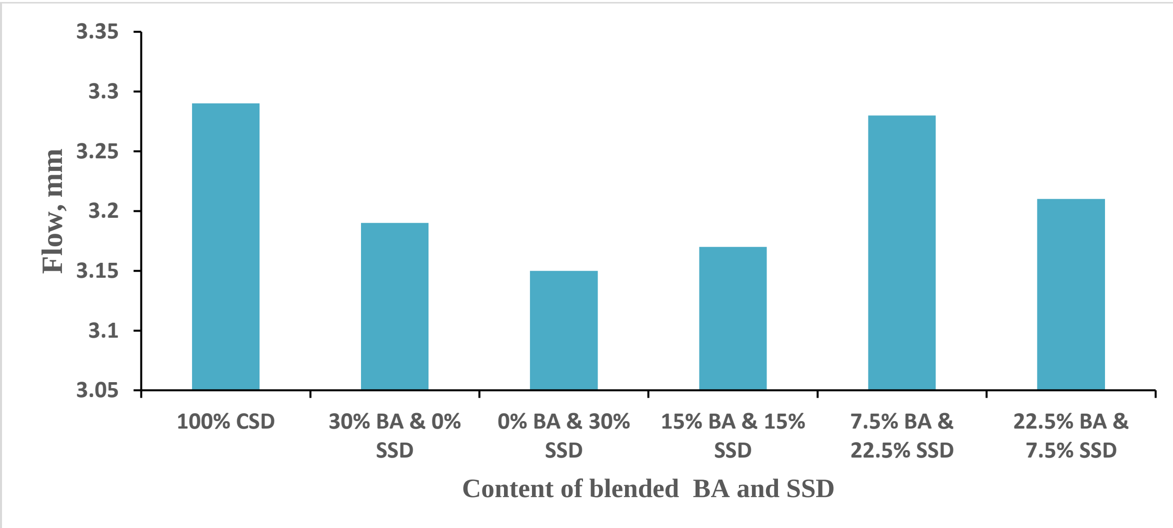


Figure 4.21. Effect of blended bagasse ash & steel slag dust (30%) on Marshal Flow

The figure shows the relationship between flow value and the replacement rate of crushed stone dust filler with blended bagasse ash & steel slag dust. Flow refers that the vertical deformation of the sample (measured from the start of loading to the point at which stability begins to decrease) in 0.25 mm. High flow values generally indicate a plastic mix that will experience permanent deformation under traffic, whereas low flow values may indicate a mix with higher-than-normal voids and insufficient asphalt for durability and one that may experience premature cracking due to mixture brittleness during the life of the pavement. According to (ERA, Pavement Design Manual, 2002) the flow value is usually specified to be in the range of (2-4) mm for heavy traffic. Figure 4.8 shows the relationship between flow value and waste tire powder content.

This test value shows the flow value initially decreased and recorded minimum value of 3.15 mm at 0%BA & 30%SSD filler content then, gradually increased as the percentage of waste blended BA and SSD content increase but it has less value than the control mix. that may experience premature cracking due to mixture brittleness during the life of the pavement. According to (ERA, Pavement Design Manual, 2002) the flow value is usually specified to be in the range of (2-4) mm for heavy traffic. Figure 4.8 shows the relationship between flow value and waste tire powder content. This test value shows the flow value initially decreased and recorded minimum value of 3.15 mm at 0%BA & 30%SSD filler content then, gradually increased as the percentage of waste blended BA and SSD content increase but it has less value than the control mix.

A maximum flow value of mix found to be 3.28 mm but the maximum value of the control mix was 3.29 mm which is greater than the mix result containing blended bagasse ash & steel slag dust filler. Since the flow value of the replacing mix was less than the control mix which can be ascribed that the bitumen content of the control mix is not sufficient to obtain greater flow value and it has some effect on durability, and may lead to cracking of the mix. This test value shows all the replacement percentage rates that satisfy the specified requirement. As discussed above, because of the relationship between flow value and the replacement rate of crushed stone dust filler with blended bagasse ash & steel slag dust, it can achieve the specification requirement of up to 30% (22.5% CSD & 7.5%) blended BA &SSD percentage replacement rate.

3. Effect of blended bagasse ash & steel slag dust on Voids in mineral aggregates and relationship

The voids in the mineral aggregates (VMA) are defined as inter-granular void space between the aggregate particles in a compacted paving mixture. Minimum VMA is necessary in mixtures to accommodate enough asphalt content, so that it can coat aggregate particles with adequate asphalt film thickness. This consequently results in a durable asphalt paving mixture. The relationship between voids in mineral aggregates (VMA) and blended bagasse ash & steel slag dust is shown in the following table and figure.

Table 4. 32: Relationship between (VMA) and replacement rate of blended bagasse ash & steel slag dust

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD &30%BA	30%SSD &0%BA	15%SSD &15%BA	22.5%SSD&7.5BA	7.5%SSD& 22.5%BA
Voids in the mineral aggregates Value (%)	13.63	14.0	13.9	14.2	15.0	14.3

Table 4.32 showed the laboratory test result of Voids in mineral aggregates with different replacement ratio of blended bagasse ash & steel slag dust from 0% SSD &30% BA up to 22.5%

SSD &7.5% BA (by weight of optimum filler content) used as a mineral filler in Hot Mix asphalt concrete production. It improved some of the combination of BA and SSD with CSD and the Voids in mineral aggregates, but the blended BA and SSD improved more voids in mineral aggregates than the combination of BA and SSD separately. From the combination of BA and SSD with CSD individually, SD was more effective and had VMA value than BA. It can be seen from the figure that lower VMA is in mixtures with 30% BA &0% SSD content and, hence, results in lower effective asphalt content.

These mixes could be less durable than those containing 0% BA & 30% SSD content. Higher voids in mineral aggregate were obtained from mixes prepared by 7.5% BA & 22.5% SSD replacement, resulting in higher effective asphalt content. This may result due to lower asphalt absorption of steel slag dust or bagasse ash. The general pattern of the figure is that the replacement rate of blended BA and SSD increases and the VMA of the paving mixture increases. Based on the laboratory results, it is indicated that the VMA of all hot mix asphalt mixtures is within the allowable limits specified in the ERA pavement design manual. According to ERA pavement design, a manual VMA value in hot mix asphalt mixtures has to be greater than 13%.

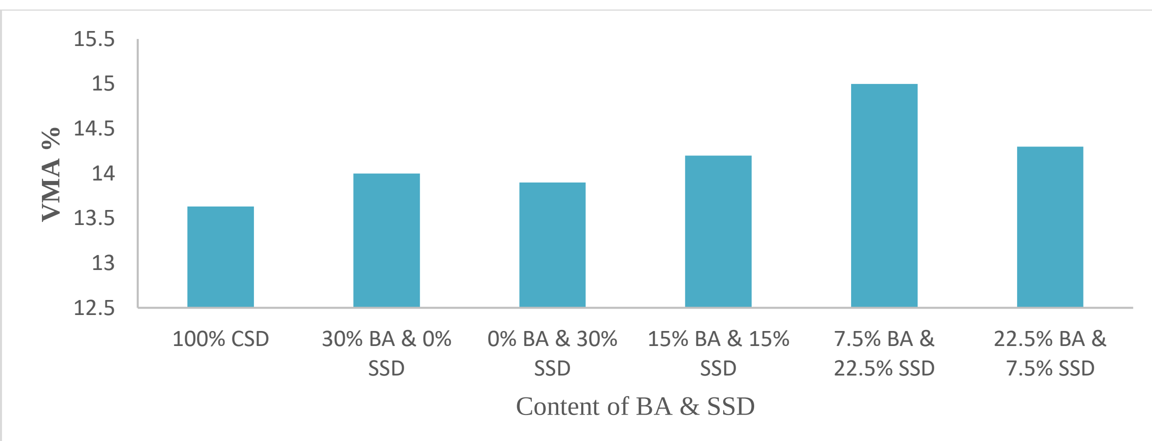


Figure 4.22. Effect of blended bagasse ash & steel slag dust (30%) on Voids in mineral aggregates

The figure determined the relationship between voids in mineral aggregate and the replacement proportion of blended BA and SSD (by optimum filler content) at a constant bitumen content of 5.10%. Based on the laboratory test results, it was indicated that the VMA of all hot mix asphalt mixtures is within the allowable limits (all the percentage rates) specified in the specification criteria (ERA, 2002). According to ERA, the 2002 VMA value in hot mix asphalt mixtures has to be greater than 13%.

As the above figure shows, the values of the voids in mineral aggregates increase with increased blended bagasse ash and steel slag dust content up to maximum value. It can be seen from the figure that lower VMA was in mixtures with blended 0% SSD and 30% BA filler content and, hence, resulted in lower effective asphalt content. These mixes could be less durable than those containing a higher blend of 7.5% BA and 22.5% SSD content. Higher voids in mineral aggregate were obtained from mixes prepared by 7.5% BA &22.5% SSD replacement, resulting in higher effective asphalt content. This may result due to lower asphalt absorption of either steel slag dust or bagasse ash.

4. Effect of blended bagasse ash & steel slag dust on Air Voids and relationship

The air voids (VA) are the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as the percent of the bulk volume of the compacted paving mixture. In this study, the laboratory test results of Air Voids with different replacement ratio of blended bagasse ash & steel slag dust from the first laboratory test of 0% SSD &30% BA up to 7.5% SS & 22.5% BA (by weight of optimum filler content 5.5%) at optimum bitumen content 5.10% used as a mineral filler in Hot Mix asphalt concrete production. The relationship between air voids (VA) and blended bagasse ash & steel slag dust is determined in the following Table 4.32 and Fig 4.23.

Table 4.33. Relationship between Air Voids (VA) and replacement rate of blended BA &SSD

Replacement ratio of blended BA and SSD (%)	100% CSD	0%SSD &30%BA	30%SSD &0%BA	15%SSD &15%BA	22.5%SSD &7.5%BA	7.5%SSD &22.5%BA
Air Voids (%)	4.08	4.6	3.8	3.5	3.0	2.8

Table 4.33 showed the laboratory test result of Air Voids with different replacement ratio of blended bagasse ash & steel slag dust from 0% SSD &30% BA up to 22.5% SS &7.5% BA (by weight of optimum filler content) used as a mineral filler in Hot Mix asphalt concrete production. The combination of BA and SSD with CSD improved the Air Voids but the blended BA and SSD

improved the Voids more than the combination of BA and SSD separately. From the combination of BA and SSD with CSD individually, SSD was more effective and had VA value than BA. The effect of both the fillers type (bagasse ash & steel slag dust) and their content on the air void of the compacted asphalt mixture is shown in Figure.

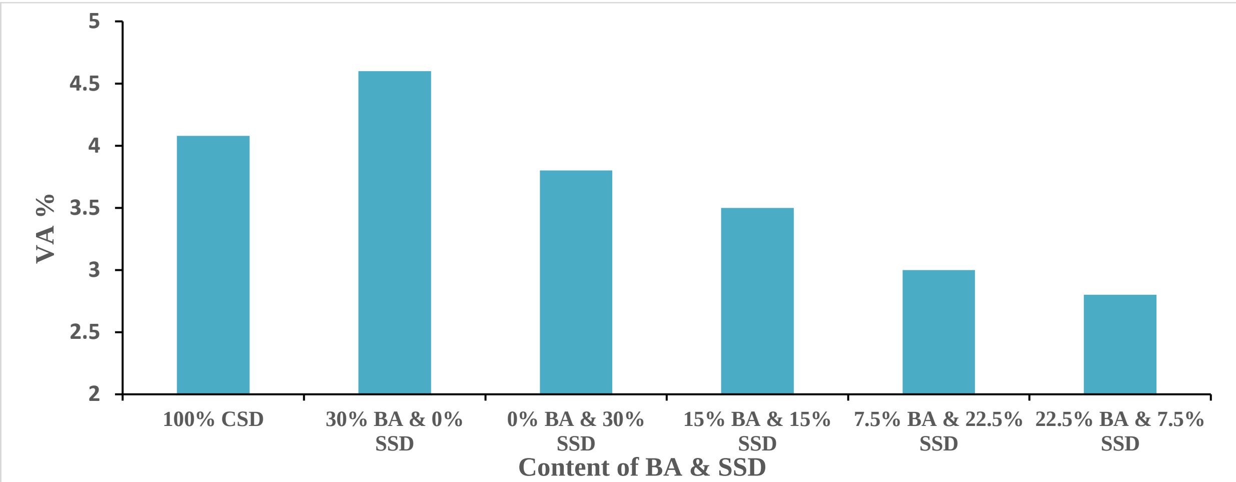


Figure 4.23. Effect of blended bagasse ash & steel slag dust (30%) on Air Voids

The figure showed the air void content for replaced mixtures: 0% SSD &30% BA-7.5% BA &22.5% SSD blended bagasse ash & steel slag dust (by weight of OFC). All the replacement rates satisfied the specification criteria ranges (3-5%) specified by the ERA pavement design manual, 2002 except at the replacement of filler by 22,5%BA and 7,5%SSD. At 7.5% BA & 22.5% SSD% blended, bagasse ash & steel slag dust content (by weight of OFC) the air void value is 3.0%, which is greater than from the value of 22,5%BA and 7,5%SSD by 0.2%. From the above figure, the air voids value of the bituminous mixes decreased gradually as the blended, bagasse ash & steel slag dust filler content increases, the decrease is within the range given in (ERA, pavement design manual, 2002 and Asphalt Institute, 2003) which is (3-5) %.

The value of air voids percentage at 30%BA and 0%SSD filler content was 4.6% which is greater than the median value of the specification. The result shows that the minimum value of VA was determined at the blended of 22.5%BA and 7.5%SSD which is 2.8% but it is less than 4.08 %of the control mixes. But this replacement rates did not satisfy the specification criteria ranges (3-5%) specified by the ERA pavement design manual, 2002, because its air void value was not found in the rages between from 3-5. which is 2.8% then it less than from the minimum value.

The value of air voids is gradually decreased with changing bagasse ash & steel slag dust ratio not reduced from the local and international specification limits when the replacements were different in content. However, mixing of the CSD with different ratios of non-conventional fillers decreased air void than mixing separately BA and SSD with CSD. further, the combination of 0% SSD &3 0% BA air void value was greater compared with 0% BA and 30% SSD.

5. Effect of blended bagasse ash & steel slag dust on Void Filled with Asphalt and relationship

The nature of aggregates and filler used in the mixture influenced the void in asphalt. It measured voids filled with asphalt as the proportion of VMAs that are occupied with asphalt binder. In this study, the laboratory test result of Voids filled with asphalt with a different replacement ratio of blended bagasse ash & steel slag dust from the first combination of 30% of blended BA and SSD (by weight of optimum filler content) used as a mineral filler in hot mix asphalt concrete production shown by laboratory test results can be shows in the following Table.

Table 4.34 Relationship between Voids filled with Asphalt (VFA) and replacement rate of blended BA &SSD

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD& 30%BA	30%SSD& 0%BA	15%SSD& 15%BA	22.5%SSD &7.5%BA	7.5%SSD D&2.5%BA
Void Filled with Asphalt Value (%)	72.41	66.8	72.7	75.8	80.3	80.1

Table 4.34 showed that the laboratory test result of Voids filled with asphalt with a different replacement ratio of blended bagasse ash & steel slag dust content of 0% BA &30% SSD up to 7.5% BA &22.5% SSD (by weight of optimum filler content) used as a mineral filler in HMA concrete production in this study. The laboratory test results and the effect of blending the bagasse ash & steel slag dust content on the voids filled with asphalt properties of the mixture and relationship were shown in the following figure.

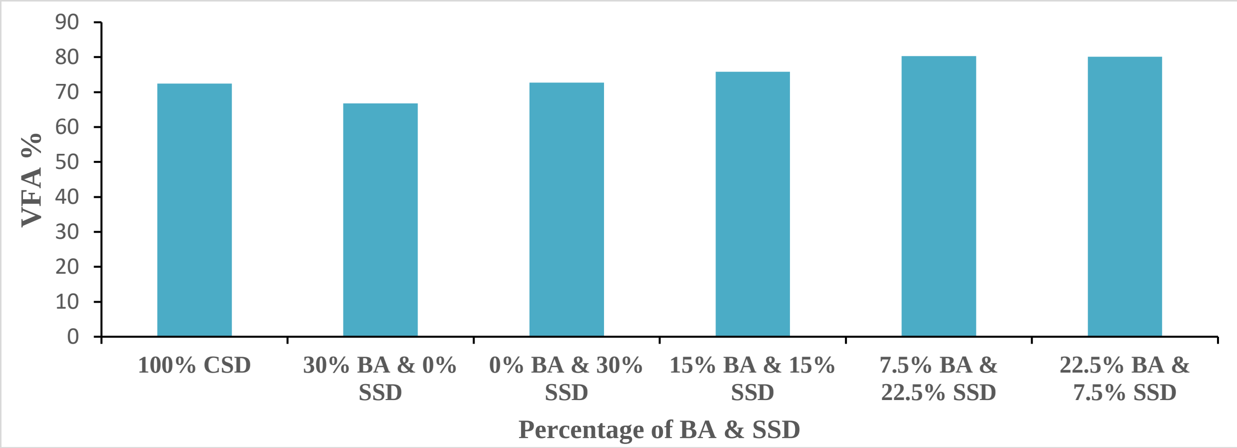


Figure 4.24. Effect of blended bagasse ash & steel slag dust (30%) on Void Filled with Asphalt

The figure showed the relationship between percent voids filled with asphalt (VFA) value and the replacement rate of crushed stone dust filler with blended bagasse ash & steel slag dust. However, mixing of the CSD with different ratios of non-conventional fillers increased Void Filled with Asphalt rather than mixing separately BA and SSD with CSD. From the combinations of BA and SSD with CSD in different ratios showed the Void Filled with Asphalt of 30% BA and 0% SSD had lower VFA value than 0% BA and 30% SSD because the quantity of SSD increased the value of Void Filled with Asphalt also increased. As the result, steel slag more effective and had higher void filled with asphalt than bagasse ash. The result shows that the value of voids filled with asphalt increase to a value of 80.3% as the replacement percentage of blended bagasse ash & steel slag dust filler content increases to 30% (blended 7.5% BA & 22.5% SSD%).

All the VFA values of the mix with a replacement percentage rate of (30%BA &0%SSD - 7.5% BA & 22.5% SSD) not fell because the replacements 22.5%BA &7.5 %SSD and 7.5% BA & 22.5% SSD) are made out of the standard specification (65-75) and their VFA values are 80.1% and 80.3 respectively. VFA represents the volume of effective bitumen content in the mixture. It is inversely related to air voids.

6. Effect of blended bagasse ash & steel slag dust on Bulk Specific Gravity and relationship

The unit weight of HMA mixes with a different replacement rate of blended bagasse ash & steel slag dust is within the range of requirement. The value of the laboratory test result of the bulk-density of non-conventional fillers of bagasse ash & steel slag dust both had different values when compared to one another by different percentage rates. As a result, the effect of both filler content on bulk density differed completely from each other. The relationship between bulk -density and blended bagasse ash & steel slag dust was determined in the following Table 4.33 and in Figure 25 below.

Table 4.34. Relationship between Bulk –density and replacement rate of blended BA &SSD

Replacement ratio of blended BA and SSD, (%)	100% CSD	0%SSD& 30%BA	30%SSD& 0%BA	15%SSD& 15%BA	22.5%SSD& 7.5%BA	7.5%SSD& 22.5%BA
Bulk specific gravity(gm/cm3)	2.35	2.332	2.345	2.343	2.347	2.344

Table-4.35 shows that the laboratory test result of bulk-density with different replacement ratio of blended bagasse ash & steel slag dust at 30% (by weight of optimum filler content) is used as a mineral filler in hot mixed asphalt concrete production. Both the combination of BA and SSD separately with CSD improved the bulk specific gravity, but the blended BA and SSD improved the bulk specific gravity rather than the combination of BA and SSD separately. In addition, from the mixing of blended BA and SSD with CSD in different ratios, the SSD was more improved than BA. This is because while steel slag filler content increases in the mix, since steel slag mix has higher specific gravity than BA, hence increased Marshall bulk density.

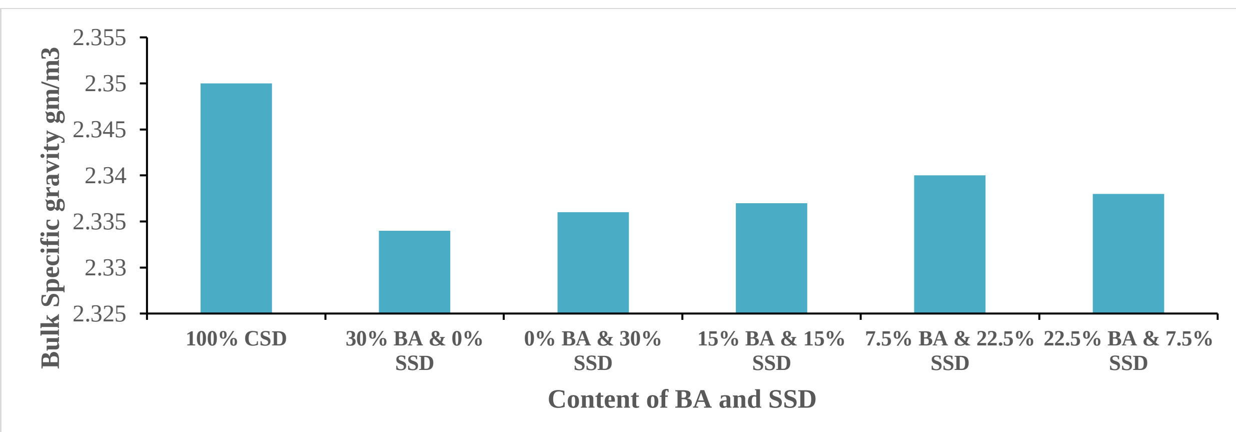


Figure 4.25. Effect of blended bagasse ash & steel slag dust (at 30%) on Bulk Specific Gravity

The figure describes the laboratory test result of a bulk-density of HMA with a different replacement rate of blended bagasse ash & steel slag dust. Adding 30% BA and 0% SSD was decreased from the 2.350 CSD to 2.337 whereas the addition of 0% BA and 30% SSD improved to 2.343. However, mixing of the CSD with different ratios of non-conventional fillers had more increased bulk density than mixing separately BA and SSD with CSD.

The main reason is that the increase in bulk density was due to the increasing of blended BA and SSD filler content in the mix. But the mix of both blended or separated had less bulk-density than from control mix, because control mix has higher specific gravity. From the combination of BA and SSD with CSD in different ratios showed that the bulk density of 7.5% BA and 22.5% SSD was higher than the bulk density of 22.5% BA and 7.5% SSD because the quantity of SSD increased the value of bulk density also increased. These, steel slag dust had more effect and bulk density than bagasse ash reason steel slag dust has higher specific gravity than bagasse ash, because SSD has specific gravity greater than BA.

Therefore, the effect of steel slag dust on Marshall Properties; steel slag dust mix has higher Marshall bulk density. This behavior is because of the dense and porous characteristics of the steel slag. Generally, the bulk density increased with the increase in blended bagasse ash & steel slag dust content, until it reaches the maximum bulk density at 30% (7.5% BA & 22.5% SSD).

7. Summary of Properties of partially replaced of CSD mix with different percentages of blended BA & SSD in HMA production.

It's noticed that all values of marshal stability, flow and volumetric properties of HMA production at 30% of non-conventional filler mixing with 70% conventional filler in different rates content not satisfy the ERA,2013 specifications. However, mixing of the CSD with different ratios of combined non-conventional fillers had greater marshal stability, flow and volumetric properties than mixing BA and SSD separately, but some values did not satisfy the ERA, specifications limits.

In addition, when compared between the combination of BA and SSD individually, the values of marshal properties have a variation i.e., steel slag dust was better than bagasse ash. Anyhow, as obviously shown above, the 30% blended bagasse ash and steel slag dust mix with 70% crushed stone dust at optimum bitumen content (5.10%) by weight of aggregates did not achieve both the local and international specifications requirements for some tested properties. It implies that replacement of crushed stone dust with blended bagasse ash and steel slag dust in hot mixed asphalt affects the performance property of asphalt concrete for a constant percentage of bitumen content (5.10%) with optimum filler content (5.5%) when their quantities increased.

There was also a comparison of the marshalling and volumetric properties of the asphalt mix combination resulted in 0% BA & 30% SSD, 30% BA and 0% SSD and 15% SSD and 15% BA, each with the weight of the optimal crushed stone dust filler (5.5%) at optimal bitumen content (5.10%), while all Marshal parameters at 30% SSD and 30% BA did not meet the standard requirements. Therefore, both BA and SSD were 30% blended together as well as separated and they were not used as a mineral filler in HMA with optimal filler content (by weight of 70% CSD) at optimal bitumen content (5.10%). Mao-Chieh Chi*, 2012, studied the effect of water absorption in mixtures containing BA. Except for the mixture with 10% BA, the water absorption increases slightly with an increasing amount of BA. Slightly less water absorption was observed for blends with 10% BA than for the control blend. However, the 20% BA blends show a slight increase in water uptake compared to the control blend.

As BA's crushed stone substitute increases to 30%, water absorption obviously increases. The high-water uptake of the BA-containing mixtures was due to the porous nature and rough surface of the BA particles. The percentage water absorption is a measure of the pore volume or porosity in hardened concrete that is occupied by water when saturated. In addition, SSD also has a porous nature and a rough surface, but less than compared to BA (Rajesh Lalsing Shirale et al., 2017). It has been reported that BA is hygroscopic and, because of BA's irregular shape with rough surfaces and highly porous textures, it needs more water to get the right consistency compared to cement (Anisha et al., 2020). BA's more porous texture increases water requirements and consequently decreases flow value, resulting in reduced workability. Therefore, a 20% replacement of crushed stone dust from mixed BA and SSD can be considered as the optimal limit.

4.17 The effect of non-Conventional filler (blended BA & SSD) in Marshal Properties

The effect of replacing different percentages of the conventional filler (CSD) with the blended of bagasse ash and steel slag dust on Marshal Stability, Flow, and different volumetric properties of the mixture was evaluated. The effect of non-conventional filler (blended of BA & SSD) in Marshall properties was determined based on the optimum filler content (5.5%) and optimum bitumen content (5.10%), at five different percentages of non-conventional filler (blended of BA & SSD) 0% (control mix, 10%,20% and 30% but each percentage of non-conventional filler also separate for five different proportions with replaced by weight of conventional filler content

(CSD). The mix with 0% of BA & SSD was used as a control mixture to evaluate the effect of both BA & SSD in a mixture, and they were abbreviated as BA & SSD. Tables 4.15 show that the asphalt mixtures laboratory test resulted with different proportions of blend of BA & SSD and CSD filler and the corresponding values of marshal properties at constant bitumen (5. 10%). In the following section, the relationship and effects of varying amounts of blend of BA & SSD on asphalt mixture properties were discussed.

8. Summary of Properties of partially replaced of CSD mix with different percentages of blended BA & SSD in HMA concrete production.

The effect of replacing different percentages of the conventional filler (CSD) with the blend of bagasse ash and steel slag dust on Marshal Stability, Flow, and different volumetric properties of the mixture was evaluate. The effect of non-conventional filler (blended of BA & SSD) in Marshal properties were determined based on the optimum filler content (5.5%) and optimum bitumen content (5.10%) at five different percentages of non-conventional filler (blended of BA & SSD) 0% (control mix, 10%, 20% and 30%). At each percentage of non-conventional filler also separate for five different proportions with replaced by weight of conventional filler content (CSD).

The mix with 0% of BA & SSD used as a control mixture to evaluate the effect of both BA & SSD in a mixture. As it was present in the table 6.1-5, the marshals mix test result for Marshall Properties indicates that the value of these test result was exceeding the value of ERA and Asphalt Institute specification limits. Thus, the test of volumetric properties of the material was slightly became rejected. Hence, it was concluded that, replacement of mineral filler (CSD) with blended bagasse ash and steel slag dust in hot mix asphalt affects the VA, VMA, VFA, marshal stability and flow when increase the amount of non-conventional filler existed in the pavement.

9. Effect of blended bagasse ash & steel slag dust as mineral filler on moisture susceptibility.

Moisture damage to asphalt mixtures is one of the major distresses in asphalt pavement. The moisture damage results from two failure mechanisms; losing bonds within the asphalt binder and losing bond adhesive bonds between the aggregate and the binder. It made six Marshall Specimens for the optimum non-conventional filler replacement mix type at the optimum asphalt content with 75 *2 blows to represent the pavement density achieved at the time of construction. Specimen specific gravity and air-void content were determined. These specimens were randomly dividing into equal groups: controlled specimens and conditioned specimens. I tested the control specimens for tensile strength at 25°C(77°F) at a constant deformation rate of 50 mm / min. (2 in.) per minutes using the indirect tensile test.

The steel pan containing the specimen was place in a water bath at 60°C (140°F) for 24 hours. After 24 hours removing specimens from in 60°C (140°F) water bath and place them in a water bath already at 25°C(77°F) for 2hours, as soon as possible after placement in the water bath remove the specimen and it was ready for mechanical testing. The conditioned specimen was tested for tensile strength similar to the control specimen. The test results for the tensile strength ratio show that the moisture susceptibility of the mix is the conditional of the test group to the control group. The TSR has to satisfy the minimum specification requirement of 80%. The tensile strength ratio (TSR) of the mix, which is an indicator of moisture-induced damage and its values were calculated as a ratio of, (Stm) average tensile strength of the moisture conditioned and (Std) average tensile strength of the dry subset (unconditioned).

When conditioning it in water for 24 hours at 60°C the blended bagasse ash & steel slag dust resists the washing effect of water and eventually results in higher tensile strength. It is a fact that the ingredients of blended bagasse ash & steel slag dust are insoluble polar molecules of the asphalt. This might be the occurrence of a different physical and chemical nature of the material, which means bagasse ash & steel slag dust both had different chemical compositions (SiO_2, Al_2O_3 and Fe_2O_3) but both had higher SiO_2. Therefore, this shows SiO2 is not soluble in either water or organic solvent because this blended bagasse ash & steel slag dust is moisture susceptibility resistance. The mixes are prepared by using blended bagasse ash & steel slag dust as mineral fillers for HMA production because they have better resistance to moisture effects.

The mixtures prepared for conventional (control 0%) and non-conventional (blended bagasse ash & steel slag dust at optimum replacement rate of filler i.e., at 20% or 5% BA & 15% SSD at constant bitumen content or 5.10%, OBC) and were evaluated to show the effect of mineral filler types used in the mixes. The study reveals that as a percent of blended bagasse ash & steel slag dust increased at a constant 5.10% of OBC, there was a slight increase in dryness of the mixes. This is because of the existence of fewer portions of binder films on aggregate surface because of loss in effective binder because of internal absorption of aggregate. This shows that the mix prepared with blended bagasse ash & steel slag dust requires higher OBC to coat the mix uniformly.

Therefore, the TSR values of the mixes are the difference in the adhesive bond between the aggregate and binder of the 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 loss effective binder of the mix. So far, despite the difference in asphalt film thickness, the TSR values at optimum replacement of the study are in good performance range that is 87.942%. The result of this shows the asphalt mixture with 20% blended bagasse ash & steel slag dust had a TSR of 87.942%, which fulfilled the specification limit of 80%.

Table 4.35. The tensile strength ratio (TSR) of the mix is an indicator of moisture-induced damage and it adjusted by using adjusting factors based on specimen thickness.

Trial	Fillers	Wet load (N)	Adjust Wet load (N)	Dry load (N)	Adjust Dry load (N)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	ITS1 (KPa)	ITS2 (KPa)	TSR	Average TSR (%)	Multiple Factors	Blended Filler types
1	20%=blended 15%BA +5%SSD	8090	7523.700	9880	9188.400	66.87	67.78	100	716.639	863.453	0.830	85.322	0.93	blended 15%BA &5%SSD
		8790	8174.700	9170	8528.100	66.88	67.87	100	778.531	800.340	0.973		0.93	
2	20%=blended 5%BA+ 15%SSD	8710	8100.300	10030	9327.900	66.96	67.81	100	770.524	876.174	0.879	87.942	0.93	blended 5%BA& 15%SSD
		9090	8453.700	9090	8453.700	66.98	67.83	100	793.826	793.826	1.000		0.93	
3	100%CSD	9090	8453.700	9890	9197.700	66.69	67.77	100	807.396	864.454	0.934	86.717	0.93	Only100 % CSD
		9790	9104.700	9190	8546.700	66.93	67.67	100	866.453	804.457	1.077		0.93	

10. Summary of Properties of partially replaced of CSD mix with different percentages of blended BA & SSD in HMA concrete production

Marshall Stability test is done for a replaced mix with different percentage rate of blended bagasse ash & steel slag dust as discussed above. The relationship between each Marshall Property with the replaced mix by blended bagasse ash & steel slag dust is discussed above the Tables and Figures.

- ✓ When steel slag dust added more than bagasse ash. The Marshall Stability, flow and volumetric properties of asphalt mixture satisfied the international and local specification limits. It started, the replacement rate from 10% to 30%.
- ✓ When bagasse ash added more than steel slag dust, the Marshall Stability, flow and volumetric properties of asphalt mixture also satisfy the international and local specification limit. These test results increased from 10% to 20% of the blended BA and SSD but decreased after the 30% replacement started, but some replacements were to meet the range of specifications limit while the other replacements also declined from the specification limit.
- ✓ When added an equal amount of both BA and SSD the marshal stability, flow and volumetric properties of asphalt mixture increased continuously from 10% -20% replacements, in the same way decrease when compared with steel slag dust added more than bagasse ash and vice versa. Further, the laboratory test results satisfied the international and local specification limits until the maximum value of the test results was reached.
- ✓ When adding BA fillers in full amount without SSD (10% BA & 0% SSD,20% BA & 0% SSD) in the same way, adding SSD fillers in full amount without BA (0% BA & 20% SSD,0% BA & 20% SSD) in partially replaced CSD then the marshal stability, flow and volumetric properties of asphalt mixture were meet standards of ERA,2002 and international specification limit and increased continuously from 10% -20% fillers replacements.
- ✓ According to in this research findings, the marshal stability, flow and volumetric properties of asphalt mixture were decreased at 30% non-conventional filler added starts (30% BA and 0% SSD, 0% BA & 30% SSD) but the test results began to decline after this test completed, which means the laboratory test of marshal stability, flow and volumetric

properties of asphalt mixture results were became out of and below standards. Therefore, it did not satisfy international and local specification limits.

- ✓ The mix obtained by using 10% and 20% replacement ratio of blended steel slag dust and bagasse ash were meets the standards specified in terms of Stability, Bulk density, flow, VA, VMA and VFA at an optimum Bitumen Content of 5.10% by optimum filler Content.

4.18 Determination of the potential replacement ratio of blended bagasse ash and steel slag dust in hot mix Asphalt Concrete production

This study was focused on determining the potential percentage ratio of blended bagasse ash & steel slag dust fillers that used to be replaced the crushed stone dust filler. This was depending on the laboratory test results, which satisfied all the specification standards. As discussed above, the study was done by 10% interval (trial-and-error method) of replacement rate until it fulfills the specification standards in all properties, as shown above in each property related to replacement rate of blended bagasse ash & steel slag dust it was satisfied up to 20% replacement rate in all properties. However, starting from 30% replacement rate, stability could not have achieved the specification standard of ERA pavement Design Manual, 2002.at 30% (15% BA &15%) the maximum of stability is 6.9KN, which is below the minimum standard requirement of ERA Pavement Design Manual, 2002. Hence, blended bagasse ash & steel slag dust fillers could be replaced crushed stone dust filler in Hot Mix Asphalt up to 20% (5% BA &15% SSD) replacement rate in all parameters requirement value.

Based on ERA, pavement Design Manual, 2002 criteria, the potential replacement ratio of blended bagasse ash & steel slag dust can be replaced crushed stone dust fillers in Hot Mix Asphalt production is 20% (by weight of OFC, i.e.,5.5% and at optimum bitumen content of 5.10%).

4.19 Determination of the optimum replacement ratio of blended bagasse ash and steel slag dust in hot mix asphalt concrete production

From this study, determining the optimum replacement ratio of blended bagasse ash & steel slag dust is necessary. Table 4.16, 4.17 & 4.18 showed the properties of replaced mix with different proportions of blended bagasse ash & steel slag dust. Based on this, the control mix with 0% of blended bagasse ash & steel slag dust was referenced as the control for the determination of optimum filler proportion-the researcher stated that a set of controls is recommended in order to get the optimum replacement rate. From this point, the asphalt mix with the following marshal results was select as the optimum replacement proportion those are: Maximum Stability, Maximum bulk density, and VA with the allowed range of specifications. These used to compare the test results while get the optimum replacement rate of blended bagasse ash & steel slag dust fillers, and they are satisfying the above three criteria.

The maximum stability, Maximum bulk density, and VA were recorded at 20% replacement rate (Considering from 10%-30% replacement rate). As shown in the table above, it satisfied the requirements of ERA pavement design manual, 2002 and Asphalt Institute, 2003 for all tested properties. Hence, it is more effective to use blended bagasse ash & steel slag dust fillers (blend by unequal amount) with maximum replacement rate of 20% blended bagasse ash & steel slag dust by weight of optimum filler content or 1.1% by weight of one specimen mixture of aggregates. Table 4.17 also represents the percentage of partial replacement rates martial properties at different filler content that all replacement rates were within the requirement specification range, at 20% blended bagasse ash & steel slag dust (by weight of OFC) the corresponding air voids value was 4.7% which is more than the median air voids in the specification.

Therefore, the mix that obtained by using 20% blended bagasse ash & steel slag dust and 80% CSD (by weight of OFC) meets the criteria of selecting optimum replacement rate. Generally, 20% blended bagasse ash & steel slag dust (by weight of optimum filler content) with 5.10% of asphalt content (by weight of total mix) was adopted as the optimum replacement rate.

4.20 Comparison of optimum replacement proportion of non-conventional filler used as mineral filler

In this study, the above figure or discussion of the relationship between the replaced mixes with the control mix is used as an input in order to determine the optimum replacement proportion of non-conventional filler (blended bagasse ash & steel slag dust). In this manner, Table 4.16, 4.17 & 4.18 and Figures from 4.8-4.19 are used to find optimum replacement proportion, which satisfied the above three controls. In addition, all the replaced mix satisfies the Marshall property that was specified in both local and international specifications.

From the above discussion the relationship between the replaced proportion of blended bagasse ash & steel slag dust with controls of the mix can be concluded as the replacement proportion at 20% of non-conventional filler blended bagasse ash & steel slag dust satisfies the above controls i.e. the mix with maximum stability, maximum bulk-density and the air void value 4.0% which is the median air voids in the specification .The selected optimum replacement proportion at 20%

(5%BA & 15%SSD) of blended bagasse ash & steel slag dust or 1.1% of blended bagasse ash & steel slag dust by weight of aggregate was selected at optimum bitumen content of 5.10%.
Therefore, 20% of blended bagasse ash & steel slag dust by weight of optimum conventional filler content (CSD) at 5.5% was adopted as the optimum replacement proportion of non-Conventional filler (blended bagasse ash & steel slag dust). Table 4.17 illustrates a compressible of marshal properties with the optimum replacement proportion of the mix, which is 20% of blended bagasse ash & steel slag dust with the local specification (ERA, Pavement Design Manual, 2002, and International Specification Manual, 2003).

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

According to this study, the conventional filler has been replaced with different proportions of non-conventional fillers. The optimum replacement proportion and some engineering properties of used materials have been examined as stated in the objectives of the research. Based on the results of experimental the following conclusions are drawn.

- ✓ Locally available industrial waste materials like steel slag and bagasse ash are used for a partial replacing conventional filler in hot mix asphalt concrete production to minimizing the consumption of conventional filler (CSD) and decrease environmental pollution. For developing countries like Ethiopia, using locally available materials is one means of enhancing the economy and reducing environmental pollution.
- ✓ Laboratory test of physical properties of aggregates (AIV, ACV, LLA, Flakiness index, Water absorption, Apparent SG, Bulk SSD S.G and Bulk Dry S.G), bitumen (Penetration grade, softening point, Ductility and Specific Gravity) and fillers (plastic index and specific gravity) used in the hot mix asphalt results are satisfied minimum requirement specification.
- ✓ All the Marshall mix properties at three different conventional fillers (4.5%, 5.5% and 6.5%) and the five different proportions of bitumen content by a total mix of aggregates were satisfied ERA, Pavement Design Manual and Asphalt Institute specification.
- ✓ The OFC of CSD was determined on the basis of maximum Marshall Stability, maximum unit weight and flow on the range. It was observed that 5.5% filler content of CSD and by using MS-2 method OBC was selected at 5.10% were used for replacement mix design of the study.
- ✓ Marshall Test result values showed that the asphalt mixtures prepared using by 20% blended steel slag dust and bagasse ash fillers and 80% CSD fillers with 5.10% of bitumen content has Maximum Stability, Maximum Bulk-Density and VA (%) within the allowable specification requirement ranges to select the optimum replacement percentage rate since, the blended steel slag dust and bagasse ash can partially replace the crushed stone dust filler in hot mix asphalt at optimum replacement rate of 20% (by weight of optimum filler

content) or 1.1% (by weight of one specimen mixture aggregate) with a constant bitumen content of 5.10%.

- ✓ From the test results, the optimum replacement percentage of blended BA and SSD was found at 20% (5%BA and 15% SSD) by weight of OFC (5.5%) at a bitumen content of 5.10%. Asphalt mixes prepared with blended BA and SSD filler are not sensitive to the action of water and result in better resistance to moisture-induced damage. The values at 20% blended BA and SSD (by weight of OFC) replacement were stability of 11.0 KN, bulk density of 2.349 gm/cm3 and air void (VA) of 4.0%, which were the best when compared to other percentage replacement ratio values. Hence, 20% (by weight of OFC) is adopted as the optimum replacement ratio of blended BA and SSD**.**
- ✓ When steel slag dust added more than bagasse ash the Marshall stability, flow and volumetric properties of asphalt mixture were satisfying the international and local specification limit.
- ✓ When bagasse ash added more than steel slag dust the Marshall stability, flow and volumetric properties of asphalt mixture also satisfy the international and local specification limit. These test results were an increase from 10% to 20% the blended BA and SSD but decrease after the 30% replacement started but some replacements were to meet the ranges of the both specifications limit while the other replacements also declined from the specification limit.
- ✓ When added an equal amount of both BA and SSD the Marshall stability, flow and volumetric properties of asphalt mixture were increase continuously from 10% -20% replacements, in the same way decrease when compared with steel slag dust added more than bagasse ash and vice versa. Further, the laboratory test results were satisfying the international and local specification limit until the maximum value of the test results got.
- ✓ When added BA fillers in full amount without SSD (10% BA &0% SSD,20% BA &0% SSD) in the same way added SSD fillers in full amount without BA (0% BA &20% SSD,0% BA & 20% SSD) in partially replaced CSD then the marshal stability, flow and some volumetric properties of asphalt mixture were meet standards of ERA,2002 and international specification limit and increase continuously from 10% -20% fillers replacements.

- ✓ According to in this research findings the Marshall stability, flow and volumetric properties of asphalt mixture were increased when non-conventional filler added starts from 10% (blended BA and SSD) up to 20% (blended BA & SSD) but the test results began declined after this test completed or when started from 30% (blended BA &SSD), which means the laboratory test of marshal stability, flow and volumetric properties of asphalt mixture results were becomes out of the rage (above and below). Therefore, it did not satisfy international and local specification limits.
- ✓ Furthermore, the result of Marshall parameters such as stability, air voids, and bulk density values were consistent within the standard specification at 20% of blended steel slag dust and bagasse ash content. Therefore, non-conventional (blended steel slag dust and bagasse ash) filler can be used in asphalt binder course with the optimum replacement rate of 20% (5% BA &15% SSD) by weight of conventional filler (CSD) for heavy traffic.
- ✓ The chemical properties of SSD and BA statistically result indicated that the MgO composition required for pozzolan was 2.00% and 1.08% respectively which is less than the maximum requirement. SiO2, Al2O3 and Fe2O3 of both samples is a good pozzolanic materials satisfied minimum requirement specification.
- ✓ From the optimum test result, the potential of BA and SSD as filler materials in HMA was at 15% of SSD and 5% of BA with 80% of CSD filler contents are satisfying the control specification those are Maximum bulk density, Maximum stability and Va% within the allowed range of specification and suggested that the utilization of partial replaced of BA and SSD for HMA.
- ✓ The asphalt mixtures with 100%CSD, 15%BA & 5%SSD, and 15% SSD &5%BA with 80% of CSD are 86.717, 85.322 and 87.942% of TSR result respectively, so all are fulfilled the TSR specification. Both BA and SSD containing mixture was industrial waste materials but SSD had higher TSR, this indicating a higher moisture resistance of HMA when compare with CSD and BA.

5.2 Recommendation

Each region of the world should play a role in environmental protection and sustainability use of natural resources. Ethiopian construction companies also play a great role by using locally waste materials partially and benefits from it as the other countries did. Therefore, based on the findings of the study following recommendations are forwarded from the researcher.

- ✓ The local road agencies are advised to use non-conventional filler (blended steel slag dust and bagasse ash) as a partial replacement of conventional filler (CSD) in hot mix asphalt with a maximum percentage of 20% (5% BA and 15% SSD) by weight of optimum CSD filler.
- ✓ The sugar and steel factories in collaboration with higher education organizations in the country should work together and establish a research team to further study the use of bagasse ash and steel slag dust as a crushed stone dust replacing material and/or uses of bagasse ash and steel slag dust in construction industry and to reprocess waste products.
- ✓ Finally, the researcher recommends the Ethiopian Road Authority there are so many researches like partial replacement of steel slag dust and bagasse ash individually as a mineral filler in hot mix asphalt production but the two materials are blended together used as partial replacement of conventional filler (CSD). Therefore, they must be used from the researchers' study work.
- ✓ It is recommended that further research should be carried out to investigate the cost effectiveness of both SSD and BA for use as fillers in HMA.
- ✓ This study investigates the effect of the blended bagasse ash and steel slag dust at optimum bitumen content. Therefore, further investigation is needed the effect of the blended bagasse ash and steel slag dust on each of bitumen content.
- ✓ Investigate the effects of using Steel Slag and bagasse ash incorporated with other waste materials on the asphalt pavement properties.
- ✓ further investigation is needed the effect of the blended bagasse ash and steel slag dust on pavement rutting and fatigue tests.

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APPEDEXI

APPEDEXI-A: - Physical properties, aggregate quality test, Bitumen quality test and Mineral filler quality test

Table A.1. Bitumen Quality Test Result

	Test method	Test No.	Test Temp. (C)	Time of test (S)	Test load (g)	Reading date (0.1mm)			Average (0.1mm)
						1st time	2nd time	3rd time	
Penetration at 25˚c	AASHTO T49/ASTM D70	1	25	5	100	63.83	61.88	60.78	62.16
		2	25	5	100	68.32	67.54	62.86	66.24
		3	25	5	100	63.59	65.98	67.94	65.84
Average penetration									64.75
	Test method	Test No.	Test temp.	Speed cm/mm			Ductility (cm)		Average (cm)
Ductility at 25˚c	AASHTO T51/ASTM D113	1	25	5			89		86.33
		2	25	5			86		
		3	25	5			84		
	Test method	Test No.	Test temp. when starting to heating (C°)			Record of liquid temp. in breaker			Softening pt. (C°)
						4min	5min	6min	
Softening point at 25˚c	AASHTO T53/ASTM D36	1	24					6min	45.85
		2	24				5min		49.35
Average (C°)									47.6
Flash point ˚c	ASTM D 92								287.9
Bitumen Specific Gravity at 25˚c					Test Method ASTM D 70				1.03

Table A.2. Physical properties of aggregate test result

Test	Test method	Test result				Specification
		25-13mm	13-6mm	3-6mm	3-0mm	
Bulk dry S. G	AASHTO T85-95	2.615	2.622	2.624	2.634	
Bulk SSD S. G		2.664	2.674	2.675	2.686	
Apparent S. G		2.749	2.765	2.767	2.779	
Water absorption	BS 812-part 2	1.863	1.967	1.978	1.986	<2
Flakiness index	BS 812 part 108	25				<45
Aggregate Crushing Value (ACV) %	BS 812 part 110	15.90				<25
Aggregate impact Value (AIV) %		7.682				
LOS Angeles Abrasion (LAA) %	AASHTO T85-95	16				<30

Table A.3. Physical Properties of Mineral Filler Test Result (CSD)

Specific gravity of mineral filler (CSD) passing sieve No. (#200)/ (0.075)		
Pycnometer code	3	C
A. mass of empty pycnometer (g)	30.36	30.73
B. mass of oven dry sample, g	24.910	25.820
C.mass of pycnometer +water g	125.110	126.100
D.Temp.of water when Mpw taken, Ti	24C°	24C°
E. mass of pycnometer+sample+water Mpws	141.670	142.920
F. Temp.when Mpws taken, Tx	27C°	27C°
G. K for Tx	0.9983	0.9983
I. Specific gravity (Gs)=k*A/(A+B-C)	2.978	2.864
J. Average Specific gravity	2.921	

Table A.4. Physical properties of non-conventional mineral filler (Steel Slag Dust)

Specific gravity of steel slag filler (SSD) passing sieve No. (#200)/ (0.075)		
Pycnometer code	C	3
A. mass of empty pycnometer (g)	30.94	30.59
B. mass of oven dry sample, g	24.000	25.000
C.mass of pycnometer +water g	125.130	124.120
D.Temp.of water when Mpw taken, Ti	26C°	26C°
E. mass of pycnometer+sample+water mpws	141.070	140.110
F. Temp.when Mpws taken, Tx	25C°	25C°
G. K for Tx	1	1
I. Specific gravity (Gs)=k*A/(A+B-C)	2.978	2.775
J. Average Specific gravity	2.876	
K. Plastic index	Non-Plastic	<4

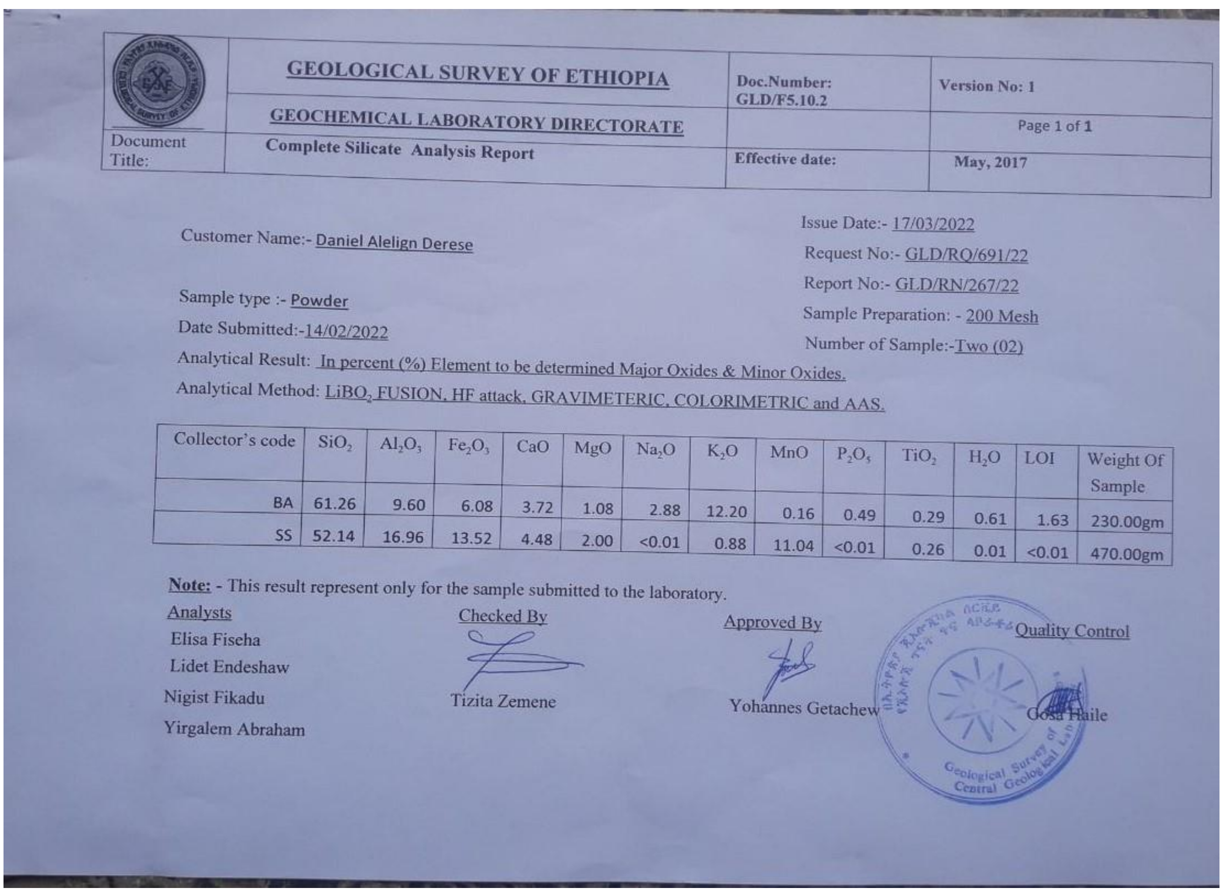
Table A.5. Physical properties of non-conventional mineral filler (Bagasse Ash)

Specific gravity of bagasse ash filler (BA) passing sieve No. (#200)/ (0.075)		
Pycnometer code	C	3
A. mass of empty pycnometer (g)	30.94	30.59
B. mass of oven dry sample, g	25	25
C.mass of pycnometer +water g	113.600	112.520
D.Temp.of water when Mpw taken, Ti	28C°	27C°
E. mass of pycnometer+sample+water mpws	129.810	128.810
F. Temp.when Mpws taken, TX	26C°	26C°
G. K for Tx	0.9997	0.9997
I. Specific gravity (Gs)=k*A/(A+B-C)	2.843	2.869
J. Average Specific gravity	2.856	
K. Plastic index	Non-Plastic	<4

Table A.6. Physical properties of blended bagasse ash and steel slag dust filler

Material Type:	Gs of Blended BA and SSD) Passing 0.075mm		
Trial No.	1	2	3
A. mass of empty pycnometer (g)	30.20	31.00	30.30
B. mass of oven dry sample, g	26.000	26.000	26.000
C.mass of pycnometer +water g	123.200	121.500	123.400
D.Temp.of water when Mpw taken, Ti	24C°	23C°	24C°
E. mass of pcynometer+sample+water mpws	139.610	138.700	140.710
F. Temp.when Mpws taken, Tx	27C°	26C°	27C°
G. K for Tx	0.9983	0.9983	0.9983
H. Apparent spec. gravity Gs=A*K/(A+B-C)	2.707	2.950	2.987
I. Average Apparent Specific gravity (Gs)	2.881		

Table A -7 Chemical properties of bagasse ash and steel slag dust filler



	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

Customer Name:- Daniel Alelign Derese

Issue Date:- 17/03/2022

Request No:- GLD/RQ/691/22

Report No:- GLD/RN/267/22

Sample type :- Powder

Date Submitted:-14/02/2022

Sample Preparation: - 200 Mesh

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	Weight Of Sample
BA	61.26	9.60	6.08	3.72	1.08	2.88	12.20	0.16	0.49	0.29	0.61	1.63	230.00gm
SS	52.14	16.96	13.52	4.48	2.00	<0.01	0.88	11.04	<0.01	0.26	0.01	<0.01	470.00gm

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

Analysts: Elisa Fiseha, Lidet Endeshaw, Nigist Fikadu, Yirgalem Abraham

Checked By: Tizita Zemene

Approved By: Yohannes Getachew

Quality Control: Gosa Haile

APPEDIX-B: - Particle Size Distribution and Gradation of Aggregate

Table B.1. Particle size distribution

Material type: coarse aggregate (CA) 25-13mm			
After Wash dry sample (g)			3560
After Wash dry sample (g)			3545.0
Sieve size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (g)
25	0.0	3560.0	100.0
19	1020.0	2540.0	71.3
12.5	2057.5	482.5	13.6
9.5	305.0	177.5	5.0
4.75	159.5	18.0	0.4
2.36	2.0	16.0	0.4
1.18	1.0	15.0	0.4
0.6		15.0	0.4
0.3		15.0	0.4
0.15		15.0	15.0
0.075		15.0	0.4
pan	0.0		
Wash loses	15.0		
Total	3560.0		

Material type: Intermediate aggregate (IA 1) 13-6 mm			
After Wash dry sample (g)			3824
After Wash dry sample (g)			3809.0
Sieve size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (g)
25	0.0	3824.0	100.0
19	0.0	3824.0	100.0
12.5	122.4	3701.6	96.80
9.5	1113.6	2588.0	67.7
4.75	2008.2	579.8	15.2
2.36	503.8	76.0	2.0
1.18	45.0	31.0	0.8
0.6	13.0	18.0	0.5
0.3	3.0	15.0	0.4
0.15		15.0	0.4
0.075		15.0	0.4
pan	0.0		
Wash loses	15.0		
Total	3824.0		

Material type: Intermediate aggregate (IA 2) 6-3 m			
After Wash dry sample (g)			3640
After Wash dry sample (g)			3620
Sieve size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (g)
25	0.0	3640.0	100.00
19	0.0	3640.0	100.00
12.5	0.0	3640.0	100.00
9.5	10.0	3630.0	99.73
4.75	446.8	3183.2	87.45
2.36	2466.8	716.4	19.68
1.18	306.0	410.4	11.27
0.6	215.6	194.8	5.35
0.3	116.2	78.6	2.16
0.15	38.6	40.0	1.10
0.075	20.0	20.0	0.55
pan			
Wash loses	20.0		
Total	3640.0		

Material type: Finer aggregate (FA) 3-0 mm			
After Wash dry sample (g)			1980
After Wash dry sample (g)			1720
Sieve size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (g)
25	0	1980	100.00
19	0	1980	100.00
12.5	0	1980	100.00
9.5	0	1980	100.00
4.75	10.6	1969.4	99.46
2.36	100	1869.4	94.41
1.18	504.6	1364.8	68.93
0.6	484.8	880	44.44
0.3	266.6	613.4	30.98
0.15	195.6	417.8	21.10
0.075	151.8	266	13.43
pan	6	260	13.13
Wash loses	260		
Total	1980		

Table B.2. Percentage Passing and Blending proportion of Asphalt Mix for 4.5% CSD.

			sieve	25	19	12.5	9.5	4.75	2.36	1.18	0.5	0.3	0.15	0.075
		TYPE												
		CA (25-13mm)		100.0	71.3	13.6	5.0	0.5	0.4	0.4	0.4	0.4	0.4	0.4
		IA 1(13-6mm)		100.0	100.0	96.80	67.7	15.2	2.0	0.8	0.5	0.4	0.4	0.4
		IA 2(6-3mm)		100.00	100.00	100.00	99.73	87.45	19.68	11.27	5.35	2.16	1.10	0.55
		FA(3-0mm)		100.00	100.00	100.00	100	99.46	94.41	68.93	44.44	30.98	21.10	13.43
		Filler		100	100	100	100	100	100	100	100	100	100	100
			sieve	25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
BLENDING I %		TYPE	Suggested percentages for binder course aggregate mix for 4.5 % filler content											
	24.5	CA (25-13mm)		24.50	17.48	3.32	1.22	0.12	0.11	0.10	0.10	0.10	0.10	0.10
	32	IA 1(13-6mm)		32.00	32.00	30.98	21.66	4.85	0.64	0.26	0.15	0.13	0.13	0.13
	16	IA 2(6-3mm)		16.00	16.00	16.00	15.96	13.99	3.15	1.80	0.86	0.35	0.18	0.09
	26.63	FA(3-0mm)		26.63	26.63	26.63	26.63	26.49	25.14	18.36	11.84	8.25	5.62	3.58
	0.87	Filler		0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
Total	100	Combined		100.00	92.98	77.80	66.33	46.33	29.91	21.39	13.82	9.69	6.89	5
		upper		100	100	88	80	65	49	37	28	19	13	8
		Middle		100	95	79.5	68	50	36	26	19	12	8.5	5
		lower		100	90	71	56	35	23	15	10	5	4	2

Table B.3. Percentage Passing and Blending proportion of Asphalt Mix for 5.5% CSD.

			sieve	25	19	12.5	9.5	4.75	2.36	1.18	0.5	0.3	0.15	0.075
		TYPE												
		CA (25-13mm)		100.0	71.3	13.6	5.0	0.5	0.4	0.4	0.4	0.4	0.4	0.4
		IA 1(13-6mm)		100.0	100.0	96.80	67.7	15.2	2.0	0.8	0.5	0.4	0.4	0.4
		IA 2(6-3mm)		100.00	100.00	100.00	99.73	87.45	19.68	11.27	5.35	2.16	1.10	0.55
		FA(3-0mm)		100.00	100.00	100.00	100	99.46	94.41	68.93	44.44	30.98	21.10	13.43
		Filler		100	100	100	100	100	100	100	100	100	100	100
			sieve	25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
BLENDING I %		TYPE	Suggested percentages for binder course aggregate mix for 5.5 % filler content											
	24.5	CA (25-13mm)		24.50	17.48	3.32	1.22	0.12	0.11	0.10	0.10	0.10	0.10	0.10
	32	IA 1(13-6mm)		32.00	32.00	30.98	21.66	4.85	0.64	0.26	0.15	0.13	0.13	0.13
	16	IA 2(6-3mm)		16.00	16.00	16.00	15.96	13.99	3.15	1.80	0.86	0.35	0.18	0.09
	25.9	FA(3-0mm)		25.90	25.90	25.90	25.90	25.76	24.45	17.85	11.51	8.02	5.47	3.48
	1.6	Filler		1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Total	100	Combined		100.00	92.98	77.80	66.33	46.33	29.95	21.62	14.22	10.20	7.47	5
		upper		100	100	88	80	65	49	37	28	19	13	8
		Middle		100	95	79.5	68	50	36	26	19	12	8.5	5
		lower		100	90	71	56	35	23	15	10	5	4	2

Table B.4. Percentage Passing and Blending proportion of Asphalt Mix for 6.5% CSD.

			sieve	25	19	12.5	9.5	4.75	2.36	1.18	0.5	0.3	0.15	0.075
		TYPE												
		CA (25-13mm)		100.0	71.3	13.6	5.0	0.5	0.4	0.4	0.4	0.4	0.4	0.4
		IA 1(13-6mm)		100.0	100.0	96.80	67.7	15.2	2.0	0.8	0.5	0.4	0.4	0.4
		IA 2(6-3mm)		100.00	100.00	100.00	99.73	87.45	19.68	11.27	5.35	2.16	1.10	0.55
		FA(3-0mm)		100.00	100.00	100.00	100	99.46	94.41	68.93	44.44	30.98	21.10	13.43
		Filler		100	100	100	100	100	100	100	100	100	100	100
			sieve	25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
BLENDING I %		TYPE	Suggested percentages for binder course aggregate mix for 6.5 % filler content											
	24.5	CA (25-13mm)		24.50	17.48	3.32	1.22	0.12	0.11	0.10	0.10	0.10	0.10	0.10
	32	IA 1(13-6mm)		32.00	32.00	30.98	21.66	4.85	0.64	0.26	0.15	0.13	0.13	0.13
	16	IA 2(6-3mm)		16.00	16.00	16.00	15.96	13.99	3.15	1.80	0.86	0.35	0.18	0.09
	25.5	FA(3-0mm)		25.50	25.50	25.50	25.50	25.36	24.08	17.58	11.33	7.90	5.38	3.43
	2	Filler		2	2	2	2	2	2	2	2	2	2	2
Total	100	Combined		100.00	92.98	77.80	66.33	46.33	29.97	21.74	14.44	10.47	7.79	6
		upper		100	100	88	80	65	49	37	28	19	13	8
		Middle		100	95	79.5	68	50	36	26	19	12	8.5	5
		lower		100	90	71	56	35	23	15	10	5	4	2

Table B.5. Percentage Passing and blending proportion conventional and non-conventional fillers (Source, Daniel Alelgn,2014).

CSD	BA&SSD	Non-conventional filler ratio for Marshall mix design by 5.5% filler ratios in 1200g total mix materials.										Total Fillers
90%CSD (4.95gm)	10% blended BA&SSD (0.55gm	Bagasse Ash (BA %)					Steel Slag Dust (SSD %)					5.50%
		0%	2.50%	5%	7.50%	10%	0%	2.50%	5%	7.50%	10%	
		0	0.014	0.275	0.536	0.55	0	0.014	0.275	0.536	0.55	10%
CSD	BA&SSD	Bagasse Ash (BA %)					Steel Slag dust (SSD %)					5.50%
80%CSD (4.4gm)	20% blended BA&SSD (1.1gm)	0%	5%	10%	15%	20%	0%	5%	10%	15%	20%	
		0	0.055	0.55	1.045	1.1	0	0.055	0.55	1.045	1.1	20%
CSD	BA&SSD	Bagasse Ash (BA %)					Steel Slag Dust (SSD %)					5.50%
70%CSD (3.85gm)	30% blended BA &SSD (1.65gm)	0%	7.50%	15%	22.50%	30%	0%	7.50%	15%	22.50%	30%	
		0	0.124	0.825	1.526	1.65	0	0.124	0.825	1.526	1.65	30%

Table B.6. Aggregate Gradation for 4.5% filler (crushed stone dust)

Aggregate gradation for filler 4.5% Crushed Stone Dust					ASTM D3515 Specification	
Sieve Size	Mass Retained	%Retain	cc. retained	% Passing	Lower limit	Upper limit
25.00	0.00	0.00	0.00	100.00	100	100
19.00	81.50	6.79	6.79	93.21	90	100
12.50	165.27	13.77	20.56	79.44	71	88
9.50	118.23	9.85	30.42	69.58	56	80
4.75	239.00	19.92	50.33	49.67	35	65
2.36	166.00	13.83	64.17	35.83	23	49
1.18	118.00	9.83	74.00	26.00	15	37
0.60	86.00	7.17	81.17	18.83	10	28
0.30	78.00	6.50	87.67	12.33	5	19
0.15	46.00	3.83	91.50	8.50	4	13
0.075	48.00	4.00	95.50	4.50	2	8
Pan	54.00	4.50	100.00	0.00		
Total	1200.00	100.00				

Table B.7. Aggregate Gradation for 5.5% filler (crushed stone dust)

Aggregate gradation for filler 5.5% Crushed Stone Dust					ASTM D3515 Specification	
Sieve Size	Mass Retained	%Retain	cc. retained	% Passing	Lower limit	Upper limit
25.00	0.00	0.00	0.00	100.00	100	100
19.00	76.00	6.33	6.33	93.67	90	100
12.50	144.00	12.00	18.33	81.67	71	88
9.50	115.00	9.58	27.92	72.08	56	80
4.75	218.00	18.17	46.08	53.92	35	65
2.36	163.00	13.58	59.67	40.33	23	49
1.18	152.00	12.67	72.33	27.67	15	37
0.60	86.00	7.17	79.50	20.50	10	28
0.30	74.00	6.17	85.67	14.33	5	19
0.15	48.00	4.00	89.67	10.33	4	13
0.075	58.00	4.83	94.50	5.50	2	8
Pan	66.00	5.50	100.00	0.00		
Total	1200.00	100.00				

Table B.8. Aggregate Gradation for 6.5% filler (crushed stone dust)

Aggregate gradation for filler 6.5% Crushed Stone Dust					ASTM D3515 Specification	
Sieve Size	Mass Retained	%Retain	cc. retained	% Passing	Lower limit	Upper limit
25.00	0.00	0.00	0.00	100.00	100	100
19.00	69.00	5.75	5.75	94.25	90	100
12.50	185.00	15.42	21.17	78.83	71	88
9.50	139.00	11.58	32.75	67.25	56	80
4.75	225.00	18.75	51.50	48.50	35	65
2.36	156.00	13.00	64.50	35.50	23	49
1.18	121.00	10.08	74.58	25.42	15	37
0.60	84.00	7.00	81.58	18.42	10	28
0.30	78.00	6.50	88.08	11.92	5	19
0.15	31.00	2.58	90.67	9.33	4	13
0.075	34.00	2.83	93.50	6.50	2	8
Pan	78.00	6.50	100.00	0.00		
Total	1200.00	100.00				

APPEDIX-C: Maximum Theoretical Density of the Uncompact Asphalt Mixtures

Test Method: ASTM Designation: D 2041 -90

Table C.1. Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures with 4.5 % Crushed Stone Dust Filler.

Test Method: ASTMD2041-90										
BC	4.00%		4.50%		5%		5.50%		6%	
Sample NO.	1	2	1	2	1	2	1	2	1	2
A	1247	1249.6	1255	1260.6	1252.2	1258.5	1256.2	1254.6	1263.6	1260.9
B	2304	2319	2304	2319	2304	2319	2304	2319	2304	2319
C	3047.3	3052.5	3049.2	3048.4	3037.8	3055.7	3040.3	3051.8	3042.7	3055.6
Gmm	2.476	2.421	2.462	2.373	2.416	2.412	2.416	2.404	2.407	2.405
Average Gmm	2.448		2.417		2.414		2.410		2.406	

Table C.2. Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures with 5.5 % Crushed Stone Dust Filler.

Test Method: ASTMD2041-90										
BC	4.0%		4.50%		5%		5.50%		6%	
Sample NO.	1	2	1	2	1	2	1	2	1	2
A	1272	1255.7	1271.9	1249.7	1254.4	1260.1	1256.2	1252.8	1263.4	1259.8
B	2304	2319	2304	2319	2304	2319	2304	2319	2304	2319
C	3057.3	3063.6	3056.5	3056.8	3041.8	3058	3040.3	3050.9	3043.6	3054.8
Gmm	2.452	2.457	2.449	2.441	2.428	2.418	2.416	2.405	2.412	2.404
Average Gmm	2.455		2.445		2.423		2.411		2.408	

Table C.3. Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures with 6.5 % Crushed Stone Dust Filler

Test Method: ASTMD2041-90										
BC	4.0%		4.50%		5%		5.50%		6%	
Sample NO.	1	2	1	2	1	2	1	2	1	2
A	1271.1	1259.9	1255.5	1260.6	1258.8	1261.8	1254.6	1251.5	1262.8	1259.8
B	2304	2319	2304	2319	2304	2319	2304	2319	2304	2319
C	3058.8	3069.7	3048.8	3066.5	3048.8	3064.6	3041.3	3053.6	3042	3055
Gmm	2.462	2.474	2.458	2.457	2.449	2.444	2.425	2.421	2.406	2.405
Average Gmm	2.468		2.458		2.447		2.423		2.406	

Table C.4. Theoretical maximum specific gravity of bituminous paving mixtures at 5.5% Crushed stone Dust and 10% blended bagasse ash and steel slag dust at bitumen content of 5.10%.

OBC	5.10%											
Filler Proportion	100%CSD and 0%blenedBA &SSD		blened10%BA &0% SSD		blened0%BA &10% SSD		blened5%BA &5% SSD		blened7.5%BA &2.5% SSD		blened2.5%BA &7.5% SSD	
Trial No.	1	2	1	2	1	2	1	2	1	2	1	2
A	1247.8	1249.6	1245.6	1240	1249	1245.5	1245.6	1241.7	1241.6	1240.5	1246.8	1247.5
B	2309.4	2308.7	2307.3	2308	2305	2306.6	2309.5	2308.4	2310.3	2308.3	2309.9	2306.67
C	3043.9	3045.7	3038.6	3036.96	3038.26	3039.19	3037.85	3042	3039.95	3038.59	3041.88	3042.67
Gmm	2.431	2.438	2.422	2.426	2.422	2.428	2.408	2.444	2.425	2.431	2.422	2.439
Average Gmm	2.434		2.424		2.425		2.426		2.428		2.430	

Table C.5. Theoretical maximum specific gravity of bituminous paving mixtures at 5.5% Crushed stone Dust and 20% blended bagasse ash and steel slag dust at bitumen content of 5.10%.

OBC	5.10%											
Filler Proportion	100%CSD and 0%blenedBA&SSD		blened20%BA &0% SSD		blened0%BA &20% SSD		blened10%BA &10% SSD		blened15%BA &5% SSD		blened5%BA &15% SSD	
Trial No.	1	2	1	2	1	2	1	2	1	2	1	2
A	1247.8	1249.6	1250.2	1249.4	1247.6	1249.7	1248.7	1249.2	1247.7	1249.5	1248.5	1250.8
B	2309.4	2308.7	2308.5	2306.8	2307.8	2306.5	2307.1	2310.6	2309.9	2308.5	2308.8	2307.9
C	3043.9	3045.7	3043.8	3043.8	3043.5	3042.6	3045.4	3044.6	3045.2	3044.8	3045.8	3044.7
Gmm	2.431	2.438	2.428	2.438	2.437	2.433	2.447	2.425	2.435	2.435	2.44	2.433
Average Gmm	2.434		2.433		2.435		2.436		2.435		2.437	

Table C.6. Theoretical maximum specific gravity of bituminous paving mixtures at 5.5% Crushed stone Dust and 30% blended bagasse ash and steel slag dust at bitumen content of 5.10%.

OBC	5.10%											
Filler Proportion	100%CSD and 0%blenedBA &SSD		blened30% BA &0% SSD		blened0% BA &30% SSD		blened15% BA &15% SSD		blened22.5 %BA &7.5% SSD		blened7.5% BA &22.5% SSD	
Trial No.	1	2	1	2	1	2	1	2	1	2	1	2
A	1247.8	1249.6	1245.5	1244.9	1246.3	1248.9	1246.7	1248.8	1249.7	1248.4	1248.6	1250.6
B	2309.4	2308.7	2306.6	2309.3	2308.3	2307.9	2310.3	2308.5	2307.8	2308.9	2308.8	2309.7
C	3043.9	3045.7	3041.79	3038.4	3041.3	3043.6	3043.5	3044.6	3043.9	3043	3045.78	3044.66
Gmm	2.431	2.438	2.441	2.414	2.428	2.434	2.428	2.436	2.433	2.427	2.440	2.425
Average Gmm	2.434		2.427		2.431		2.432		2.430		2.433	

Where: k=1.0 at 25C°

CSD (Crushed stone Dust)

A. Mass of Dry Sample in Air

B. Mass of jar filled with water

C. Mass of jar filled with water +sample

APENDIX D: - Theoretical maximum specific gravity of bituminous paving mixtures at 5.5% conventional filler (Crushed stone Dust) and at 5.10% OBC

Table D.1. Marshall Test Results Prepared by 4.5 % Crushed Stone Dust Filler Content by Weight of Total Mix.

MARSHALL PROPERTIES OF BITOMINIOUS MIXTURE ASTMD1559/AASHTO T 245				S.G OF AGGREGATE		
				Fraction of size, mm	Proportion	Gsb
				a. (13-25mm)	24.5	2.595
Tested by:	Daniel A.	Percent of Crushed Stone Dust Filled by Weight of Total Mix: 6.50%		b.(6-13mm)	32	2.586
Description:	Binder course			c. (3-6mm)	16	2.59
Purpose	Final Thesis			d. (0-3mm)	25.9	2.61
Marshall compaction	2*75 Blows			e. Filler	1.6	….
				Combined (Gsb)	100	2.595
Grade of Asphalt:	60/70	S.G of Asphalt:	1.03			
Bulk S.G of Aggregate	2.595					
Abs. Asphalt. %By wt. of agg. (Pba):			0.37			

Asphalt Content, %	Specimen Height,(mm)	Max.SG of the Mix,(Gmm)	Mass of Specimen in [g]			Volume of Specimen [cm3]	Bulk SG of Compacted Mix.	Air Void %	V.M.A%	V.F.A%	Stability			Flow(mm)
			Air Dry	Water	SSD	G	H	I	J	K	Load (KN)	Factor	Ajusted load(KN)	
A	B	C	D	E	F	F - E	D/G	(C-H)*100/D	(100-(((100A)*H))	(((J-I)*100)/J)				
4	63.5		1226.2	689.3	1227.8	538.5	2.277	7.000	15.775	55.626	7.90	0.93	7.35	2.35
	63.7		1229.4	692.6	1231.3	538.7	2.282	6.792	15.587	56.425	8.04	0.93	7.48	2.18
	64.9		1230.6	704.5	1234.8	530.3	2.321	5.223	14.166	63.129	8.40	0.96	8.06	2.22
Average	64.03	2.448	1228.733	695.4667	1231.300	535.833	2.293	6.338	15.176	58.393	8.11	0.94	7.63	2.25
4.5	65.3		1227.6	695.6	1230	534.4	2.297	4.975	15.474	67.847	8.59	0.96	8.25	2.70
	64.6		1231.4	696.3	1232.5	536.2	2.297	5.001	15.166	67.023	8.61	0.93	8.01	2.72
	63.5		1227.7	696.5	1229	532.5	2.306	4.629	15.379	69.904	8.64	0.96	8.29	3.13
Average	64.47	2.417	1228.900	696.1333	1230.500	534.367	2.300	4.868	15.340	68.258	8.61	0.95	8.18	2.85
5	64.6		1229.7	702.2	1231.5	529.3	2.323	3.746	14.962	74.962	9.24	0.96	8.87	3.25
	63.8		1234.5	702.8	1235.7	532.9	2.317	4.023	15.206	73.543	9.44	0.96	9.06	3.20
	65.1		1232.9	699.9	1236.6	536.7	2.297	4.826	15.361	68.582	9.40	0.93	8.74	2.99
Average	64.50	2.414	1232.3667	701.633	1234.600	532.967	2.312	4.199	15.176	72.335	9.36	0.95	8.89	3.15
5.5	63.8		1229.6	702.5	1230.2	527.7	2.330	3.327	15.160	78.054	8.82	0.96	8.47	3.62
	66.7		1228.8	703.4	1229.9	526.5	2.334	3.170	15.022	78.899	8.78	0.96	8.43	4.02
	64.6		1232.9	703.3	1233.8	530.5	2.324	3.579	15.381	76.730	8.68	0.96	8.33	3.64
Average	65.03	2.410	1230.4333	703.067	1231.3	528.233	2.329	3.359	15.187	77.894	8.76	0.96	8.41	3.76
6	64.8		1231.9	705.9	1232.8	526.9	2.338	2.830	15.322	81.527	7.99	0.96	7.67	3.98
	65.6		1231.8	706.9	1233.9	527	2.337	2.857	15.345	81.383	8.34	0.96	8.01	3.96
	64.8		1232.9	707.8	1234.5	526.7	2.341	2.715	9.810	72.328	8.35	0.96	8.02	4.15
Average	65.07	2.406	1232.200	706.867	1233.733	526.867	2.339	2.801	13.492	78.413	8.23	0.96	7.90	4.03

Table D.2. Marshall Test Results Prepared by 5.5 % Crushed Stone Dust Filler Content by Weight of Total Mix.

MARSHALL PROPERTIES OF BITOMINIOUS MIXTURE ASTMD1559/AASHTO T 245			
Tested by:	Daniel A.	Percent of Crushed Stone Dust Filled by Weight of Total Mix: 6.50%	
Description:	Binder course		
Purpose	Final Thesis		
Marshall compaction	2*75 Blows		
Grade of Asphalt:	60/70	S.G of Asphalt:	1.03
Bulk S.G of Aggregate	2.595		
Abs. Asphalt. %By wt. of agg. (Pba):			0.37

S.G OF AGGREGATE		
Fraction of size, mm	Proportion	Gsb
a. (13-25mm)	24.5	2.595
b.(6-13mm)	32	2.586
c. (3-6mm)	16	2.59
d. (0-3mm)	25.9	2.61
e. Filler	1.6	….
Combined (Gsb)	100	2.595

Asphalt Content, %	Specimen Height,(mm)	Max.SG of the Mix,[Gmm]	Mass of Specimen in [g]			Volume of Spec.(cm3	Bulk SG of Compacte	Air Void %	V.M.A%	V.F.A%	Stability			Flow (mm)
			Air Dry	Water	SSD	G	H	I	J	K	Load (KN)	Factor	Adjust ed Load (KN)	
A	B	C	D	E	F	F - E	D/G	(C-H)*100/D	(100-(((100A)*	(((J-I)*100)/J)				
4	63.5		1225.7	696.8	1227.8	531	2.308	5.960	14.620241	59.237	8.92	0.96	8.56	2.47
	61.7		1226.7	695.6	1228.5	532.9	2.302	6.219	14.855	58.139	8.80	0.96	8.45	2.48
	62.9		1227.6	696.6	1228.7	532.1	2.307	6.009	14.665	59.027	7.21	0.96	6.92	2.52
Average	62.7	2.455	1226.67	696.33	1228.33	532.00	2.31	6.06	14.71	58.80	8.31	0.96	7.98	2.49
4.5	61		1227.9	698.6	1228.1	529.5	2.319	5.156	14.671	64.858	9.97	0.96	9.57	2.7
	62.6		1226.8	697.9	1228.2	530.3	2.313	5.384	14.876	63.810	10.09	0.96	9.69	3.18
	62.2		1227.7	699.8	1227.2	527.4	2.328	4.794	14.346	66.584	9.98	0.96	9.58	2.57
Average	61.93	2.445	1227.47	698.77	1227.83	529.07	2.32	5.11	14.63	65.08	10.01	0.96	9.61	2.82
5	62.2		1229.9	704.8	1231.5	526.7	2.335	3.634	14.528	74.985	10.77	0.96	10.34	2.89
	61.8		1233.8	703.8	1233.7	529.9	2.328	3.912	14.775	73.519	10.72	0.96	10.29	3.28
	61		1232.9	705.9	1234.6	528.7	2.332	3.765	14.644	74.292	10.76	0.96	10.33	3.32
Average	61.67	2.423	1232.20	704.83	1233.27	528.43	2.33	3.77	14.65	74.26	10.75	0.96	10.32	3.16
5.5	61.8		1229.6	704.7	1230.7	526	2.338	3.029	14.885	79.654	10.55	0.96	10.13	3.99
	62.7		1228.8	704.6	1229.9	525.3	2.339	2.963	14.827	80.020	10.68	0.96	10.25	2.99
	61		1230.9	705.9	1233.8	527.9	2.332	3.275	15.102	78.311	10.65	0.96	10.22	3.81
Average	61.83	2.411	1229.77	705.07	1231.47	526.40	2.34	3.09	14.94	79.33	10.63	0.96	10.20	3.60
	61.3		1232.1	706.6	1233.7	527.1	2.338	2.931	15.341	80.892425	9.12	0.96	8.76	3.53
	62.1		1229.4	706.8	1231.5	524.7	2.343	2.701	15.140	82.160	8.22	0.96	7.89	4.33
6	61		1229.3	703.6	1230.2	526.6	2.334	3.060	15.453	80.199	8.12	0.96	7.80	3.72
Average	61.47	2.408	1230.27	705.67	1231.80	526.13	2.34	2.90	15.31	81.08	8.49	0.96	8.15	3.86

Table D.3. Marshall Test Results Prepared by 6.5 % Crushed Stone Dust Filler Content by Weight of Total Mix

MARSHALL PROPERTIES OF BITOMINIOUS MIXTURE ASTMD1559/AASHTO T 245				S.G OF AGGREGATE		
				Fraction of size, mm	Proportion	Gsb
				a. (13-25mm)	24.5	2.595
Tested by:	Daniel A.	Percent of Crushed Stone Dust Filled by Weight of Total Mix: 6.50%		b.(6-13mm)	32	2.586
Description:	Binder course			c. (3-6mm)	16	2.59
Purpose	Final Thesis			d. (0-3mm)	25.9	2.61
Marshall compaction	2*75 Blows			e. Filler	1.6	….
				Combined (Gsb)	100	2.595
Grade of Asphalt:	60/70	S.G of Asphalt:	1.03			
Bulk S.G of Aggregate	2.595					
Abs. Asphalt. %By wt. of agg. (Pba):			0.37			

Asphalt Content, %	Specimen Height,(mm)	Max.SG of the Mix,[Gmm]	Mass of Specimen in [g]			Volume of Spec.(cm3)	Bulk SG of Comp. Mix	Air Void %	V.M.A%	V.F.A%	Stability			Flow (mm)
			Air Dry	Water	SSD	G	H	I	J	K	Load (KN)	Factor	Adjust ed Load (KN)	
A	B	C	D	E	F	F - E	D/G	(C-H)*100/D	(100-(((100-A)*H)/Gsb)	(((J-I)*100)/J)				
4	63.5		1228.9	698.6	1230.8	532.2	2.309	6.443	14.590	55.843	7.97	0.96	7.65	2.22
	61.7		1231.4	697.5	1232.9	535.4	2.300	6.813	14.928	54.363	8.16	0.96	7.83	2.4
	62.9		1230.6	698.6	1233.8	535.2	2.299	6.838	14.952	54.263	7.98	0.96	7.66	2.32
Average	62.7	2.468	1230.30	698.23	1232.50	534.27	2.30	6.70	14.82	54.82	8.04	0.96	7.72	2.31
4.5	61		1229.6	700.9	1232.9	532	2.311	5.954	14.955	60.185	9.65	0.96	9.26	2.75
	62.6		1232.4	701.9	1233.8	531.9	2.317	5.722	14.745	61.191	9.61	0.96	9.23	2.66
	62.2		1229.7	702.8	1232.8	530	2.320	5.592	14.627	61.771	10.34	0.96	9.93	2.78
Average	61.93	2.458	1230.57	701.87	1233.17	531.30	2.32	5.76	14.78	61.05	9.87	0.96	9.47	2.73
5	62.2		1230.8	705.7	1231.5	525.8	2.341	4.328	14.319	69.773	10.7	0.96	10.27	2.85
	61.8		1232.5	704.2	1235.7	531.5	2.319	5.224	15.121	65.454	9.95	0.96	9.55	3.36
	61		1233.9	704.3	1236.6	532.3	2.318	5.259	15.152	65.295	10.49	0.96	10.07	3.45
Average	61.67	2.447	1232.40	704.73	1234.60	529.87	2.33	4.94	14.86	66.79	10.38	0.96	9.96	3.22
5.5	61.8		1232.8	703.9	1233.8	529.9	2.326	3.993	15.292	73.891	10.52	0.96	10.10	3.32
	62.7		1233.8	705.4	1235.6	530.2	2.327	3.969	15.271	74.010	10.38	0.96	9.96	3.88
	61		1234.9	706.9	1235.5	528.6	2.336	3.592	14.939	75.952	10.75	0.96	10.320	3.68
Average	61.83	2.423	1233.83	705.40	1234.97	529.57	2.33	3.85	15.17	74.62	10.55	0.96	10.13	3.63
6	61.3		1233.8	705.6	1235.7	530.1	2.327	3.251	15.704	79.3006771	9.67	0.96	9.28	3.99
	62.1		1234.7	706.8	1235.4	528.6	2.336	2.905	15.403	81.138	9.68	0.96	9.29	4.1
	61		1235.2	709.6	1236.5	526.9	2.344	2.553	15.095	83.091	9.67	0.96	9.28	4.18
Average	61.47	2.406	1234.57	707.33	1235.87	528.53	2.34	2.90	15.40	81.18	9.67	0.96	9.29	4.09

MARSHALL TEST RESULTS

OFC = 5.5% and OBC =5.10%

APPEDIX-E Specimens with different proportion of conventional and non-conventional filler

Table E.1. Combination of 10% Blended Bagasse Ash and Steel Slag Dust with 90% Crushed Stone Dust Filler Contents.

Asphalt content by wt. total mix, %	Sample No.	ρA (g/cm3)	Air Void (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)	SSD and BA Content by % of total Mix
5.1	1	2.342	4.2	12.6	67.0	9.3	2.71	0%SSD&10%BA
	2	2.340	4.1	12.6	67.4	8.4	2.69	
	3	2.341	4.1	12.6	67.4	8.4	2.69	
	Average	2.341	4.1	12.6	67.3	8.7	2.70	
5.1	1	2.344	4.0	13.2	69.3	9.2	2.69	10%SSD&0%BA
	2	2.345	4.3	13.4	68.2	9.2	2.67	
	3	2.344	4.3	13.4	68.0	9.2	2.69	
	Average	2.345	4.2	13.3	68.5	9.2	2.68	
5.1	1	2.343	4.1	13.9	70.2	9.7	2.72	5%SSD&5%BA
	2	2.345	4.1	13.9	70.3	9.4	2.71	
	3	2.342	4.5	14.2	68.4	9.4	2.73	
	Average	2.343	4.3	14.0	69.6	9.5	2.72	
5.1	1	2.341	4.3	14.7	70.6	10.19	2.79	2.5%SSD&7.5%BA
	2	2.343	4.4	14.7	70.1	10.09	2.80	
	3	2.341	4.5	15.8	69.7	10.08	2.81	
	Average	2.342	4.4	14.7	70.2	10.12	2.80	
5.1	1	2.304	4.5	15.4	71.1	10.32	2.82	7.5%SSD&2.5%BA
	2	2.312	4.1	15.1	72.6	10.33	2.79	
	3	2.313	4.1	15.1	73.0	10.34	2.84	
	Average	2.310	4.2	15.2	72.2	10.30	2.82	

Table E.2. Combination of 20% Blended Bagasse Ash and Steel Slag Dust with 80% Crushed Stone Dust Filler Contents

Asphalt content by wt. total mix, %	**Sample No.**	**ρA (g/cm3)**	**Air Void (%)**	**VMA (%)**	**VFA (%)**	**Stability (KN)**	**Flow (mm)**	SSD and BA Content by % of total Mix
5.1	1	2.345	4.3	15.4	68.4	10.3	3.06	0%SSD&20%BA
	2	2.347	4.3	15.3	68.8	10.6	3.04	
	3	2.348	3.8	13.5	71.2	10.9	3.06	
	Average	2.347	4.1	15.4	69.5	10.6	3.05	
5.1	1	2.343	4.0	16.5	71.4	10.5	3.08	20%SSD&0%BA
	2	2.346	4.3	15.8	70.0	10.7	3.06	
	3	2.342	4.3	15.9	70.2	10.3	3.07	
	Average	2.344	4.2	16.0	70.5	10.5	3.07	
5.1	1	2.346	4.3	15.0	71.4	10.4	3.07	10%SSD&10%BA
	2	2.347	4.0	14.7	72.9	11.3	3.05	
	3	2.344	4.3	15.0	71.5	10.3	2.99	
	Average	2.346	4.2	14.9	72.0	10.7	3.04	
5.1	1	2.345	4.0	14.1	73.6	10.6	3.08	15%SSD&5%BA
	2	2.342	4.0	13.4	73.9	10.6	3.05	
	3	2.348	4.2	13.3	72.8	11.1	3.04	
	Average	2.345	4.1	14.3	73.4	10.8	3.06	
5.1	1	2.306	4.4	16.3	73.2	10.9	3.08	15%SSD&5%BA
	2	2.318	3.9	15.8	75.5	11.0	3.06	
	3	2.317	3.9	15.9	75.4	11.2	3.09	
	Average	2.314	4.0	16.0	74.7	11.0	3.08	

Table E.3. Combination of 30% Blended Bagasse Ash and Steel Slag Dust with 70% Crushed Stone Dust Filler Contents

Asphalt content by wt. total mix, %	Sample No.	ρA (g/cm3)	Air Void (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)	SSD and BA Content by % of total Mix
5.1	1	2.336	4.6	14.0	66.9	6.6	3.17	0%SSD&30%BA
	2	2.337	4.7	14.1	66.4	6.6	3.18	
	3	2.338	4.6	67.3	67.3	6.8	3.21	
	Average	2.337	4.6	14.0	66.8	6.6	3.19	
5.1	1	2.343	3.9	14.0	72.0	6.7	3.15	30%SSD&0%BA
	2	2.345	3.6	13.7	74.0	6.8	3.15	
	3	2.340	3.9	14.0	72.1	6.7	3.14	
	Average	2.343	3.8	13.9	72.7	6.7	3.15	
5.1	1	2.338	3.6	14.3	75.2	6.8	3.24	15%SSD&15%BA
	2	2.339	3.6	14.4	74.7	6.8	3.18	
	3	2.337	3.2	14.0	77.4	6.9	3.09	
	Average	2.338	3.5	14.2	75.8	6.8	3.17	
5.1	1	2.335	2.8	14.2	80.5	6.8	3.20	7.5%SSD&22.5%BA
	2	2.334	3.1	14.5	78.7	6.7	3.22	
	3	2.332	2.7	14.1	81.2	6.8	3.21	
	Average	2.334	2.8	14.3	80.1	6.8	3.21	
5.1	1	2.347	2.8	14.9	81.4	6.94	3.28	22.5%SSD&7.5%BA
	2	2.345	2.8	14.9	81.1	6.93	3.29	
	3	2.339	3.3	15.4	78.3	6.92	3.27	
	Average	2.344	3.0	15.0	80.3	6.93	3.28	

APENDIX-F: Plastic Index (PI) of Mineral Filler According to ASTMD 4318 Method

Table F.1. Liquid Limit (LL) of Crushed Stone Dust

Liquid Limit of Crushed Stone Dust				
Determination	**Liquid Limit**			
Number of blows	25.5	22.6	19.3	18.2
Test No	1	2	3	4
Container No	C9	C13	A4	C14
Wt. of container + wet soil, g	24.91	33.46	31.56	27.57
Wt. of container + dry soil, g	21.25	27.03	25.71	22.61
Wt. of container, g	17.02	19.10	19.34	16.94
Wt. of water, g	3.66	6.43	5.85	4.96
Wt. of dry soil, g	4.23	7.93	6.37	5.67
Moisture content, %	86.5	81.1	91.8	87.5
Average of Moisture content, %	86.73			

Table F.2. Plastic Limit (PL) of Crushed Stone Dust

Plastic Limit of Crushed Stone Dust		
Test	1	2
Container	C-31	G8
Wt. of container + wet soil, g	29.31	29.34
Wt. of container + dry soil, g	24.60	24.82
Wt. of container, g	19.52	18.73
Wt. of water, g	4.71	4.52
Wt. of dry soil, g	5.08	6.09
Moisture container, %	92.72	74.2
Average Moisture Content, %	83.5	
Plasticity Index (PI)=LL-PL	3.23%	

Table F.3. Liquid Limit (LL) of Steel Slag Dust

Liquid Limit of Steel Slag Dust				
Determination	**Liquid Limit**			
Number of blows	25.7	22.8	19.5	18.4
Test No	1	2	3	4
Container No	C9	C13	A4	C14
Wt. of container + wet soil, g	24.81	34.46	30.69	26.67
Wt. of container + dry soil, g	21.30	27.43	25.62	22.66
Wt. of container, g	17.08	19.12	19.87	17.94
Wt. of water, g	3.51	7.03	5.07	4.01
Wt. of dry soil, g	4.22	8.31	5.75	4.72
Moisture content, %	83.2	84.6	88.2	85.0
Average Moisture content, %	85.23			

Table F.4. Plastic Limit (PL) of Steel Slag Dust

Plastic Limit of Steel Slag Dust		
Test	1	2
Container	C-03	G10
Wt. of container + wet soil, g	29.31	29.29
Wt. of container + dry soil, g	24.74	24.82
Wt. of container, g	19.52	18.92
Wt. of water, g	4.57	4.47
Wt. of dry soil, g	5.22	5.90
Moisture container, %	87.55	75.8
Average Moisture Content, %	81.7	
Plasticity Index (PI)=LL-PL	3.53%	

Table F.5. Liquid Limit (LL) of Bagasse Ash

Liquid Limit of Bagasse Ash				
Determination	**Liquid Limit**			
Number of blows	25.5	22.6	19.3	18.2
Test No	1	2	3	4
Container No	C9	C13	A4	C14
Wt. of container + wet soil, g	24.88	33.59	30.59	26.95
Wt. of container + dry soil, g	21.25	27.03	25.71	22.61
Wt. of container, g	17.02	19.10	19.34	16.94
Wt. of water, g	3.63	6.56	4.88	4.34
Wt. of dry soil, g	4.23	7.93	6.37	5.67
Moisture content, %	85.8	82.7	76.6	76.5
Average of Moisture content, %	80.4			

Table F.6. Plastic Limit (PL) of Bagasse Ash

Plastic Limit of Bagasse Ash		
Test	1	2
Container	C-31	G8
Wt. of container + wet soil, g	29.13	29.14
Wt. of container + dry soil, g	24.77	24.84
Wt. of container, g	19.52	18.73
Wt. of water, g	4.36	4.30
Wt. of dry soil, g	5.25	6.11
Moisture container, %	83.05	70.4
Average Moisture Content, %	76.7	
Plasticity Index (PI)=LL-PL	3.7	

Table F.7. Stability Correlation Ratios

Volume of Specimen cm^3	Approximate Thickness of Specimen		Correlation Ratio
	mm	in.	
302 to 316	38.1	1 1/2	2.78
317 to 328	39.7	1 9/16	2.50
329 to 340	41.3	1 5/8	2.27
341 to 353	42.9	1 11/16	2.08
354 to 367	44.4	1 3/4	1.92
368 to 379	46.0	1 13/16	1.79
380 to 392	47.6	1 7/8	1.67
393 to 405	49.2	1 15/16	1.56
406 to 420	50.8	2	1.47
421 to 431	52.4	2 1/6	1.39
432 to 443	54.0	2 1/8	1.32
444 to 456	55.6	2 3/16	1.25
457 to 470	57.2	2 1/4	1.19
471 to 482	58.7	2 5/16	1.14
483 to 495	60.3	2 3/8	1.09
496 to 508	61.9	2 7/16	1.04
509 to 522	63.5	2 1/2	1.00
523 to 535	65.1	2 9/16	0.96
536 to 546	66.7	2 5/8	0.93
547 to 559	68.3	2 11/16	0.89
560 to 573	69.8	2 3/4	0.86
574 to 585	71.4	2 13/16	0.83
586 to 598	73.0	2 7/8	0.81
599 to 610	74.6	2 15/16	0.78
611 to 625	76.2	3	0.76

Source: Asphalt Institute Manual Series No.2 (Ms-2), Sixth Edition.

Table F.8. Moisture Susceptibility of Asphalt Mixes.

Moisture Susceptibility for Wet and Dry Sample. Test Method: ASTMD4867										
OBC %	Mix%	Gmm	Sample No.	ρA (g/cm)	Gmb	Air Void (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
			Wet Samples							
5.1	5.50% (100% CSD)	2.446	1	2.46	2.268	7.2	14.69	69.8	10.4	2.21
			2	2.43	2.278	7	13.86	69.89	9.97	2.19
			Average	2.445	2.273	7.1	14.275	69.845	10.185	2.2
5.1	0.055%BA+ 1.045SSD +4.4CSD	2.442	1	2.465	2.278	7.1	13.79	69.9	10.9	2.9
			2	2.46	2.279	7.1	13.78	70.4	9.95	2.86
			Average	2.4625	2.2785	7.1	13.785	70.15	10.425	2.88
5.1	1.045BA+ 0.055SSD +4.4CSD	2.438	1	2.455	2.271	6.9	13.67	70.4	9.89	3.75
			2	2.43	2.277	6.9	14.6	66.9	10.54	3.84
			Average	2.4425	2.274	6.9	14.135	68.65	10.215	3.795
			Dry Samples							
5.1	5.50% (100%CSD)	2.441	1	2.282	2.271	7	14.65	70.4	9.3	3.81
			2	2.282	2.268	7	15.04	69.98	9.6	3.92
			Average	2.282	2.2695	7	14.845	70.19	9.45	3.865
5.1	0.055%SSD+ 1.045BA+ +4.4CSD	2.443	1	2.315	2.261	6.8	14.73	72.6	8.3	3.98
			2	2.29	2.273	6.9	14.62	69.97	8.7	3.97
			Average	2.3025	2.267	6.85	14.675	71.285	8.5	3.975
5.1	1.045SSD+ 0.055BA +4.4CSD	2.446	1	2.439	2.268	6.8	14.6	69.98	10.4	2.21
			2	2.438	2.278	6.8	16.2	69.89	9.67	2.19
			Average	2.4385	2.273	6.8	15.4	69.935	10.035	2.2

Table F.9. Compared the TSR value of Moisture Susceptibility for Wet and Dry Samples blended conventional and non-conventional filler. Test Method: ASTMD4867

Trial	Fillers	Wet Peak load (N)	Adjust Wet Peak load (N)	Dry Peak load (N)	Adjust Dry Peak load (N)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	ITS1 = 2000 P/πDT (KPa)	ITS2 = 2000 P/πDT (KPa)	TSR	Average TSR (%)	Multiple Factors	Blended Filler types
1	20%=blended 15%BA +5%SSD	8090	7523.700	9880	9188.400	66.87	67.78	100	716.639	863.453	0.830	85.322	0.93	blended 15%BA &5%SSD
		8790	8174.700	9170	8528.100	66.88	67.87	100	778.531	800.340	0.973		0.93	
2	20%=blended 5%BA+ 15%SSD	8710	8100.300	10030	9327.900	66.96	67.81	100	770.524	876.174	0.879	87.942	0.93	blended 5%BA &15%SSD
		9090	8453.700	9090	8453.700	66.98	67.83	100	793.826	793.826	1.000		0.93	
3	100%CSD	9090	8453.700	9890	9197.700	66.69	67.77	100	807.396	864.454	0.934	86.717	0.93	Only100% CSD
		9790	9104.700	9190	8546.700	66.93	67.67	100	866.453	804.457	1.077		0.93	

APENDEX-G: - Sample of photos taken Marshall Specimens preparation in laboratory work.

Materials taken from the site. Source Abebe Tadie,2014.

Material milling in laboratory. Source Dejene Dereje,2014

Sieve arrangement by size and sieve the aggregates by different sieve number (Source Dejene Dereje,2014)

Arrange and Weight the aggregates by each size used for preparation of specimens with different proportion of conventional and nonconventional filler (Source Dejene Dereje,2014).

Mixing asphalt mixture before compaction (Source Dejene Dereje,2014).

Compacted mixed materials by using compactor machine manually (Source Dejene Dereje,2014).

Compacted hot mix asphalt concrete specimens cool down and extracted (removed in mold) (Source Dejene Dereje,2014)

Weighting the hot mix asphalt specimen after air dry and in water (Source Dejene Dereje,2014).

Making dry specimen by cloth after weight in water and also weighting specimen after dry (Source, Abebe Tadie,2014).

Uncompact hot mix asphalt specimen ready for Gmm (Source, Daniel Alelgn,2014,2014).

Shaking the sample of Gmm (Source Dejene Dereje,2014).

Sink the specimen in water bath at 45°c for measuring stability and flow (Source Dejene Dereje,2014).

Recording the Marshall Test results stability and flow of specimens (Source Dejene Dereje,2014).

Sink the specimen in water bath at 45°c and in cool water bath for measuring TSR at optimum replacement of non-conventional (Source Dejene Dereje,2014).

Recording result of conditioned and unconditioned the Marshall Test results of specimens for determine the value of TSR (Source Dejene Dereje,2014).

Soaking the BA and SSD and Ready the sample for liquid limit test (Source Dejene Dereje,2014).